Enclosure 7

Edwin I. Hatch Nuclear Plant
Request for License Amendment
Measurement Uncertainty Recapture Power Uprate

Plant Modifications

Introduction

The Edwin I. Hatch Nuclear Plant is currently licensed to operate at a maximum rated thermal power (RTP) of 2763 MWt. This power level is supported by a number of analyses and evaluations performed with an RTP uncertainty of ≥ 2%, either through 10 CFR 50, Appendix K, "ECCS Evaluations Models" or Regulatory Guide 1.49. By applying a reduced thermal power uncertainty to these analyses, Plant Hatch can justify increasing the reactor thermal power level and still remain within the boundary of these specific analyses. Southern Nuclear Operating Company (SNC) is requesting approval to increase the licensed RTP by 1.5% to 2804 MWt. This power increase will be accomplished by using a more accurate main feedwater flow measurement system to provide input into the calculated core thermal power (CTP) of each unit.

The 1.5% uprate is based upon reducing margin that is assumed in analyses to account for the measurement uncertainties associated with calculating the CTP of each unit. Plant Hatch's current accident and transient analyses include a minimum 2% margin on RTP to account for power measurement uncertainty. This power measurement uncertainty was originally required by 10 CFR 50, Appendix K, which required a 2% margin between the licensed power level and the power level assumed for the emergency core cooling system (ECCS) evaluations. In 2000, the NRC amended 10 CFR 50, Appendix K, to provide licensees the option of maintaining the 2% power margin or applying a reduced margin. If the licensee elects to apply a reduced margin, the new assumed power level has to account for measurement uncertainties in the instrumentation used in the core thermal power computation. The revised Appendix K rule has an effective date of July 31, 2000.

The feedwater flow measurement uncertainty is the most significant contributor to CTP measurement uncertainty. Based upon this fact and on the Appendix K rule change, SNC proposes a reduced power measurement uncertainty of 0.5% and an increase in RTP of 1.5%. To accomplish the reduction in uncertainty and the increase in power, SNC will install a Crossflow™ system on both units.

The Crossflow™ system provides a more accurate measurement of feedwater flow than the currently installed instrumentation used for the CTP calculation at Plant Hatch. Combustion Engineering Topical Report CENPD-397-P-A, Rev. 01 "Improved Flow Measurement Accuracy Using CROSSFLOW Ultrasonic Flow Measurement Technology,"[(1)] documents the theory, design, and operating features of the Crossflow™ system and its ability to achieve increased flow measurement accuracy. In a safety evaluation dated March 20, 2000, the NRC approved CENPD-397-P-A, Rev. 01[(1)] for referencing in license applications for power uprates. The Crossflow™ system will provide a measured feedwater mass flow to within an assumed 0.42% for both Hatch units. Tables E7-2 and E7-4 provide the total RTP uncertainty (95/95 power measurement uncertainty) for Units 1 and 2, respectively. The bounding resultant RTP uncertainty is for Unit 2, which is - 0.461% RTP. Therefore, the total power measurement uncertainty required by Appendix K of 0.5% for each unit is justified. This value (0.5%) was used in the safety analyses supporting this license amendment request. The reduced power measurement uncertainty alleviates the need for the 2% power margin originally required by Appendix K, thereby allowing an increase in the RTP available for electrical generation.

Discussion

This enclosure addresses the selected guidance items specified in Attachment 1 of NRC Regulatory Issue Summary (RIS) 2002-03, "Guidance on the Content of Measurement Uncertainty Recapture Power Uprate Applications,"[2] specifically to items I, VII.2, VII.3, and VII.4. The specific RIS 2002-03 guidance items are in bold and the applicable Plant Hatch information to follow:

I. Feedwater flow measurement technique and power measurement uncertainty

1. A detailed description of the plant-specific implementation of the feedwater flow measurement technique and the power increase gained as a result of implementing this technique. This description should include:

A. Identification (by document title, number, and date) of the approved topical report on the feedwater flow measurement technique

The feedwater flow measurement system being installed at Plant Hatch Units 1 and 2 is the AMAG/Westinghouse CROSSFLOW ultrasonic flow measurement (UFM) system. The design of this advanced flow measurement system is addressed in detail by the manufacturer in topical report CENPD-397-P-A, Rev. 01.[1]

The Unit 1 system consists of three flow-measurement devices installed on the "A" feedwater pipe, and a single device on the "B" feedwater pipe. The Unit 2 system (to be installed in the 2003 spring refueling outage) will consist of one device installed on each feedwater pipe. Each flow measurement device is composed of eight non-intrusive flow transducers (four primary/four redundant) strapped on the feedwater piping and a set of temperature sensing transducers connected via coax cable to a remote panel that acts as a data acquisition system and viewing station. An AMAG CORRTEMP ultrasonic temperature measurement system used to correct the current RTD-based feedwater temperature is included in each unit system.

B. *A reference to the NRC's approval of the proposed feedwater flow measurement technique*

NRC approval of the proposed feedwater flow measurement technique was granted via NRC letter dated, March 20, 2000, " Acceptance for Referencing of CENPD-397-P, Revision-01-P, 'Improved Flow Measurement Accuracy Using CROSSFLOW Ultrasonic Flow Measurement Technology'" (TAC NO. MA5452).

C. *A discussion of the plant-specific implementation of the guidelines in the topical report and the staff's letter/safety evaluation approving the topical report for the feedwater flow measurement technique*

The Crossflow UFM will be installed in accordance with the requirements of CENPD-397-P-A, Rev. 01[(1)], Section 8.0, Crossflow Field Implementation. This system will be used for fulltime online CTP determination. The system will be provided with a software layer that will integrate the systems to the plant process computer to correct the current venturi-based flow and current RTD-based temperature.

D. *The dispositions of the criteria that the NRC staff stated should be addressed (i.e., the criteria included in the staff's approval of the technique) when implementing the feedwater flow measurement technique*

In approving Topical Report CENDP-397-P-A, Rev. 01[(1)], the NRC established four criteria to be addressed by each licensee in requesting a measurement uncertainty recapture power uprate license amendment. The four criteria and a discussion of how each will be satisfied for Plant Hatch follow:

Criterion 1

The licensee should discuss the development of maintenance and calibration procedures that will be implemented with the Crossflow UFM installation. These procedures should include process and contingencies for an inoperable Crossflow UFM and the effect on thermal power measurement and plant operation.

Implementation of the power uprate license amendment will include developing the necessary procedures and documents required for operation, maintenance, calibration, testing, and training at the uprated power level with the new Crossflow UFM system. Plant maintenance and calibration procedures will be revised to incorporate the Crossflow maintenance and calibration requirements prior to declaring the system operational and prior to increasing power above the current license thermal power level.

Plant operation with the Crossflow UFM system out of service is discussed in Sections G and H below.

Criterion 2

For plants that currently have the Crossflow UFM installed, the licensee should provide an evaluation of the operational and maintenance history of the installed UFM and confirm that the instrumentation is representative of the Crossflow UFM and is bounded by the requirements set forth in Topical Report CENPD-397-P.

This criterion is not applicable to Plant Hatch Units 1 and 2. Plant Hatch currently uses flow venturies for the feedwater flow measurement contribution to the CTP computation. The installation and operation of the Crossflow system is in anticipation of approval of the proposed amendment. Installation of the systems will be completed prior to implementation of the requested license amendment.

Criterion 3

The licensee should confirm that the methodology used to calculate the uncertainty of the Crossflow UFM in comparison to the current feedwater flow instrumentation is based on accepted plant setpoint methodology (with regard to the development of instrument uncertainty). If an alternative methodology is used, the application should be justified and applied to both the venturi and the Crossflow UFM for comparison.

The Plant Hatch heat balance uncertainty study[3] was performed using ISA-RP67.04, Part II -1994, "Methodologies for the Determination of Setpoints for Nuclear Safety Related Instrumentation"[4] as the instrument uncertainty determination methodology. This study provides the total CTP uncertainty by evaluating the various contributions of the variables from the measured instrumentation to the CTP. A baseline condition was established based upon heat balance process conditions. Each measurement variable was then varied independently by a nominal error to determine the sensitivity (weighting factor) of that error on the output CTP calculation.

The analysis provides a total measurement uncertainty for CTP assuming a Crossflow total uncertainty of 0.42% of actual flow. The calculation provides all weighting factors and other parameter uncertainties, so that computation of the final uncertainty, based upon the final vendor specification, could be easily determined.

For Plant Hatch, the primary feedwater flow measurement will be made with the flow venturies. The venturi measurement will be corrected on a very frequent basis automatically within the plant computer. Preliminary information from the UFM vendor, based upon current testing and configuration, shows the maximum total feedwater flow error from the UFMs to be ± 0.42% actual flow.

To provide a clear understanding of the uncertainties of the CTP computation, using the current configuration, as compared to the UFM corrected (after uprate) configuration, Tables E7-1 through E7-4 were created. Tables E7-1 and E7-2 address Unit 1, and Tables E7-3 and E7-4 address Unit 2. The tables provide a summary of the CTP input parameter uncertainties, the associated sensitivity, and the contributions of uncertainty to the CTP computation uncertainty.

Criterion 4

The licensee of a plant at which the installed Crossflow UFM was not calibrated to a site-specific piping configuration (Flow profile and meter factors not representative of the plant-specific installation) should submit additional justification. This justification should show that the meter installation is either independent of the plant-specific flow profile for the stated accuracy, or that the installation can be shown to be equivalent to known calibration and plant configurations for the specific installation, including the propagation of flow profile effects at higher Reynolds numbers. Additionally, for previously installed and calibrated Crossflow UFM, the licensee should confirm that the plant-specific installation follows the guidelines in the Crossflow UFM topical report.

Both Unit 1 and Unit 2 calibrations for the UFMs will be performed with a mockup laboratory installation, modeling the actual to-be-installed plant configuration. Therefore, the laboratory setup inherently models this configuration. Thus, the flow profile and meter factors are representative of the plant-specific installation, and no additional justification is required.

E. A calculation of the total power measurement uncertainty at the plant, explicitly identifying all parameters and their individual contribution to the power uncertainty

Reference 3 (Attachment 1 to Enclosure 7) is an instrument uncertainty calculation and study that fully defines all parameters which contribute to the total power measurement uncertainty. It determines sensitivities of the uncertainty associated with the measurement of each parameter to the uncertainty of the total power computation, as well as the total power measurement uncertainty for various configurations, including the use of UFMs to correct the venturi measurement and current configuration. This calculation was performed in accordance with Reference 4.

F. Information to specifically address the following aspects of the calibration and maintenance procedures related to all instruments that affect the power calorimetric:

i. ***maintaining calibration***
Calibration and maintenance will be performed using site procedures developed from the Crossflow system technical and O&M manuals. All work will be performed in accordance with site work control procedures. Verification of acceptable Crossflow system operation will be provided by local onboard system diagnostics.

Calibration of other instrumentation that contributes to the power calorimetric computation is performed periodically, with appropriate precision. M&TE, setting tolerances, calibration frequencies, and instrumentation accuracy were evaluated and accounted for within the uncertainty determination of Reference 1.

ii. ***controlling software and hardware configuration***
Software and hardware configuration for the Crossflow system and all other instrumentation that affect the power calorimetric are controlled through the plant modification process, which will require evaluation of any changes necessary to Reference 3. Changes to software and/or hardware are evaluated through the 10 CFR 50.59 process.

iii. ***performing corrective actions***
Corrective actions involving maintenance will be performed by I&C maintenance personnel, qualified in accordance with Hatch I&C Training Program, and formally trained on the Crossflow system.

iv. ***reporting deficiencies to the manufacturer***
Reliability of the Crossflow system will be monitored by Plant Hatch Engineering personnel in accordance with the requirements of the Condition Reporting system. Although use of the Crossflow system is non-safety related for this application, the system is designed and manufactured under the vendor's quality control program.

v. ***receiving and addressing manufacturer deficiency reports***
The Crossflow system purchase order includes the requirement that Westinghouse inform SNC of any deficiencies in accordance with maintenance agreement reporting requirements. Disposition of manufacturer deficiency reports are handled through the SNC Condition Reporting system.

G. ***A proposed allowed outage time for the instrument, along with the technical basis for the time selected***

The proposed allowed outage time for any ultrasonic flow meter is 72 hours, to provide sufficient time for troubleshooting, repair, calibration, and return of the system to operation. The instrument uncertainties computed within Reference 3 for the case of UFM corrected venturi flow measurement take credit for the fact that selected feedwater flow venturi uncertainties are compensated for by the UFM correction. These uncertainties include such items as feedwater flow element errors, venturi fouling, and the following errors for the feedwater flow transmitters:

- time dependent drift,
- measurement and test equipment (M&TE) effect,
- setting tolerance effect, and
- static pressure effect.

Given that the outage time of the UFM begins during operation at or near 100% power, any fouling of the venturi will occur in the original feedwater flow reading and eliminated due to the UFM correction just prior to the instrument outage. M&TE and setting tolerance errors are introduced in the calibration process and do not change between calibrations at a given point on the instrument scale. Static pressure effect is constant for a single point on the transmitter scale at a certain static pressure value. Therefore, with the exception of feedwater flow transmitter drift, all other error terms remain approximately the same during the instrument outage, if process conditions remain approximately the same. Thus, these errors are compensated for by the UFM correction just prior to the outage. The feedwater flow transmitters are Rosemount transmitters, which have a very small instrument drift term (0.25% URL for 6 months). Drift is compensated for just prior to the instrument outage; thus, the only time-dependent drift term is the amount of drift occurring during the time of the instrument outage. The error during a 72-hour interval is considered to be negligible in comparison to other error terms, and is of no significance. Therefore, the 72-hour outage time is considered acceptable.

The outage time is considered applicable only if power is not significantly altered in this time interval. Therefore, if power is changed significantly during the outage time, the actions stated below will be implemented at the time of the change.

H. Proposed actions to reduce power level if the allowed outage time is exceeded, including a discussion of the technical basis for the proposed reduced power level

If the outage time of the UFM is exceeded, the uncertainties of the secondary calorimetric computation will be considered as equal to the uncertainties as shown in Tables E7-1 and E7-3. The negative uncertainties are of concern, since these represent the worst case (reading a lower power level than actual). Therefore, the largest error is for Unit 1, or -1.228% RTP. Since the current licensed power level is based upon an error of 2% RTP, the power level will be reduced to an amount that is 0.5% above the current licensed level, or 2777 MWt for both units. Because the venturi instrumentation should be reading more accurately with the UFM correction just prior to the instrument outage, and since the power reduction will be very small, leaving the process conditions very close to the pre-outage situation, the venturi readings will not be returned to a correction factor of 1.0, but left with the correction factor used just prior to the instrument outage.

VII. Other

2. A statement confirming that the licensee has identified all modifications associated with the proposed power uprate, with respect to the following aspects of plant operations that are necessary to ensure that changes in operator actions do not adversely affect defense in depth or safety margins:

A. emergency or abnormal operating procedures

B. control room controls, displays (including the safety parameter display system) and alarms

C. the control room plant reference simulator

D. the operator training program

SNC identified all significant modifications associated with this power uprate. These include the following for each unit.

1) Install, test, calibrate, and start up the UFMs.

   This modification will also install the necessary hardware and software to provide the UFM input to the plant computer and automatically correct the feedwater flow venturi readings to the UFM readings.

2) Rescale average power range monitors (APRMs) to provide 0 -100% power output for 0 - 2804 MWt input. This modification will also rescale the flow-referenced high power trip function to 0.57W + 56.8% RTP for two-loop operation and 0.57W + 56.8% - 0.57 ΔW RTP for single-loop operation. This modification will also rescale the Plant Computer to associate 100% RTP with 2804 MWt. (See Enclosure 1.)

3) Provide changes to the plant simulator, to provide the UFM readings on the plant computer and APRMs, to reflect the correct % RTP value to megawatt thermal correlations and show the corrections to the feedwater flow venturi readings.

4) Provide changes to operator training procedures and guides to reflect required actions during UFM outages, to reflect accuracy of the core thermal power and feedwater flow measurements under the two scenarios.

5) Change operating procedures to reflect the approved allowed outage time for the UFMs, detailing the steps that must be taken to reduce power level, in accordance with items I.1.G and I.1.H above.

6) Other modifications, not addressed by Technical Specifications, required to be performed in support of this project will be performed under the 10 CFR 50.59 evaluation process prior to implementation of the power uprate. (These include, but are not limited to, changes to the flow-referenced settings for rod block within the APRMs.)

3. A statement confirming licensee intent to complete the modifications identified in Item 2 above (including the training of operators), prior to implementation of the power uprate.

SNC fully intends to complete the installation of all modifications identified in item 2 above, including the modifications to the simulator, prior to implementation of the proposed power uprate. In addition, SNC will provide operator training on the plant changes and operational aspects of the plant due to this project prior to implementation.

4. A statement confirming licensee intent to revise existing plant operating procedures related to temporary operation above "full steady-state licensed power levels" to reduce the magnitude of the allowed deviation from the licensed power level. The magnitude should be reduced from the pre-power uprate value of 2 percent to a lower value corresponding to the uncertainty in power level credited by the proposed power uprate application.

Existing plant operating procedures related to operation above "full steady-state licensed power levels" are based upon the guidance of NRC Memorandum SSINS No. 0200[5], which states: *"It is permissible to briefly exceed the "full, steady-state licensed power level" by as much as 2% for as long as 15 minutes. In no case should 102% power be exceeded, but lesser power "excursions" for longer periods should be allowed, with the above as guidance (i. e., 1% excess for 30 minutes, 1/2 for one hour, etc., should be allowed)."*

The proposed power uprate of 1.5% is based upon justifications provided in Enclosure 8. NEDC-33056P[6], "Thermal Power Optimization and Power Averaging Guidelines," Revision 1, February 2002 evaluates the effects of a 1.5% uprate on the various aspects of reactor power variation (bi-stable flow phenomena, accidents and transients, core flow measurements, and thermal limits) and concludes that the existing guidelines[5] are still acceptable for operation after implementation of the improved feedwater measurement and 1.5% uprate.

SNC proposes to follow the recommendations provided in Reference 6 for temporary operation above "full steady-state licensed power levels."

REFERENCES

1. CENPD-397-P-A, Rev. 01, "Improved Flow Measurement Accuracy Using CROSSFLOW Ultrasonic Flow Measurement Technology," dated May 2000.

2. NRC Regulatory Issue Summary 2002-03, "Guidance on the Content of Measurement Uncertainty Recapture Power Uprate Applications," January 31, 2002.

3. SINH-02-069, "Uncertainty Study for the Heat Balance Computation Including an Evaluation of UFM Feedwater Flow Measurement Devices," Revision 0.

4. ISA-RP67.04, Part II – 1994, "Methodologies for the Determination of Setpoints for Nuclear Safety Related Instrumentation," May 1995.

5. NRC Memorandum SSINS No. 0200, "Discussion of Licensed Power Level" (AITS F14580H2), August 22, 1980, (NRC Inspection Manual: Inspection Procedure 61706: Core Thermal Power Evaluation).

6. NEDC-33056P " Thermal Power Optimization and Power Averaging Guidelines," Revision 1, February 2002.

TABLE E7-1

UNIT 1
PROCESS PARAMETER INPUTS TO CORE THERMAL POWER
CURRENT CONFIGURATION USING VENTURIES WITH NO UFM CORRECTION

Parameter	Uncertainty	Sensitivity (%RTP/Parameter Units)	Contribution to CTP Computation (±%RTP)
Feedwater Flow (% DP Span)	1.5289	0.6988	1.068395
Feedwater Flow Element Errors (% Actual Flow)	0.559	0.9983	0.55805
Dependent FW Flow Term (% DP Span)	0.0784	0.6988	0.054786
Feedwater Temperature (°F)	1.2711	0.1309	0.166387
Reactor Pressure (% Span)	1.078	0.0568	0.06123
CRD System Flow (% DP Span)	2.3727	0.0049	0.011626
CRD System Flow Element Effects (% Actual Flow)	1.4142	0.0035	0.00495
CRD Inlet Temperature (°F)	1.8144	0.0003	0.000544
RWCU Flow (% DP Span)	1.9002	0.0008	0.00152
RWCU Flow Element Effects (% Actual Flow)	0.7071	0.0012	0.000849
RWCU Inlet Temperature (°F)	3.0429	0.0014	0.00426
RWCU Outlet Temperature (°F)	3.0429	0.0012	0.003651
Recirc Pump Power (% Span)	1.327	0.0030	0.003981
Correction Factor (MW)	0.550	0.0362	0.019910
Square Root Sum of the Squares (SRSS) Total Uncertainty			**1.227% RTP**
RWCU Flow Bias (% DP Span)	-1.7864	0.0008	-0.001429
Feedwater Flow Venturi Fouling (% Actual Flow)	+0.6000	0.9983	+0.598980
		Total Bias Error	**-0.001, +0.599% RTP**
		Total RTP Uncertainty	**-1.228, +1.826% RTP**

TABLE E7-2

UNIT 1
PROCESS PARAMETER INPUTS TO CORE THERMAL POWER VENTURIES CORRECTED BY CROSSFLOW UFMS WITH 0.42% ACTUAL FLOW UNCERTAINTY

Parameter	Uncertainty	Sensitivity (%RTP/Parameter Units)	Contribution to CTP Computation (±%RTP)
UFM Flow (% Actual Flow)	0.42	0.9983	0.419286
Feedwater Temperature (°F)	1.2711	0.1309	0.166387
Reactor Pressure (% Span)	1.078	0.0568	0.06123
CRD System Flow (% DP Span)	2.3727	0.0049	0.011626
CRD system Flow Element Effects (% Actual Flow)	1.4142	0.0035	0.00495
CRD Inlet Temperature (°F)	1.8144	0.0003	0.000544
RWCU Flow (% DP Span)	1.9002	0.0008	0.001520
RWCU Flow Element Effects (% Actual Flow)	0.7071	0.0012	0.000849
RWCU Inlet Temperature (°F)	3.0429	0.0014	0.00426
RWCU Outlet Temperature (°F	3.0429	0.0012	0.003651
Recirc Pump Power (% Span)	1.327	0.003	0.003981
Correction Factor (MW)	0.550	0.0362	0.019910
Square Root Sum of the Squares (SRSS) Total Uncertainty			**0.456**
RWCU Flow Bias (% DP Span)	-1.7864	0.0008	-0.001429
		Total Bias Error	**-0.001% RTP**
		Total RTP Uncertainty	**-0.457, +0.456% RTP**

TABLE E7-3

UNIT 2
PROCESS PARAMETER INPUTS TO CORE THERMAL POWER
CURRENT CONFIGURATION USING VENTURIES WITH NO UFM CORRECTION

Parameter	Uncertainty	Sensitivity (%RTP/Parameter Units)	Contribution to CTP Computation (±%RTP)
Feedwater Flow (% DP Span)	1.5135	0.6476	0.980143
Feedwater Flow Element Errors (% Actual Flow)	0.559	0.9983	0.558050
Dependent FW Flow Term (% DP Span)	0.0918	0.6476	0.059449
Feedwater Temperature (°F)	1.2711	0.1384	0.17592
Reactor Pressure (% Span)	1.078	0.0589	0.063494
CRD System Flow (% DP Span)	2.3727	0.0049	0.011626
CRD system Flow Element Effects (% Actual Flow)	1.4142	0.0035	0.00495
CRD Inlet Temperature (°F)	1.8144	0.0003	0.000544
RWCU Flow (% DP Span)	1.9008	0.0008	0.001521
RWCU Flow Element Effects (% Actual Flow)	0.7071	0.0012	0.000849
RWCU Inlet Temperature (°F)	3.0429	0.0014	0.00426
RWCU Outlet Temperature (°F)	3.0429	0.0012	0.003651
Recirc Pump Power (% Span)	1.327	0.003	0.003981
Correction Factor (MW)	0.550	0.0362	0.019910
Square Root Sum of the Squares (SRSS) Total Uncertainty			**1.154% RTP**
RWCU Flow Bias (% DP Span)	-1.5294	0.0008	-0.001224
Feedwater Flow Venturi Fouling (% Actual Flow)	+0.6000	0.9983	+0.598980
		Total Bias Error	**-0.001, +0.599% RTP**
		Total RTP Uncertainty	**-1.155, +1.753% RTP**

TABLE E7-4

UNIT 2
PROCESS PARAMETER INPUTS TO CORE THERMAL POWER
VENTURIES CORRECTED BY CROSSFLOW UFMS WITH 0.42% ACTUAL FLOW UNCERTAINTY

Parameter	Uncertainty	Sensitivity (%RTP/Parameter Units)	Contribution to CTP Computation (±%RTP)
UFM Flow (% Actual Flow)	0.42	0.9983	0.419286
Feedwater Temperature (°F)	1.2711	0.1384	0.17592
Reactor Pressure (% Span)	1.078	0.0589	0.063494
CRD System Flow (% DP Span)	2.3727	0.0049	0.011626
CRD system Flow Element Effects (% Actual Flow)	1.4142	0.0035	0.00495
CRD Inlet Temperature (°F)	1.8144	0.0003	0.000544
RWCU Flow (% DP Span)	1.9008	0.0008	0.001521
RWCU Flow Element Effects (% Actual Flow)	0.7071	0.0012	0.000849
RWCU Inlet Temperature (°F)	3.0429	0.0014	0.00426
RWCU Outlet Temperature (°F)	3.0429	0.0012	0.003651
Recirc Pump Power (% Span)	1.327	0.003	0.003981
Correction Factor (MW)	0.550	0.0362	0.019910
Square Root Sum of the Squares (SRSS) Total Uncertainty			**0.460% RTP**
RWCU Flow Bias (% DP Span)	-1.5294	0.0008	-0.001224
		Total Bias Error	**-0.001% RTP**
		Total RTP Uncertainty	**-0.461, +0.460% RTP**

ATTACHMENT 1
TO
ENCLOSURE 7

UNCERTAINTY STUDY FOR THE HEAT BALANCE COMPUTATION INCLUDING AN EVALUATION OF UFM FEEDWATER FLOW MEASUREMENT DEVICES

Performed for: E. I. Hatch Nuclear Plant

SINH-02-069, Revision 0

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RECORD OF REVISIONS

Rev.	Date	Pages	Description	Originator
0	11/26/02	1-89	Initial Issue	Kirk R. Melson

1.0 OBJECTIVE / SCOPE

E. I. Hatch Nuclear Plant is performing a Minor Power Uprate Project, based on a reduction in the presently assumed 2% Heat Balance uncertainty. The purpose of this study is to evaluate the total measurement uncertainty of the heat balance computation under the following two conditions:

Case 1: current configuration, using feedwater flow venturis to measure feedwater flow, and
Case 2: configuration after installation of Westinghouse Crossflow Ultrasonic Flowmeters (UFMs), which will be used to automatically correct the venturi readings on a continuous basis within the Plant Computer.

2.0 FUNCTIONAL DESCRIPTION

The heat balance computation is performed within the Plant Computer per Reference 9.8.4. This computation derives the total core thermal power by computing the heat added to the different water sources flowing in and out of the reactor vessel. Specifically, the computation is performed as derived below.

Applying the 1st Law of Thermodynamics (Conservation of Energy), the thermal power generated by the reactor core is expressed as follows, assuming steady state conditions:

$$Q_{CORE} = Q_{FW} + Q_{CR} + Q_{CU} + CF - Q_P$$

where:

	Q_{CORE}	=	Thermal Power Generated by Reactor Core
	Q_{FW}	=	Heat Applied to Feedwater
	Q_{CR}	=	Heat Applied to Control Rod Drive System
	Q_{CU}	=	Heat Applied to Reactor Water Clean Up System
	C_F	=	Correction Factor, Which Includes the Effects of Radiative Heat Loss and CRD Flow Corrections
	Q_P	=	Heat Added by Recirculation Pumps

This equation is verified via References 9.8.4 and 9.2.1.

3.0 METHODOLOGY

This study is performed, using Reference 9.1 as the instrument uncertainty determination methodology. Since a number of different variables are measured with instrumentation in the heat balance equation, and since these variables are not equally weighted in the effects of the error propagation, weighting factors are assigned to each variable. This is done first by establishing a baseline condition, and then varying each measurement independently by a nominal error value to determine its effect on the output core thermal power calculation. For the CRD Inlet Temperature and the RWCU Inlet and Outlet Temperature measurements, because of the fact that thermocouples are used, and the fact that the spans of these instruments are so large in comparison to the small errors, ±5°F is chosen for this nominal error value. For the Ultrasonic Flow Meters, since errors are significantly less than ±1% of Actual Flow, the nominal value of ±1% Actual Flow is used to establish the weighting factors. For all other parameters, a nominal error value of ±5% Span is used to determine the weighting factors.

The baseline process conditions are established in the sub-sections of Section 6.1 per Figures 1.2-2 and 1.2-3 of Reference 9.8.1. The weighting factors are determined in Section 6.2. Total loop uncertainties of the various parameters that feed into the heat balance computation are performed within Section 6.3. Finally, each of the total loop uncertainties are multiplied by their respective weighting factors, and combined to form the total measurement uncertainty for the heat balance thermal power computation in Section 6.4.

There are two bias terms in the measurement, one of which result from the fact that the operating density of the RWCU water is different than the density assumed when the flow / differential pressure relationship was determined for the flow orifice. The other bias term is from the fouling of the Feedwater Flow venturis. This bias may or may not be present, but may vary up to a limit specified herein. Errors for these bias terms are performed separately from the random terms, which are combined via the Square Root of the Sum of the Squares (SRSS) methodology in accordance with Reference 9.1.1.

Where multiple signals are used to determine averages for use in heat balance functions, the uncertainty of the average signal, c, is determined using the methodology of Reference 6.1.1, Section K2.

$$c = \pm\sqrt{(k1 * a)^2 + (k2 * b)^2 \ldots};$$

k1 = k2 = 1/no. signals;
a = b = single signal loop error

$$c = \pm\sqrt{\frac{NumberSignals * (a)^2}{(NumberSignals)^2}} = \pm\frac{a}{\sqrt{NumberSignals}}$$

4.0 DESIGN INPUTS

4.1 MISCELLANEOUS DESIGN INPUTS

4.1.1 Reference 9.8.10 shows that for BWR-4 designs, the moisture carryover content is effectively zero, and should be treated as such in the Core Thermal Power computations. This reference also states that the uncertainty of this value when used at a BWR-4 is negligible. Therefore, there are no uncertainties in this estimate, and none are included in this computation. The model for the heat balance calculation will be changed to reflect a moisture carryover content of zero, per Reference 9.8.10.

4.1.2 References 9.8.12 and 9.8.13, plant data was taken for a number of variables for the Extended Uprate Plant Performance tests. Data was recorded from plant instruments, as well as from Measurement & Test Equipment (M&TE) at various process points. This data is used to determine the upstream tap pressure of the feedwater flow venturis to be used for determining feedwater flow parameters. Note that the M&TE readings are used, as opposed to the plant readings, as the M&TE readings are taken at the process points of interest and are more accurate than the plant instrumentation. (It should be noted here that these pressures are used to determine enthalpies and densities for the feedwater. Neither enthalpy nor density is a strong function of pressure in this region of the steam tables. However, the operating pressures are extrapolated for correctness of the computations.)

In order to determine the upstream tap pressures, Reference 9.8.12 performed testing at the new operating power level of 2763 MWt. From Appendix A, sheet 6 of 10, parameters P074A_1 and P074B_1 are the two nozzle pressure readings, 1113.47034 and 1118.48291 psia respectively for Test 2-3; and 1114.03223 and 1119.10312 psia respectively for Test 4-1. In order to determine a nominal Unit 1 nozzle pressure, these values are averaged.

The average value of these 4 readings is 1116.27215 psia. Therefore, the nominal Unit 1 nozzle pressure is determined to be as follows:

$$P_{noz1} = 1116 \text{ psia}$$

In a similar manner, Reference 9.8.13 is used to determine the nominal pressure. However, Reference 9.8.13 only performed testing up to a power level of 2708 MWt. Therefore, in order to determine nozzle pressure for Unit 2, the values are extrapolated. From Appendix C, sheet 8 of 13, parameters P074A_1 and P074B_1 are the two nozzle pressure readings, 1119.643 and 1120.057 psia respectively for Test 2-5. In order to determine a nominal Unit 1 nozzle pressure, these values are averaged to obtain 1119.85 psia. Document reviews and SNC interviews indicate that the test control for power level during test performance was not adequate, so the value for QT on Sheet 10 of 13 of

Appendix C, 2723.445 MWt is used for the actual power level of the test.

From Sections 6.2.9, it can be seen that errors in actual flow rate (in terms of % Actual FW flow) are on a near 1:1 relationship to errors in percent of rated power. When normalized, this means that in terms of percent, % Actual FW Flow approximates % power. Also, flow is related to the differential pressure across the FW venturis by a square root relationship. Since the output pressure of the venturis is approximately 1050 psia per Figure 1.2-2 of Reference 9.8.1, the extrapolation of nozzle pressure to a power level of 2763 MWt is performed as follows. (Approximate values)

$$Q = K1 \times Flow = K2 \times (DP)^{0.5}$$

$$\begin{aligned} K2 &= Q1/(DP1)^{0.5} \\ &= 2723.445 / (1119.85-1050)^{0.5} \\ &= 325.8633 \end{aligned}$$

$$\begin{aligned} P_{noz2} &= (Q2/K2)^2 + 1050 \text{ psia} \\ &= (2763/325.8633)^2 + 1050 \text{ psia} \\ &= 1121.894 \text{ psia} \end{aligned}$$

Therefore, the nozzle pressure for Unit 2 at 100% power operating conditions is extrapolated from test results to be as follows.

$$P_{noz2} = 1122 \text{ psia}$$

4.2 FEEDWATER FLOW UNCERTAINTY CONSIDERATIONS

Per References 9.7.1 through 9.7.12, the Feedwater Flow instrument loop consists of flow elements, power supplies and transmitters, which provide direct input to the Plant Computer. The following is a detailed listing of the considerations necessary for each instrument in this instrument loop configuration.

Note that for Case 2, the uncertainties of the Feedwater Flow instrument loop are continuously compensated out, by continuous automatic correction of the Plant Computer Feedwater Flow reading to match those of the Ultrasonic Flow Meters. Therefore, all errors derived within this section apply to Case 1 only.

4.2.1 FEEDWATER FLOW ELEMENT AND FLUID DENSITY

TAG NUMBERS:	1(2)C32-N001A, B	[9.7.1, 7]
MANUFACTURER:	Permutit	[9.6.1, 2]
Flow Span:	0 – 8 Mlb_m/hr	[9.3.1, 2]

4.2.1.1 Per Reference 9.5.24, the required Reference Accuracy of the flow element is ± 0.5% at a 95% confidence. However, References 9.6.2 and 9.6.13 show that the laboratories calibrated the flow elements to an accuracy of ± 0.25%. This uncertainty is a result of the potential inaccuracy of the test flow used in the establishment of the discharge coefficient of the flow element. This accuracy is therefore a direct result of the test flow inaccuracy, and is in terms of %Actual Flow. Subsequent inspections have revealed no reason to increase this uncertainty value. Since this error is input to the flow measurement via an error in the discharge coefficient, this error is compensated for when the venturi flow value is corrected to the UFM value.

$$RA_{FWFE} = \pm 0.2500\% \text{ Actual Flow}$$

4.2.1.2 Per Section II-II-3 of Reference 9.1.2, the installation effects for the flow element are dependent on the compliance with standards in the installation of the venturi. If the guidelines of Figure II-II-1 are met, the errors due to piping installation effects are limited to ±0.5%, but if they are not, an additional ±0.5% is required to be added. Per References 9.6.1 and 9.6.2, the feedwater flow venturis are installed as a part of a GE assembly, which includes a long section of 18" piping, using flow straighteners in the upstream and downstream piping sections. Per the same references, the Beta ratios are nominally 0.5 for Unit 1 and 0.5161 and 0.5151 for the two flow elements in Unit 2. Reference 9.1.2 Figure II-II-1, item (H) is the most correct figure for assessing the acceptability of the installation. A Beta ratio of approximately 0.5 would require a minimum of 5 diameters upstream and 2 diameters downstream of straight piping. This would equate to approximately 7.5' upstream and 3' downstream. Per the descriptions and construction details in References 9.6.1 and 9.6.2, these requirements are fully met by these installations. Per Section C.3 of Reference 9.1.1, this error is considered as an error to the discharge coefficient, which is proportional to the Actual Flow value. Therefore,

$$IE_{FWFE} = \pm 0.5000\% \text{ Actual Flow}$$

Because of the detailed design using flow straighteners and long sections of piping, any errors, due to installation effects, in the flow to differential pressure characteristic at 100% power operating conditions, are considered to be minor and capable of being compensated for by the UFM correction process.

4.2.1.3 Per References 9.3.1 and 9.3.2 and Assumption 5.3, the calibration tables for the associated transmitters are computed, taking into account the feedwater temperature at 100% power conditions. The calculations compute the correct densities and account for thermal expansion of the venturis. Additionally, per Attachment 1 to Reference 9.3.2, Attachment E to this calculation, and References 9.8.16 and 9.8.17, the plant computer compensates the feedwater flow signal for feedwater temperature changes, and this compensation accounts for changes in thermal expansion factor. The only possible expansion factor error would be due to errors in the temperature signal to the plant computer, which would affect the compensation algorithm.

Errors in the temperature signal are so small that the resulting error in compensation for thermal expansion factor (EF) is negligible.

EF_{FWFE} = Negligible

4.2.1.4 Per Attachment 1 to Reference 9.3.2, Attachment E to this calculation, and References 9.8.16 and 9.8.17, the plant computer compensates the feedwater flow signal for feedwater temperature changes, and this compensation accounts for changes in feedwater density. The only remaining density error would be due to errors in the temperature signal to the plant computer, which would affect the compensation algorithm. Errors in the indicated feedwater temperature affect the accuracy of the flow reading because of the associated density errors.

Per Section 6.3.2 of this calculation, an error for each temperature instrument loop in the plant computer has been determined as follows.

$TU_{FWT} = \pm 2.5421°F$

In this case, per Attachment E, the plant computer takes the average of the two feedwater temperature measurements to use for compensation of the associated loop flow. Therefore, the uncertainty is expressed as follows for this average.

TLU (Avg FW Temp) = SRSS (TUs of 2 FW Temp Signals) / No. Signals
$= (2x(\text{TU of Single FW Temp Signal})^2)^{1/2}/2$
$= \text{TU of Single FW Temp Signal} / (2)^{1/2}$

$TLU_{FWT\text{-}Comp} = TU_{FWT} / (2)^{1/2} = \pm 1.7975°F$

For conservatism, and to account for small errors in the temperature compensation algorithm within the plant computer, a ±2°F temperature variation around the nominal value would reasonably bound the normal operating scenario. Therefore, the density error is computed based on this variation.

Using normalized values from Section 6.1.1 for the nominal flow rates at 100% Power Operation,

Unit 1

C(100% Power)	=	71.9625% Flow Span
A(100% Power)	=	51.7860% DP Span

Unit 2

C(100% Power)	=	74.6875% Flow Span
A(100% Power)	=	55.7822% DP Span

Per Figures 1.2-2 and 1.2-3 of Reference 9.8.1, the nominal feedwater temperatures for the two Units at 100% power operating conditions is 397.5°F for Unit 1 and 425.1°F for Unit 2. Per Design Input 4.1.2, the nozzle pressures for Unit 1 and 2 during 100% power operation are 1116 psia and 1122 psia, respectively. Per Assumption 5.3, at the completion of this project, the calibration tables of the feedwater flow transmitters will be adjusted to the heat balance operating conditions. Per Assumption 5.4, the present heat balance conditions are treated as the baseline. Therefore, the following band of densities is considered for the two units, as linearly interpolated from Reference 9.8.2.

Unit 1

ρ1-(1116 psia and 395.5°F)	=	54.1307 lbm/ft^3
ρ1(1116 psia and 397.5°F)	=	54.0488 lbm/ft^3
ρ1+(1116 psia and 399.5°F)	=	53.9671 lbm/ft^3

Unit 2

ρ2-(1122 psia and 423.1°F)	=	52.9711 lbm/ft^3
ρ2(1122 psia and 425.1°F)	=	52.8839 lbm/ft^3
ρ2+(1122 psia and 427.1°F)	=	52.7970 lbm/ft^3

Per Reference 9.8.4, the input signal is multiplied by a constant to determine mass flow rate. Therefore, holding mass flow rate at a constant value equal to the heat balance figures and holding all other terms in the flow equation constant except for DP and density, the following are the effects on the differential pressure reading.

The equation is derived from References 9.3.1 and 9.3.2.

$DP = K / \rho$

$K_1 = DP_{1i} \times \rho_1$
$= 51.7860\%\ DP\ Span \times 54.0488 lbm/ft^3$
$= 2798.9712\%\ DP\ Span \times lbm/ft^3$

$K_2 = DP_{2i} \times \rho_2$
$= 55.7822\%\ DP\ Span \times 52.8839 lbm/ft^3$
$= 2949.9803\%\ DP\ Span \times lbm/ft^3$

Therefore, the change in DP readings due to the density changes from those assumed at calibration are as follows:

$DP_{1-} = K_1 / \rho_{1-}$
$= 2798.9712 / 54.1307$
$= 51.7076\%$ DP Span

$PE_{r1-} = +DP_{1-} - DP_{1i}$
$= +51.7076 - 51.7860$
$= -0.0784\%$ DP Span

$DP_{1+} = K_1 / \rho_{1+}$
$= 2798.9712 / 53.9671$
$= 51.8644\%$ DP Span

$PE_{r1+} = +DP_{1+} - DP_{1i}$
$= +51.8644 - 51.7860$
$= +0.0784\%$ DP Span

This is treated as a random uncertainty, as the temperature effect that causes this error is random.

$PE_{FWFE1} = \pm 0.0784\%$ DP Span

$DP_{2-} = K_2 / \rho_{2-}$
$= 2949.9803 / 52.9711$
$= 55.6904\%$ DP Span

$PE_{r2-} = +DP_{2-} - DP_{2i}$
$= +55.6904 - 55.7822$
$= -0.0918\%$ DP Span

DP_{2+} = K_2 / ρ_{2+}
= 2949.9803 / 52.7970
= 55.8740% DP Span

PE_{r2+} = $+DP_{2+}-DP_{2i}$
= +55.8740- 55.7822
= +0.0918% DP Span

PE_{FWFE2} = ±0.0918% DP Span

Per Reference 9.8.8, when the UFMs are used to correct the venturi flow readings, the correction factor is updated continuously (generally not longer than 1 minute between updates). Any temperature compensation error for the venturi reading is compensated out. Therefore, this error term is only applicable without UFM correction.

NOTE: Because this error is directly due to the error of the Feedwater Temperature measurement, this term is dependent with the Feedwater Temperature Total Loop Uncertainty. The Feedwater temperature measurement is the reference for the calculation of Feedwater density and Feedwater enthalpy. Since the change in either of these terms is not random with respect to a directional change in Feedwater temperature, a dependent relationship exists between the density and enthalpy functions. Therefore, this term must be treated separately from the other terms in this loop, until combined with the Feedwater Temperature Error.

4.2.1.5 Feedwater Flow venturi fouling is an accepted phenomenon throughout the nuclear industry. For Hatch, tracer tests performed in the early 1990's and several inspections showed excellent agreement between measured and indicated feedwater flows. Feedwater flow has also been compared to steam and condensate flows in order to trend possible feedwater fouling effects. At Hatch, no fouling trends were evident.

Research was performed to determine if any industry data exists which would help to determine the feedwater venturi fouling for this specific plant. Per Reference 9.8.11, "The most common cause of changes in nozzle bias is the phenomenon of fouling. Fouling induced biases have proven to be difficult to predict, both in magnitude and in variation over a fuel cycle. Long term comparisons of data from LEFM, nozzles, and other plant instruments have confirmed the presence of fouling in at least 21 plants. The average value is 1%... The average change in bias observed in 4 BWR's with the LEFM is 0.6%." Since venturi fouling can occur during a cycle, and is dependent on water chemistry, and process temperatures and pressures, the value from Reference 9.8.11 is conservatively chosen to envelope fouling at Hatch.

PE_{bFWFE} = + 0.6% Actual Flow

Since UFMs actually correct the Feedwater Flow reading during power operation, this error is eliminated for Case 2.

4.2.2 FEEDWATER FLOW TRANSMITTER CONSIDERATIONS

TAG NUMBER:	1(2)C32-N002A, B	[9.7.1-12]
MANUFACTURER:	ROSEMOUNT	[9.5.23, 24]
MODEL NUMBER:	1151DP6B22MB (Smart)	[9.5.23, 24]
1C32-N002A SPAN:	0 – 2367.9 "H_2O	[Att. C]
1C32-N002B SPAN:	0 – 2357.6 "H_2O	[Att. C]
2C32-N002A SPAN:	0 – 2325.2 "H_2O	[Att. C]
2C32-N002B SPAN:	0 – 2310.1 "H_2O	[Att. C]

4.2.2.1 Per Reference 9.4.1, the Analyzed Drift (DA) for the flow transmitter is ± 1.447% DP Span for a period of 30 months between calibrations. This includes the effects of Drift (DR), Reference Accuracy (RA) and Measurement & Test Equipment (M&TE).

DA_{FWFT} = ± 1.4770% DP Span

4.2.2.2 Setting Tolerance effects are due to the flexibility of the technician in the calibration process. The effect is bounded by the As-Left setting tolerance of the device. Per References 9.2.2 and 9.2.3, the As-Left setting tolerance is ± 0.2500% Span for Unit 1 and ± 0.1250% Span for Unit 2.

ST_{FWFT1} = ± 0.2500% DP Span
ST_{FWFT2} = ± 0.1250% DP Span

4.2.2.3 Per Reference 9.6.4, the flow transmitter has specifications for static pressure zero and span effect. Per Reference 9.3.1 & 9.3.2, the zero effect is fully calibrated out, and the span effect is compensated for in the establishment of the calibration parameters for the transmitters. The residual static pressure span effect is due to the fact that each transmitter responds slightly differently with respect to the span effect, and the correction procedure given merely corrects for the average transmitter response of the all transmitters produced. This effect is specified in Reference 9.6.4 as ± 0.25% of input reading per 1000 psi. Per Design Input 4.1.2, the highest nominal operating nozzle pressure is for Unit 2. Since the pressures are close to each other from Unit 1 to Unit 2, the error for Unit 2 is conservatively applied to both units, using 1122 psia as the pressure value. Calibration is performed at approximately 14.7 psia. Conservatively using 100% span to compute this figure, we obtain the following Static Pressure Effect (SPE).

SPE_{FWFT} = ± 0.25% DP Span x (1122-14.7) / 1000 psi

SPE_{FWFT} = ± 0.2768% DP Span

4.2.2.4 Per Reference 9.6.4, the flow transmitter Power Supply Effect (PSE_{FWFT}) is given as less than ±0.005% URL per Volt, and the load effect is negligible. Per References 9.5.1 and 9.5.2, the power supplies for the flow transmitters regulate the voltage supplied to the transmitter to 26.5 ± 1.5 VDC. Per Reference 9.6.4, the URL is 100 psid (2773 "H_2O). Use of the transmitter with the least calibrated span maximizes this uncertainty term; therefore, the span for 2C32-N002B is used to compute this term. Therefore, the flow transmitter Power Supply Effect (PSE_{FWFT}) is given as:

PSE_{FWFT} = ± (0.005% URL / VDC)(1.5 VDC) x [2773 "H_2O / 2310.1 "H_2O]
PSE_{FWFT} = ± 0.0090% DP Span (Only Use with No UFM Correction)

4.2.2.5 Per Reference 9.6.4, the flow transmitter Temperature Effect (TE_{FWFT}) is given as ± (0.2% URL + 0.18% Span) / 100°F, and the URL is 2773 "H_2O. Use of the transmitter with the least calibrated span maximizes this uncertainty term; therefore, the span for 2C32-N002B is used to compute this term. The transmitters are not accessible during operation, and are located in the Turbine Building per Reference 9.8.5. Per Reference 9.8.6, the maximum temperature during normal operation in this room is 100°F, and the normal temperature is 70°F. Therefore, the maximum difference in temperature between operating conditions and calibration conditions is 30°F, which covers calibrations in the field or in the laboratory. Therefore, the temperature effect is computed as follows:

TE_{FWFT} = ± [[(0.2%)(2773 "H_2O) / 2310.1 "H_2O] + 0.18% Span] x (30°F/100°F)
TE_{FWFT} = ± 0.1260% DP Span

4.2.3 ULTRASONIC FLOW METER (UFM) UNCERTAINTY CONSIDERATIONS

4.2.3.1 Per Reference 9.8.3, "On the basis of the staff's review of the Topical Report CENPD-397-P, Revision 01 (Proprietary and Non-Proprietary), the staff concludes that the CROSSFLOW UFM is designed and tested to achieve the flow measurement uncertainty of 0.5 percent or better, with a 95 percent confidence interval." However, Westinghouse is making changes to the design of the Crossflow UFM system to provide significantly better accuracy. Based on Reference 9.8.3, the Crossflow UFM is at least accurate to 0.5 percent of actual flow. At the point of issuance of this evaluation, based on preliminary laboratory results, the accuracy for the Hatch specific Crossflow system is anticipated to be ±0.42% actual flow. Therefore, the Total parameter Uncertainty (TU) is derived as follows:

$TU_{UFMXFLOB}$ = ± 0.4200% Actual Flow (95% Confidence Factor)

4.3 FEEDWATER TEMPERATURE UNCERTAINTY CONSIDERATIONS

Per References 9.7.1 and 9.7.13-9.7.23, the Feedwater Temperature instrument loop to the Plant Computer consists only of the Temperature Element and the Temperature Transmitter, which directly feeds the Plant Computer. The temperature transmitters are calibrated individually. Per discussions with plant personnel, once every 5 to 6 years, a loop calibration check is performed, using an oil bath for the temperature element. The plant computer reading is checked to be within ±0.5°F of a precision measurement in the oil bath for a 3-point calibration. If the measurement differs by more than the criteria, then the RTD is replaced. For conservatism, no credit is taken for reductions in uncertainty due to this loop calibration.

4.3.1 FEEDWATER TEMPERATURE ELEMENT

TAG NUMBER:	1(2)B21-N041A-D	[9.7.1, 13]
MANUFACTURER:	Rosemount	[9.5.11, 13]
TYPE:	177 L - 200 Ω Platinum RTD	[9.5.11, 13]

4.3.1.1 Per References 9.5.11-14, the system accuracy for platinum temperature elements, the associated leads and temperature transmitter is ± 0.30°F. This term is addressed in Section 4.3.2.1.

4.3.1.2 The RTD has no adjustment and therefore cannot be calibrated. Therefore, the errors that can be introduced during calibration (Setting Tolerance and M&TE) do not apply to this device.

ST_{FWTE} = N/A
$M\&TE_{FWTE}$ = N/A

4.3.1.3 RTD lead wire effects are negligible with 4-wire RTDs. Per References 9.7.14 and 9.7.15, these are 4-wire RTDs. Therefore, RTD Lead Wire Effects are negligible for this application.

LW_{FWTE} = N/A

4.3.1.4 RTD Self-Heating Effects are negligible if used with flowing fluids. Therefore, Self-Heating Effects are negligible for this application.

SH_{FWTE} = N/A

4.3.2 FEEDWATER TEMPERATURE TRANSMITTER

TAG NUMBER:	1(2)B21-N602A-D	[9.7.1, 9.7.13-23]
MANUFACTURER:	Rosemount	[9.5.12, 14]
MODEL NUMBER:	414H	[9.5.12, 14]
SPAN:	150°F	[9.2.6, 7]
SPAN:	~150mVDC	[9.2.6, 7]

The Vendor Technical Manuals do not contain performance specifications for these devices, and Rosemount no longer has supporting specification sheets. However, Reference 9.6.11 contains technical information on a similar product from Rosemount. In the absence of specification type information for the 414H transmitter, specifications for the 414L are used.

4.3.2.1 Per References 9.5.12 and 9.5.14, the reference accuracy of the temperature sensor and transmitter as a matched pair is given as ±0.3°F for 3σ. For this evaluation, we must consider 2σ uncertainties, or ±0.2°F. Per Reference 9.6.11, the Model 414L temperature transmitters are accurate to ±0.1% with platinum RTDs. The range of these transmitters is 150°F, which gives a transmitter error of ±0.15°F. Therefore in accordance with the data sheets, in order to provide the error of the total system, the Reference Accuracy is conservatively assigned as follows:

$$RA_{FWTT} = \pm 0.2000°F$$

4.3.2.2 Setting Tolerance effects are due to the flexibility of the technician in the calibration process. The effect is bounded by the As-Left setting tolerance of the device. Per References 9.2.6 and 9.2.7, the As-Left setting tolerance is ± 0.3000 mVdc. Therefore,

$$ST_{FWTT} = \pm (0.3000/149.96) \times 150°F$$
$$ST_{FWTT} = \pm 0.3001°F$$

4.3.2.3 Measurement and Test Equipment effects (M&TE) are errors introduced during the calibration process and are constant at a given point on the calibration curve throughout an operating cycle. M&TE is chosen to be at least as accurate as the equipment being calibrated, and generally considerably more accurate. Therefore, in order to provide the technician with flexibility in the choice of M&TE, the M&TE uncertainty is conservatively set equal to the device Reference Accuracy.

$$M\&TE_{FWTT} = \pm 0.2000°F$$

4.3.2.4 Reference 9.6.11 does not specify any drift uncertainty values. Because of the redundancy in signals, and the use of these signals in different applications, significant drift would be detected and corrected. For conservatism, the magnitude of the drift uncertainty is set equal to the Reference Accuracy term. Therefore,

$$DR_{FWTT} = \pm 0.2000°F$$

4.3.2.5 Per Reference 9.6.11, the temperature transmitter Power Supply Effect (PSE) is given as less than or equal to ±0.01% for a ±10% line change. Per References 9.7.14 and 9.7.15, the 120 VAC instrument bus powers the temperature transmitters. Per Section 8.7.3 (Unit 1) and Section 8.3.1.1.4 (Unit 2) of Reference 9.8.1, the instrument AC power system is regulated to within ± 10%. Therefore, the temperature transmitter Power Supply Effect is given as:

$$PSE_{FWTT} = \pm (0.0001) \times (150°F)$$
$$PSE_{FWTT} = \pm 0.0150°F$$

4.3.2.6 Per Reference 9.6.11, the temperature transmitter Temperature Effect (TE) is given as ± 0.05°F / °F. Per Reference 9.8.5, the temperature transmitters are located in the Turbine Building. Per Reference 9.8.6, the maximum temperature during normal operation in this room is approximately 100°F, and the normal temperature is 70°F. However, because of the location of the devices, a maximum temperature of 120°F is conservatively used for computing temperature effect for these devices. The maximum difference in temperature between operating conditions and calibration conditions is 50°F, which covers calibrations in the field or in the laboratory. Therefore, the temperature effect is computed as follows:

$$TE_{FWTT} = \pm (0.05°F/°F) \times (50°F)$$
$$TE_{FWTT} = \pm 2.5000°F$$

4.3.3 UFM FEEDWATER TEMPERATURE

4.3.3.1 The Westinghouse Crossflow UFMs are temperature compensated within the Crossflow system, using separate temperature measurement equipment from the existing installed feedwater temperature sensors. The error of that temperature is included within the overall uncertainty for the UFM as given in Section 4.2.3.1 above. There are no additional UFM temperature errors that need to be considered, and for Case 2, the UFM temperature error is NOT a dependent term with the Feedwater temperature error (which is used in the enthalpy determination), since different instruments are used to supply the temperature input to Feedwater density and the enthalpy calculation.

4.4 REACTOR PRESSURE UNCERTAINTY CONSIDERATIONS

Per References 9.7.16, 20, 24 and 25, the Reactor Pressure transmitter is a direct input to the Plant Computer, with no intermediate devices. Therefore, the pressure transmitter and Plant Computer are the only devices in the loop for which instrument uncertainty must be considered.

4.4.1 REACTOR PRESSURE TRANSMITTER

TAG NUMBER:	1(2)C32-N005A, B	[9.7.16, 20, 24, 25]
MANUFACTURER:	Rosemount	[9.5.5, 6]
MODEL NUMBER:	1151GP9	[9.5.5, 6]
URL:	3000 PSIG	[9.6.4]
SPAN:	0-1200 PSIG*	[9.2.2, 9.2.3]

* Includes 14 psi (U1) and 14.5 psi (U2) sensing line pressure offset. [9.2.2, 9.2.3]

4.4.1.1 Drift analysis has shown gauge pressure transmitters to perform more accurately than differential pressure transmitters, in terms of % Span. Also, Rosemount 1151 transmitters perform at least equally with, if not more accurately, than Rosemount 1153 transmitters in terms of drift. There has been no specific drift analysis for Rosemount 1151 gauge pressure transmitters, but specific drift analyses were prepared for Rosemount 1153 Range Code 9 transmitters (Reference 9.4.2), and for Rosemount 1151 differential pressure transmitters (Reference 9.4.1). (Note however that Reference 9.4.2 limits application of the conclusions to transmitters with Turndown Factors less than or equal to 2, which is not the case for these transmitters.) Reference 9.4.2 computes the Analyzed Drift (DA) for Rosemount 1153 Range Code 9 gauge pressure transmitters to be lower than that shown in Reference 9.4.1 for the Rosemount 1151 differential pressure transmitters. Therefore, for conservatism, the drift value for the Rosemount 1151 differential pressure transmitters is used for this application. Per Reference 9.4.1, the Analyzed Drift (DA) is applied to these transmitters as ± 1.447% DP Span for a period of 30 months between calibrations. This includes the effects of Drift (DR), Reference Accuracy (RA) and Measurement & Test Equipment (M&TE).

$DA_{RPT} =$ ± 1.4470% Span

4.4.1.2 Setting Tolerance effects are due to the flexibility of the technician in the calibration process. The effect is bounded by the As-Left setting tolerance of the device. Per References 9.2.2 and 9.2.3, the As-Left setting tolerance is ± 0.2500% Span.

$ST_{RPT} =$ ± 0.2500% Span

4.4.1.3 Per Reference 9.6.4, the pressure transmitter Power Supply Effect (PSE_{RPT}) is given as less than ±0.005% URL per Volt, and the load effect is negligible. Per References 9.5.3 and 9.5.4, the power supplies for the pressure transmitters are rated to 26.5 ± 1.5VDC. Per Reference 9.6.4, the URL is 3000 psig. Therefore, the pressure transmitter Power Supply Effect (PSE_{RPT}) is given as:

$$PSE_{RPT} = \pm (0.005\% \text{ URL / VDC}) \times (1.5 \text{ VDC}) \times (3000\text{psig / } 1200 \text{ psig})$$

$$PSE_{RPT} = \pm 0.01875\% \text{ Span}$$

4.4.1.4 Per Reference 9.6.4, the pressure transmitter Temperature Effect (TE_{FWFT}) is ± (0.4% URL + 0.36% Span) / 100°F, and the URL is 3000 psig. The transmitters are located in the Reactor Building at elevation 158' per Reference 9.8.5. Per Reference 9.8.7, the maximum temperature during normal operation at this location is 100°F. Per Reference 9.8.6, the normal temperature in the area (assumed for calibration conditions) is 70°F. Therefore, the maximum difference in temperature between operating conditions and calibration conditions is 30°F, which covers calibrations in the field or in the laboratory. Therefore, the temperature effect is computed as follows:

$$TE_{RPT} = \pm [[(0.4\%)(3000 \text{ psig}) / 1200 \text{ psig}] + 0.36\% \text{ Span}](30°F/100°F)$$

$$TE_{RPT} = \pm 0.4080\% \text{ Span}$$

4.5 CONTROL ROD DRIVE FLOW UNCERTAINTY CONSIDERATIONS

Per References 9.7.16, 20, and 26-29, the Control Rod Drive Flow instrument loop consists only of the flow element and the flow transmitter, which is directly input to the Plant Computer.

4.5.1 CONTROL ROD DRIVE FLOW ELEMENT AND FLUID DENSITY

TAG NUMBERS:	1(2)C11-N003	[9.7.26, 28]
MANUFACTURER:	Badger	[9.5.20, 22]
Span:	0-200"H_2O	[9.2.4, 5]
Flow Span:	0-100 GPM (0-50,000 lbm/hr on Plant Computer)	[9.5.20, 22]

4.5.1.1 Per Reference 9.7.47, the rated accuracy of the flow element is ±1%. This uncertainty is a result of the potential inaccuracy of the test flow used in the establishment of the discharge coefficient for the flow element. This accuracy is therefore a direct result of the test flow inaccuracy, and is in terms of %Actual Flow.

RA_{CRDFE} = ± 1.0000% Actual Flow

4.5.1.2 Per Section II-II-3 of Reference 9.1.2, the installation effects for the flow element are dependent on the compliance with standards in the installation of the flow nozzle. If the guidelines of Figure II-II-1 are met, the errors due to piping installation effects are limited to ±0.5%, but if they are not, an additional ±0.5% is required to be added. Per References 9.5.20 and 9.5.22, the line size is 2 inches. Per References 9.7.41 and 9.7.42, there are 10 diameters of straight pipe from the nearest bend to the entrance of the nozzle, and approximately 5 diameters of straight pipe after the nozzle until the next bend. Reference 9.1.2 Figure II-II-1, item(C) is the most correct figure for assessing the acceptability of the installation. Figure II-II-1, item (C), requires more than 12 diameters of straight piping before the nozzle, no matter what the Beta ratio is. Therefore, the existing installation does not meet the requirements, and the additional ±0.5% is added. Per Section C.3 of Reference 9.1.1, this error is considered as an error to the discharge coefficient, which is proportional to the Actual Flow value. Therefore,

IE_{CRDFE} = ± 1.0000% Actual Flow

4.5.1.3 Per References 9.2.4, 9.2.5, 9.5.20, 9.5.22 and Figures 1.2-2 and 1.2-3 of Reference 9.8.1, the flow nozzles are sized for operating conditions at approximately 100% power. The process condition used to size the flow nozzle is Specific Gravity ~ 1, and process temperature = 150°F. Per Reference 9.8.14, the design temperature range for this system is 40°F to 150°F. This is a small temperature band to consider, and the nozzle is closely matched to it. The small change in temperature will not significantly affect the characteristics of the flow orifice itself. Therefore, the effect on the measurement from the thermal expansion factor of the nozzle is negligible.

EF_{CRDFE} = Negligible

4.5.1.4 The CRD System Flow reading is not temperature (density) compensated within the Plant Computer. Changes in operating temperature of the CRD system water affect the accuracy of the reading because of the associated changes in density from that assumed for the calibrations of the transmitters.

Per References 9.5.20 and 9.5.22, the base condition for the design and calibration of the orifice plates is approximately a Specific Gravity of 1. However, during operation, the source of the CRD water can either be the Condensate Storage Tank or the Condensate System. The water from these sources has a wide range of possible temperatures; therefore, the design temperature range is considered in this analysis. Per Reference 9.8.14, the design temperature range for this system is 40°F to 150°F. Therefore, the errors from calibration conditions are considered, and the largest error conservatively applied in both directions as a random term. The base condition assumed for calibration is Specific Gravity = 1, which implies the Saturated Water condition at 68°F (Reference 9.8.2).

ρ_{base} = 62.3208 lbm/ft^3

Using normalized values from Section 6.1.4 for the nominal flow rates at 100% Power Operation, for Unit 2 are:

CRD Flow (U2) = 60.4706% Flow Span
CRD Flow (U2) = 36.5669% DP Span

The temperature band to be considered is 40°F to 150°F, at a pressure of approximately 1050 psia, corresponding to the reactor pressure.

ρ-(1050 psia and 40°F) = 62.6566 lbm/ft^3
ρ_{base} = 62.3208 lbm/ft^3
ρ+(1050 psia and 150°F) = 61.3874 lbm/ft^3

Per Reference 9.8.4, the input signal is multiplied by a constant to determine mass flow rate. Therefore, holding mass flow rate at a constant value equal to the heat balance figures and holding all other terms in the flow equation constant except for DP and density, the following are the effects on the differential pressure reading.

$DP = K / \rho$

$K_2 = DP_{2i} \times \rho_2$
= 36.5669% DP Span x 62.3208 lbm/ft^3
= 2278.8785% DP Span x lbm/ft^3

Therefore, the change in DP readings due to the density changes from calibration conditions are as follows:

$DP_{2-} = K_2 / \rho_{2-}$
= 2278.8785 / 62.6566
= 36.3709% DP Span

$PE_{r2-} = +DP_{2-} - DP_{2i}$
= +36.3709- 36.5669
= -0.1960% DP Span

$DP_{2+} = K_2 / \rho 2_+$
= 2278.8785 / 61.3874
= 37.1229% DP Span

$$PE_{r2+} = +DP_{2+} - DP_{2i}$$
$$= +37.1229 - 36.5669$$
$$= +0.5560\% \text{ DP Span}$$

The largest value is conservatively applied in both directions.

$$PE_{CRDFE} = \pm 0.5560\% \text{ DP Span}$$

4.5.2 CONTROL ROD DRIVE FLOW TRANSMITTER

TAG NUMBER:	1(2)C11-N004	[9.7.16, 20, 26-29]
MANUFACTURER:	General Electric	[9.5.21, 23]
MODEL NUMBER:	555111BCAA3ABA	[9.5.21, 23]
Span:	0-200"H_2O	[9.2.4, 5]
Span:	10-50mADC	[9.2.4, 5]
Flow Span:	0-100 GPM (0-50,000 lbm/hr on Plant Computer)	[9.5.20, 22]

4.5.2.1 Per Reference 9.6.7, the Reference Accuracy, including the effects of linearity, hysteresis and repeatability, for the G.E. 555 transmitter is ± 0.4% of Span. Therefore,

$$RA_{CRDFT} = \pm 0.4000\% \text{ DP Span}$$

4.5.2.2 Setting Tolerance effects are due to the flexibility of the technician in the calibration process. The effect is bounded by the As-Left setting tolerance of the device. Per References 9.2.4 and 9.2.5, the As-Left setting tolerance is ± 0.5000% Span.

$$ST_{CRDFT} = \pm 0.5000\% \text{ DP Span}$$

4.5.2.3 Measurement and Test Equipment effects (M&TE) are errors introduced during the calibration process and are constant at a given point on the calibration curve throughout an operating cycle. M&TE is chosen to be at least as accurate as the equipment being calibrated, and generally more accurate. Therefore, in order to provide the technician with flexibility in the choice of M&TE, the M&TE uncertainty is conservatively set equal to the device Reference Accuracy.

$$M\&TE_{CRDFT} = \pm 0.4000\% \text{ DP Span}$$

4.5.2.4 Per Reference 9.6.7, the flow transmitter has specifications for static pressure effect as ± 0.4% Span / 500 psi from 100% to 50% Span, or ± 0.4% Span to ± 1.0% Span / 500 psi from 49% to 20% Span. Per Figures 1.2-2 and 1.2-3 of Reference 9.8.1, the operating pressure for both units is approximately 1050 psia. Also per these figures, the normal flow rate of the CRD system is $3x10^4$ lb/hr, which per Section 6.1.4, corresponds to 60 GPM, which is 60% Flow Span and 36% DP Span. The static pressure effect is conservatively assigned as ± 1.0% Span / 500 psi. Calibration is performed at 14.7 psia. Therefore,

SPE_{CRDFT} = ± 1.0% DP Span x (1050-14.7) / 500 psi
SPE_{CRDFT} = ± 2.0706% DP Span

4.5.2.5 Per Reference 9.6.7, no power supply effect is specified for these transmitters. Given the large magnitude of the other accuracy specifications for this device, power supply effects are negligible in comparison. Therefore,

PSE_{CRDFT} = Negligible

4.5.2.6 Per Reference 9.6.7, the flow transmitter has specifications for temperature effect as ± 1% Span / 100°F from 100% to 50% Span; or ± 1% Span to ± 2% Span / 100°F Span from 49% to 20% Span. Per Figures 1.2-2 and 1.2-3 of Reference 9.8.1, the normal flow rate of the CRD system is $3x10^4$ lb/hr, which per Section 6.1.4, corresponds to 60 GPM, which is 60% Flow Span and 36% DP Span. Therefore, the normal temperature effect is conservatively assigned as ± 2.0% Span / 100°F. Per Reference 9.8.5, the transmitters are located at elevations 87 and 111 within the Reactor Building. Per Reference 9.8.7, the maximum normal operating temperature at these locations is 104°F, and the normal temperature (assumed for calibration conditions) is 70°F. Therefore, the maximum difference in temperature between operating conditions and calibration conditions is 34°F, which covers calibrations in the field or in the laboratory. Therefore, the temperature effect is computed as follows:

TE_{CRDFT} = ± 2.0% DP Span x (34°F) / 100°F
TE_{CRDFT} = ± 0.6800% DP Span

4.6 CONTROL ROD DRIVE INLET TEMPERATURE UNCERTAINTY CONSIDERATIONS

Per References 9.7.16, 22, and 26-29, the Control Rod Drive Inlet Temperature instrument loop consists only of the temperature element (thermocouple), which directly feeds its signal to the Plant Computer.

4.6.1 CONTROL ROD DRIVE INLET TEMPERATURE ELEMENT

TAG NUMBER:	1(2)C11-N061	[9.7.16, 22, 26-29]
MANUFACTURER:	Omega	[9.5.7, 8]
TYPE:	Type T Thermocouple	[9.5.7, 8]
RANGE:	0-752°F*	[9.8.9]

* References 9.5.7 and 9.5.8 show a range of 0-900°F for these thermocouples. However, it also identifies these as Omega Type T Thermocouples. Per Reference 9.8.9, a type T thermocouple maximum output is at 752°F. Since these thermocouples are reading CRD System temperature, which is normally 123°F, the range of these thermocouples is established as 0 to the maximum temperature, 752°F.

4.6.1.1 Per Reference 9.8.9, the limits of error for an Omega Type T thermocouple are ± 1.0°C or 0.75%, whichever is greater, when above 0°C. The normal temperature for the CRD water is 123.2°F or 123.5°F per Figures 1.2-2 and 1.2-3 of Reference 9.8.3. For comparison, 0.75% of 52°C (125.6°F) is 0.39°C. Therefore, ± 1.0°C (± 1.8000°F) is used. The Reference Accuracy (RA) of the temperature element is:

$$RA_{CRDTE} = \pm 1.8000°F$$

4.6.1.2 The thermocouple has no adjustment and therefore cannot be calibrated. Therefore, the errors that can be introduced during calibration (Setting Tolerance and M&TE) do not apply to this device.

$$ST_{CRDTE} = N/A$$
$$M\&TE_{CRDTE} = N/A$$

4.7 REACTOR WATER CLEANUP (RWCU) FLOW UNCERTAINTY CONSIDERATIONS

Per References 9.7.17, 20, and 30-33, the RWCU Flow instrument loop consists only of the flow element and the flow transmitter, which is directly input to the Plant Computer.

4.7.1 RWCU FLOW ELEMENT AND FLUID DENSITY

TAG NUMBERS:	1(2)G31-N035	[9.7.30, 32]
MANUFACTURER:	GE / Vickery Simms	[9.5.27, 9.6.3]
SPAN:	0 – 300 GPM	[9.5.27, 9.6.3]
FLOW SPAN:	0 – 200" H_2O	[9.5.27, 9.6.3]

4.7.1.1 The Reference Accuracy of the flow element is given by the Unit 2 data sheet (Reference 9.5.27) to be ±0.5%. Per References 9.6.3 and 9.6.12, the orifice bore calculations are identical for the Unit 1 and Unit 2 flow elements. This accuracy is a result of the potential inaccuracy of the test flow used in the establishment of the discharge coefficient for the flow element. This accuracy is therefore a direct result of the test flow inaccuracy, and is in terms of %Actual Flow.

$$RA_{CUFE} = \pm 0.5000\% \text{ Actual Flow}$$

4.7.1.2 Per Section II-II-3 of Reference 9.1.2, the installation effects for the flow element are dependent on the compliance with standards in the installation of the flow nozzle. If the guidelines of Figure II-II-1 are met, the errors due to piping installation effects are limited to ±0.5%, but if they are not, an additional ±0.5% is required to be added. Per Reference 9.5.27, the line size is 4 inches. Per References 9.7.43 and 9.7.44, there are at least 10.5 feet of straight piping upstream of the orifice and at least 2 ½ feet of straight piping downstream. This equates to at least 31 diameters upstream and at least 7 diameters downstream. Reference 9.1.2 Figure II-II-1, item(C) is the most correct figure for assessing the acceptability of the installation. Per References 9.6.3 and 9.6.12, the Beta ratio is 0.6813 or 0.6613. Figure (C) requires approximately 21 straight upstream diameters, and approximately 3 straight pipe diameters downstream. The installation meets the requirements of Figure (C), and the additional uncertainty does not require consideration. Per Section C.3 of Reference 9.1.1, this error is considered as an error to the discharge coefficient, which is proportional to the Actual Flow value. Therefore,

$$IE_{CUFE} = \pm 0.5000\% \text{ Actual Flow}$$

4.7.1.3 Per References 9.6.3 and 9.6.12, the flow nozzles are sized for operating conditions at approximately 100% power. The temperature used to size the flow nozzle is 545°F, which is close to the approximate 533.7°F or 531.2°F for the 100% power condition. The small change in temperature will not significantly affect the characteristics of the flow orifice itself. Therefore, the effect on the measurement from the thermal expansion factor of the nozzle is negligible.

EF_{CUFE} = Negligible

4.7.1.4 The RWCU System Flow reading is not temperature (density) compensated within the Plant Computer. Changes in operating temperature of the RWCU system inlet water affect the accuracy of the reading because the associated changes in density affect the relationship of the flow to the differential pressure for the flow orifice.

There are two specific sub-categories of density uncertainties related to these flow elements. One difference is due to the fact that the nominal heat balance density conditions at 100% power differ from the assumed conditions for the calibrations of the transmitters, which produces a bias in the measurement. The second part of this uncertainty is due to the normal random variations in density during 100% power operation. This is the random portion of this error, and it is computed separately.

Bias

References 9.6.3 and 9.6.12 are the bore diameter computations for the two subject flow elements. These computations use a specific gravity of 0.74 (pressure = 1178 psig and temperature = 545°F). The calibration procedures for the transmitters (References 9.2.8 and 9.2.9) use the differential pressure span determined by the bore diameter calculation as the endpoints. Per Figures 1.2-2 and 1.2-3 of Reference 9.8.1, these conditions differ from the nominal heat balance conditions, thereby producing a bias in the flow reading. In order to convert the specific gravity to density, the following equation is used. The base condition for this computation is the density used in the calibration, not the heat balance condition.

$$\rho_0 = SG / v_{f0}$$

where: SG = the specific gravity
v_{f0} = the specific volume at the Ref. Temp. of 60°F
(References 9.6.3 and 9.6.12 show Ref. Temp. of 60°F.)

$$\rho_0 = 0.74 / 0.016033$$
$$= 46.1548 \text{ lbm/ft}^3$$

The conditions as shown by the heat balance are (1050 psia and 531.2°F) for Unit 1 and (1050 psia and 533.7°F) for Unit 2. These conditions yield the following densities.

$\rho 1$(1050 psia and 531.2°F) = 47.2456 lbm/ft^3
$\rho 2$(1050 psia and 533.7°F) = 47.0788 lbm/ft^3

Using normalized values from Section 6.1.6 for the nominal flow rates at 100% Power Operation,

RWCU Flow (U1) = 87.9626% Flow Span
RWCU Flow (U1) = 77.3741% DP Span

RWCU Flow (U2) = 88.2742% Flow Span
RWCU Flow (U2) = 77.9234% DP Span

Per Reference 9.8.4, the input signal is multiplied by a constant to determine mass flow rate. Therefore, holding mass flow rate at a constant value equal to the heat balance figures and holding all other terms in the flow equation constant except for DP and density, the following are the effects on the differential pressure reading.

$DP = K / \rho$

K_1 = $DP_{1i} \times \rho_0$
= 77.3741% DP Span x 46.1548 lbm/ft^3
= 3571.1861% DP Span x lbm/ft^3

K_2 = $DP_{2i} \times \rho_0$
= 77.9234% DP Span x 46.1548lbm/ft^3
= 3596.5389% DP Span x lbm/ft^3

Therefore, the changes in DP readings due to the density changes, from those used for calibration, are as follows:

DP_1 = K_1 / ρ_1
= 3571.1861 / 47.2456
= 75.5877% DP Span

PE_{b1CU} = $+DP_1 - DP_{1i}$
= +75.5877- 77.3741
= -1.7864% DP Span

DP_2 = K_2 / ρ_2
= 3596.5389 / 47.0788

= 76.3940% DP Span

PE_{b2CU} = $+DP_2 - DP_{2I}$
= +76.3940- 77.9234
= -1.5294% DP Span

Random

In order to quantify the normal variations in density of the RWCU inlet water, a spreadsheet containing Plant Computer data for 19 runs of the heat balance on Hatch Unit 2 is included as Attachment D. These runs were recorded once per minute over a 19-minute period on November 1, 2001. There is only 1 computer point indication for the RWCU System inlet temperature. This means that 19 RWCU System inlet temperature readings were taken during that period of time. A statistical account of the data from that spreadsheet is listed below.

Parameter	FW Temp (Deg F)
Mean	536.3998
St Dev	0.032517
2 Std Devs	0.065034
Min	536.324
Max	536.485
Range	0.161
No. Readings	19

Per Figure 1.2-2 of Reference 9.8.1, the readings above differ from the nominal values at 100% power. The mean is 2.6998°F higher than the nominal reading. However, note that the maximum value minus the minimum value is 0.161°F and that a 2 standard deviation figure is only 0.065034°F. Given all of the above information, a ±5°F temperature variation around the nominal value bounds the normal operating scenario. Therefore, the density error is computed based on this variation. The base condition for this computation is the heat balance condition.

Using a similar approach to that above taken for the bias determination, the random errors are determined as follows:

$$\rho = SG / v_f$$

The temperature band to be considered for Unit 1 is 531.2 ± 5°F.

ρ1-(1050 psia and 526.2°F) = 47.5656 lbm/ft^3

$\rho 1$(1050 psia and 531.2°F) = 47.2456 lbm/ft^3
$\rho 1+$(1050 psia and 536.2°F) = 46.9131 lbm/ft^3

The temperature band to be considered for Unit 2 is 533.7 ± 5°F

$\rho 2-$(1050 psia and 528.7°F) = 47.4077 lbm/ft^3
$\rho 2$(1050 psia and 533.7°F) = 47.0788 lbm/ft^3
$\rho 2+$(1050 psia and 538.7°F) = 46.7486 lbm/ft^3

Using normalized values from Section 6.1.6 for the nominal flow rates at 100% Power Operation,

RWCU Flow (U1) = 87.9626% Flow Span
RWCU Flow (U1) = 77.3741% DP Span

RWCU Flow (U2) = 88.2742% Flow Span
RWCU Flow (U2) = 77.9234% DP Span

Per Reference 9.8.4, the input signal is multiplied by a constant to determine mass flow rate. Therefore, holding mass flow rate at a constant value equal to the heat balance figures and holding all other terms in the flow equation constant except for DP and density, the following are the effects on the differential pressure reading.

$DP = K / \rho$

$K_3 = DP_{1i} \times \rho_1$
$= 77.3741\%$ DP Span x 47.2456lbm/ft^3
$= 3655.5858\%$ DP Span x lbm/ft^3

$K_4 = DP_{2i} \times \rho_2$
$= 77.9234\%$ DP Span x 47.0788lbm/ft^3
$= 3668.5402\%$ DP Span x lbm/ft^3

Therefore, the changes in DP readings, due to the density changes from those used for calibration, are as follows:

$DP_{1-} = K_3 / \rho_{1-}$
$= 3655.5858 / 47.5656$
$= 76.8536\%$ DP Span

$PE_{r1-} = +DP_{1-} - DP_{1i}$
$= +76.8536 - 77.3741$
$= -0.5205\%$ DP Span

DP_{1+} = K_3 / ρ_{1+}
= 3655.5858 / 46.9131
= 77.9225% DP Span

PE_{r1+} = $+DP_{1+} - DP_{1i}$
= +77.9225- 77.3741
= +0.5484% DP Span

The larger of the errors is used and treated as a random uncertainty.

PE_{CUFE1} = ±0.5484% DP Span

DP_{2-} = K_4 / ρ_{2-}
= 3668.5402 / 47.4077
= 77.3828% DP Span

PE_{r2-} = $+DP_{2-} - DP_{2i}$
= +77.3828- 77.9234
= -0.5406% DP Span

DP_{2+} = $K_4 / \rho 2_{+}$
= 3668.5402 / 46.7486
= 78.4738% DP Span

PE_{r2+} = $+DP_{2+} - DP_{2i}$
= +78.4738- 77.9234
= 0.5504% DP Span

The larger of the errors is used and treated as a random uncertainty.

PE_{CUFE2} = ±0.5504% DP Span

4.7.2 RWCU FLOW TRANSMITTER

TAG NUMBER:	1(2)G31-N036	[9.7.17, 20, 30-33]
MANUFACTURER:	BARTON	[9.5.18, 19]
MODEL NUMBER:	764	[9.5.18, 19]
SPAN:	0-300 GPM (0-200"H_2O)	[9.5.18, 19]

4.7.2.1 Per Reference 9.4.3, the Analyzed Drift (DA) for the flow transmitter is ± 1.577% DP Span for a period of 30 months between calibrations. This includes the effects of Drift (DR), Reference Accuracy (RA) and Measurement & Test Equipment (M&TE).

DA_{CUFT} = ± 1.577% DP Span

4.7.2.2 Setting Tolerance effects are due to the flexibility of the technician in the calibration process. The effect is bounded by the As-Left setting tolerance of the device. Per References 9.2.8, 9.2.9, 9.2.11 and 9.2.12, the As-Left setting tolerance is ± 0.5000% Span.

ST_{CUFT} = ± 0.5000% DP Span

4.7.2.3 Per Reference 9.6.5, the flow transmitter has a static pressure effect of ± 0.5% of maximum span per 1000 psig. Per Figures 1.2-2 and 1.2-3 of Reference 9.8.1, the enthalpy of the water at the inlet to the RWCU is computed using a pressure of 1050 psia. Therefore, the effect is computed conservatively using 1050 psia during operating conditions. Calibration is performed at 14.7 psia. Conservatively using 100% span to compute this figure, we obtain the following Static Pressure Effect (SPE).

SPE_{CUFT} = ± 0.5% DP Span x (1050 -14.7) / 1000 psi
SPE_{CUFT} = ± 0.5177% DP Span

4.7.2.4 Per Reference 9.6.5, the flow transmitter Power Supply Effect (PSE) is given as less than ±0.05% Span per Volt, and the load effect is shown as 0.1% Span for a 100-ohm change. The load effect is only significant when changing between calibration and operating conditions, since the loads on the transmitter are different. The 100-ohm change is judged to be an adequate value for this computation. Per Reference 9.5.28 and Assumption 5.4.1, the power supplies are identified as GE/B&W/Bailey 570-06. Per Reference 9.6.6, these power supplies have an output of 52.5 VDC ± 8%. Therefore, the flow transmitter Power Supply Effect (PSE_{CUFT}) is given as:

PSE_{CUFT} = $\pm \{[(0.05\%\ Span / VDC)(52.5\ VDC)(.08)]^2 + [0.1\%\ Span]^2\}^{0.5}$
PSE_{CUFT} = ± 0.2326% DP Span

4.7.2.5 Per Reference 9.6.5, the flow transmitter Temperature Effect (TE) is given as ± 1.0% maximum span / 100°F, for the temperature range of 40°F to 150°F. Per Reference 9.8.5, the transmitters are located at elevation 158' within the Reactor Building. Per Reference 9.8.7, the maximum normal operating temperature at these locations is 100°F. Therefore, the maximum difference in temperature between operating conditions and calibration conditions is 50°F. Therefore, the temperature effect is computed as follows:

TE_{CUFT} = ± 1.0% Span x (50°F/100°F)
TE_{CUFT} = ± 0.5000% DP Span

4.8 RWCU INLET / OUTLET TEMPERATURE UNCERTAINTY CONSIDERATIONS

Per References 9.7.18, 19, 22, 23, and 30-33, the RWCU Inlet and Outlet Temperature instrument loops consist only of the temperature elements, which are directly input to the Plant Computer.

4.8.1 RWCU INLET / OUTLET TEMPERATURE ELEMENTS

TAG NUMBER:	1(2)G31-N004, N015	[9.7.18, 19, 22, 23, 30-33]
MANUFACTURER:	NECI	[9.5.16-17, 5.2]
TYPE:	Cu / Con T/C	[9.5.16-17, 5.2]
RANGE:	0-600°F	[9.5.16-17, 5.2]

4.8.1.1 Per References 9.5.15, 9.5.16 and 9.5.17, the rated accuracy of these thermocouples is 0.75%. This agrees with References 9.7.45 and 9.7.46. The normal temperature for the RWCU water is 434°F or 436.8°F per Figures 1.2-2 and 1.2-3 of Reference 9.8.3. For conservatism, 225°C (437°F) is used for the computation. Therefore, the Reference Accuracy (RA) of the temperature element is:

$$RA_{CUTE} = \pm (0.75/100) \times 225°C \times (1.8°F/°C)$$
$$RA_{CUTE} = \pm 3.0375°F$$

4.8.1.2 The thermocouple has no adjustment and therefore cannot be calibrated. Therefore, the errors that can be introduced during calibration (Setting Tolerance and M&TE) do not apply to this device.

$$ST_{RWCUTE} = N/A$$
$$M\&TE_{RWCUTE} = N/A$$

4.9 RECIRCULATION PUMP POWER UNCERTAINTY CONSIDERATIONS

Per References 9.7.16, 17, 20, 21, and 35-40, the Recirculation Pump power signal is fed directly to the Plant Computer from the watt transducers.

4.9.1 PUMP WATT TRANSDUCER

TAG NUMBER:	1(2)B31-R771, R772	[9.7.16, 17, 20, 21, 35-40]
MANUFACTURER:	Ohio Semitronics	[9.5.9, 10]
MODEL NUMBER:	PC5-004B	[9.5.9, 10]
RANGE:	0-8.4 MW	

4.9.1.1 Per Reference 9.6.8, the accuracy of the PC5 Watt Transducer is ±0.5% Full Scale, including the effects of power factor, linearity, repeatability, and current sensor. Therefore, the Reference Accuracy, based on a 100% reading, is shown as follows.

$RA_{RPWT} = \pm 0.5000\%$ Span

4.9.1.2 Setting Tolerance effects are due to the flexibility of the technician in the calibration process. The effect is bounded by the As-Left setting tolerance of the device. Per Reference 9.2.10, the As-Left setting tolerance is ± 0.5% Span.

$ST_{RPWT} = \pm 0.5000\%$ Span

4.9.1.3 Measurement & Test Equipment (M&TE) are errors introduced during the calibration process. The M&TE effect is a function of the accuracy of the test equipment used during calibration. M&TE is chosen to be at least as accurate as the equipment being calibrated, and generally more accurate. This value is conservatively assigned to be equal to the As-Left setting tolerance of the transducers, in order to maximize the flexibility in choice of test equipment by the technician.

$M\&TE_{RPWT} = \pm 0.5000\%$ Span

4.9.1.4 Per Reference 9.6.8, the Temperature Effect of the PC5 Watt Transducer is ±1.0% Reading, ±0.10% Full Scale for a temperature range of –10°C to 60°C. Per Reference 9.8.5, the transmitters are located at elevation 158' within the Reactor Building. Per Reference 9.8.7, the maximum normal operating temperature at these locations is 100°F. Therefore, the ambient temperature of these devices is well within these limits. For conservatism, the two terms are combined via SRSS assuming a 100% scale reading.

$$TE_{RPWT} = \pm [(1.0)^2 + (0.1)^2]^{1/2} \text{ \% Span}$$
$$TE_{RPWT} = \pm 1.0050\text{\% Span}$$

4.10 MISCELLANEOUS HEAT BALANCE ANALYSIS INPUTS

4.10.1 PLANT COMPUTER (PC) INPUT UNCERTAINTIES

4.10.1.1 Per Section 2.3.2.1 of Reference 9.6.9, the Analog Input card with the highest values of gain accuracy and linearity is the AC 4050 to AC 4060. The Gain Accuracy is shown to be ± 0.01% Full Scale. The linearity is given as 0.015% Full Scale. The scale ranges for each signal are programmed into the processor, such that the input spans are equal to the full-scale values. The errors are combined in SRSS fashion.

$$RA_{PC} = \pm [(0.01)^2 + (0.015)^2]^{1/2} \text{ \% Span}$$
$$RA_{PC} = \pm 0.0180\text{\% Span}$$

4.10.1.2 Setting Tolerance effects are errors introduced during the calibration process. Per Section 2.3.1.5 of Reference 9.6.9, the analog input cards incorporate a separate monitoring channel, which allows the user to conduct periodic checks and calibration routines on the system. This allows self-monitoring and calibration by the Plant Computer. Because of this, and the fact that these routines are performed on all Plant Computer input hardware, the calibration process is highly accurate. Therefore, the values of Setting Tolerance and M&TE are negligible with respect to the other error terms.

$$ST_{PC} = M\&TE_{PC} = \text{Negligible}$$

4.10.1.3 Because of the internal system performance checks during operation, significant instrument drift would be detected very quickly within the Plant Computer. Therefore, instrument drift is not applicable for the Plant Computer.

$$DR_{PC} = \text{N/A}$$

4.10.1.4 Per Reference 9.6.9, no temperature effect specification is listed for the Plant Computer. Because the Plant Computer equipment is kept in a very controlled temperature environment, the variation in temperature is very small. For these reasons, the temperature effect for the Plant Computer is negligible when compared to the other uncertainty terms associated with the instrument loops.

TE_{PC} = Negligible

4.10.1.6 The Resolution effect for the Plant Computer input card is conservatively treated as ± 1 LSB. Per Reference 9.6.9, the A/D converters for the Plant Computer are 14-bit converters. However, per discussions with plant personnel, only 12 bits are used in the conversion process. The value is computed as follows:

RES_{PC}= $\pm 1 \times [1/2^{12}] \times 100\%$
RES_{PC}= ± 0.0244% Span

4.10.1.7 The computational error of the Plant Computer involves the errors in the algorithms and conversions which are produced in the Plant Computer software. Per References 9.6.10 and 9.8.4, the steam table utility functions are performed in accordance with the ASME steam tables or Keenan & Keyes. These are very accurate sources, and correct for the applications, such that any potential minor error in the tables themselves are negligible with respect to other Heat Balance error terms. Other functions are performed digitally to many significant digits. Therefore, the computational errors associated with the Plant Computer are negligible with respect to the other instrument uncertainties present in the instrument loops.

COM_{PC} = Negligible

4.10.2 HEAT BALANCE CORRECTION FACTOR (CF) INPUT UNCERTAINTIES

4.10.2.1 Per Reference 9.8.10, the normal Q_{RAD} (radiative heat loss) used for Hatch is 1.1 MW. Per Reference 9.2.1, a Correction Factor (CF) of 2.0 MW is added to the manual heat balance computation to account for radiative heat losses and CRD Flow correction. Therefore, 0.9 MW is conservatively added to the manual total power computation to account for CRD Flow correction and other non-instrumented losses. Per Reference 9.8.4, the term used with the heat balance computation on the Plant Computer is labeled QRADX. At the present time, the value of this constant is 1.7 MW, and is intended to account for Q_{RAD} (radiative heat losses) and other non-instrumented losses, as documented in Reference 9.8.18. The Q_{RAD} term included in QRADX is 1.1 MW, and an additional approximate 0.6 MW is included to account for other non-instrumented losses, such as:

a) Recirculation Pump Seal Inflow,
b) Reference Leg Keepfill System Flow,
c) Inflow Through RWCU Seals,
d) RWCU Leakage, and
e) Significant Variations in CRD Temperature. (This term was included prior to installation of CRD Temperature measurement on the plant computer, and no longer exists.)

The adjustment to QRADX for the non-instrumented losses is assessed periodically to ensure that a conservative value is being used. Therefore, any errors in these measurements are in the conservative direction, such that they cause the Core Thermal Power measurement to be higher than actual. Therefore, these uncertainties do not need to be considered in this calculation.

Section 4.5.1.4 of this calculation computes error terms that fully account for errors in CRD flow indication, due to density differences between the calibration assumed values and the actual process values. Therefore, CRD flow measurement errors are fully accounted for. Since the manual heat balance Correction Factor (CF) is larger than the Plant Computer adjustment, QRADX, even more conservatism exists with this measurement, and no uncertainties from the additional non-instrumented losses need to be considered in this calculation.

4.10.2.2 Per Section 4.10.2.1, Q_{RAD} (radiative heat losses) used for Hatch is 1.1 MW, both in the manual and Plant Computer generated heat balance computations. This value is derived from Reference 9.8.10, which also states that the uncertainty in this value is large, up to 50% of the value, or ±0.55 MW. Therefore, this uncertainty is considered in the computation of measurement uncertainty for the core thermal power computation.

$TU_{QRAD} = \pm 0.5500$ MW

5.0 ASSUMPTIONS AND ENGINEERING JUDGMENTS

5.1 Per Reference 9.5.28, the power supply for the Unit 2 RWCU flow transmitter instrument loop is a GE/Bailey/B&W Model 570-06. The data sheet series S-18454 for Unit 1 was not available for reference, but this same model number is shown in NUCLEIS for Unit 1. Since the designs for this instrumentation appears to be identical between units, and since the model is the same in NUCLEIS, it is assumed that the Unit 1 power supply is the same model number.

5.2 Per References 9.5.16-17, the Unit 2 RWCU Temperature Element is an NECI Cu / Con thermocouple with a range of 0-600°F. The data sheet series S-18454 for Unit 1 was not available for reference. Reference 9.5.15 shows the purchase specification requirements to be the same for Unit 1 as shown on References 9.5.16-17. Since the designs for this instrumentation appear to be identical between units, it is assumed that the Unit 1 thermocouples have similar performance characteristics to the Unit 2 thermocouples.

5.3 Per References 9.3.1 and 9.3.2 and per Figures 1.2-2 and 1.2-3 of Reference 9.8.1, the calibration tables for the transmitters are not performed for the exact heat balance conditions. It is assumed that at the completion of this project, the transmitter calibration calculations, References 9.3.1 and 9.3.2, will be revised to reflect the projected heat balance conditions after the power uprate.

5.4 Because the present heat balance conditions will not change significantly, this analysis is performed using the present heat balance conditions. Because the power uprate is of such a small magnitude (only 1.5%), the uncertainty values derived herein are valid after power uprate.

5.5 References 9.5.7 and 9.5.8 show a range of 0-900°F for the CRD System Inlet thermocouples. However, these references also identify these as Omega Type T thermocouples. Per Reference 9.8.9, a type T thermocouple maximum output is at 752°F. Since these thermocouples are reading CRD System temperature, which is normally 123°F, the range of these thermocouples is established as 0 to the maximum temperature, 752°F.

5.6 Although specific gravities and enthalpies are a function of both pressure and temperature, they are significantly more affected by pressure for steam and by temperature for subcooled water. When determining the weighting factors for the steam pressure uncertainties, the effects on the steam enthalpy were considered. However, the Plant Computer also uses steam pressure in the determination of enthalpy for the feedwater temperature, CRD water temperature, and RWCU water temperature. Because pressure has such an insignificant affect on enthalpy and since the relative contributions to the thermal power computation are very small, these effects are considered negligible.

5.7 Various of the vendor documents for flow elements researched by this calculation express accuracy for the flow elements in terms of %. Although flow element output is actually a differential pressure reading, the error in the flow element is generally considered to be the error of the calibration process, which establishes a given flow rate and determines an appropriate discharge coefficient, which would allow conversion of the differential pressure from the flow element to the correct flow rate, within the stated accuracy. Since the error is in the discharge coefficient, and since the error of the flow element is zero at zero flow conditions, the error is proportional to actual flow rate, not a span value. Therefore, the % accuracy values are established as % Actual Flow for the purposes of this calculation. Interpretation of this error as proportional to flow versus differential pressure is conservative at the subject flow rates.

5.8 Per recent industry direction with regard to Reference 9.1.1, random errors that share a common cause (such as common environment or M&TE) are not considered dependent. Therefore, the dependent errors are limited to those errors that directly affect more than one factor of the heat balance computation. For this calculation, the density errors for the Feedwater Flow Element, which are produced via the temperature compensation algorithm within the plant computer, are considered dependent with the Feedwater Temperature error used for the development of Feedwater enthalpy. Therefore, these two errors are added prior to the SRSS process, per Reference 9.1.1. This only applies to Case 1, since UFM correction eliminates the Feedwater Flow density error, which is based on Feedwater Temperature.

5.8 Per Reference 9.8.8, the Feedwater Flow venturi instrument loop will be continuously corrected, based on the readings of the Westinghouse Crossflow UFMs. New correction factors are implemented no less often than once per minute. This operation reduces the measurement error for Feedwater Flow to that of the UFMs alone. All errors of the Feedwater Flow venturi instrument loop are calibrated out, to within the error of the UFMs. Therefore, no Feedwater Flow venturi instrument loop errors are considered in Case 2.

6.0 ANALYSIS

Computations are performed to an accuracy of several significant digits, but presented in this study rounded to four decimal places in most cases. Hand verification of this study utilizing the rounded values could result in slightly different results due to round off errors. Final answers are rounded to three decimal places.

6.1 ESTABLISHMENT OF BASELINE CONDITIONS

Per Section 2.0,

$$Q_{CORE} = Q_{FW} + Q_{CR} + Q_{CU} + CF - Q_P$$

where:

Q_{CORE}	=	Thermal Power Generated by Reactor Core
Q_{FW}	=	Heat Applied to Feedwater to Steam Process
Q_{CR}	=	Heat Applied to Control Rod Drive System
Q_{CU}	=	Heat Applied to Reactor Water Clean Up System
C_F	=	Correction Factor, Which Includes the Effects of Radiative Heat Loss and CRD Flow Corrections
Q_P	=	Heat Added by Recirculation Pumps

Figures 1.2-2 and 1.2-3 of Reference 9.8.1 establish the baseline Reactor System Heat Balance conditions for 100% rated conditions (2763 MWt) for each Unit. The equations for figuring the heat balance, in process units, are identical, since the physical parameters are the same. There are small differences, however, in the baseline heat balance 100% power conditions.

Where the exact parameters are given directly on the figures, no computations are required. However, where the exact parameters are not given, computations are performed to determine the baselines.

6.1.1 BASELINE CONDITIONS FOR FEEDWATER FLOW

Per Figures 1.2-2 and 1.2-3 of Reference 9.8.1, the following values are obtained for 100% Power operating conditions.

Feedwater Flow
11.514 Mlbm / hr (Unit 1)
5.757 Mlbm / hr (Unit 1) per loop
11.950 Mlbm / hr (Unit 2)
5.975 Mlbm / hr (Unit 2) per loop

These values need to be converted to units of differential pressure, in order to apply the uncertainty values and observe the affect on the heat balance calculation. In order for this to be done, density must be determined.

Per Design Input 4.1.2, the nominal feedwater flow upstream venturi tap pressures are as follows.

P_{noz1} = 1116 psia
P_{noz2} = 1122 psia

Attachment C is a tabular listing of the values with References 9.3.1 and 9.3.2, as computed using the upstream tap pressures shown above, and the values of other parameters defined by Figures 1.2-2 and 1.2-3 of Reference 9.8.1.

The value, h_s, is the full-scale differential pressure, as computed at operating conditions, which produces an indication of 8 Mlbm/hr in each feedwater flow loop. As computed in Attachment C, the four h_s values are as follows:

1C32N002A	2405.70 inWC
1C32N002B	2395.17 inWC
2C32N002A	2362.53 inWC
2C32N002B	2347.23 inWC

Since each of the differential pressure values correspond to the same flow rates, and since most of the errors for the flow loops are expressed in % DP Span, the analysis can be performed on any of the instrument loops. In a normalized fashion, given that the density of the feedwater does not change, the flow is related to the differential pressure as a square root function, such that:

$$C = (A)^{1/2}$$

Where C is a normalized fraction of the full-scale flow rate of 8 Mlbm/hr. A is the normalized fraction of full-scale differential pressure.

Unit 1
The heat balance flow rate through each feedwater flow loop is 5.7570 Mlbm/hr, as shown in Figure 1.2-3 of Reference 9.8.1. This corresponds to a C value of

$$C(100\%\ Power) = 5.7570/8 = 0.719625$$

Expressed as a percentage,

$$C(100\%\ Power) = 71.9625\%\ Flow\ Span$$

Therefore, the A value is computed as follows:

$$A(100\%\ Power) = C^2 = (0.719625)^2 = 0.517860$$

Expressed as a percentage,

A(100% Power) = 51.7860% DP Span

Unit 2
The heat balance flow rate through each feedwater flow loop is 5.9750 Mlbm/hr, as shown in Figure 1.2-2 of Reference 9.8.1. This corresponds to a C value of

C(100% Power) = 5.9750/ 8 = 0.746875

Expressed as a percentage,

C(100% Power) = 74.6875% Flow Span

Therefore, the A value is computed as follows:

A(100% Power) = C^2 = $(0.746875)^2$ = 0.557822

Expressed as a percentage,

A(100% Power) = 55.7822% DP Span

6.1.2 BASELINE CONDITIONS FOR FEEDWATER TEMPERATURE

Per Figures 1.2-2 and 1.2-3 of Reference 9.8.1, the following values are obtained for 100% Power operating conditions.

Feedwater Temperature 397.5°F (Unit 1)
425.1°F (Unit 2)

Also, per the same references, the baseline enthalpies of the feedwater are 373.4 BTU/lbm (Unit 1) and 403.2 BTU/lbm (Unit 2).

6.1.3 BASELINE CONDITIONS FOR REACTOR PRESSURE

Per Figures 1.2-2 and 1.2-3 of Reference 9.8.1, the following values are obtained for 100% Power operating conditions.

Reactor Pressure 1050 psia (Both Units)

For saturated conditions, per Reference 9.8.2, the baseline condition of steam enthalpy is 1191 BTU/lbm.

6.1.4 BASELINE CONDITIONS FOR CONTROL ROD DRIVE (CRD) SYSTEM FLOW

Per Figures 1.2-2 and 1.2-3 of Reference 9.8.1, the following values are obtained for 100% Power operating conditions.

Control Rod Drive System Flow 30,000 lbm/hr (Both Units)

The temperatures are as shown in Section 6.1.5, which yield densities of the following, given a pressure of approximately 1050 psia.

$\rho 1$(1050 psia and 123.2°F) = 61.8582 lbm/ft^3
$\rho 2$(1050 psia and 123.5°F) = 61.8525 lbm/ft^3

Therefore, flow rate is equal to the following:

Flow (vol) = Flow (mass) x (7.48052 gal / ft^3)/ (ρ x (60 min/hr))
Flow1 (vol) = Flow1 (mass) x (7.48052 gal / ft^3)/ ($\rho 1_{CRD}$ x (60 min/hr))
Flow1 (vol) = (30000 lbm/hr) x (7.48052 gal/ft^3)/ (61.8582 lbm/ft^3 x (60 min/hr))
Flow1 (vol) = 60.4651 GPM

Flow2 (vol) = Flow2 (mass) x (7.48052 gal / ft^3)/ ($\rho 2_{CRD}$ x (60 min/hr))
Flow2 (vol) = (30000 lbm/hr) x (7.48052 gal / ft^3)/ (61.8525 lbm / ft^3 x (60 min/hr))
Flow2 (vol) = 60.4706 GPM

The differential pressure transmitters are calibrated to measure 0-100 GPM,. Therefore, expressing each flow rate as in units of % Flow Span, and then in % DP Span,

CRD Flow (U1) = 60.4651% Flow Span
CRD Flow (U1) = (0.604651)^2 x 100% DP Span
CRD Flow (U1) = 36.5603% DP Span

CRD Flow (U2) = 60.4706% Flow Span
CRD Flow (U2) = (0.604706)^2 x 100% DP Span
CRD Flow (U2) = 36.5669% DP Span

6.1.5 BASELINE CONDITIONS FOR CONTROL ROD DRIVE (CRD) SYSTEM TEMPERATURE

Per Figures 1.2-2 and 1.2-3 of Reference 9.8.1, the following values are obtained for 100% Power operating conditions.

Control Rod Drive Sys Temp 123.2°F (Unit 1)
123.5°F (Unit 2)

6.1.6 BASELINE CONDITIONS FOR REACTOR WATER CLEANUP (RWCU) SYSTEM FLOW

Per Figures 1.2-2 and 1.2-3 of Reference 9.8.1, the following values are obtained for 100% Power operating conditions.

RWCU Flow 100,000 lbm/hr (Both Units)

The flow rate is obtained in the inlet to RWCU from the Reactor. Therefore, the inlet temperatures are used for temperature determination. As seen in Section 6.1.7, the inlet temperatures are 531.2°F (Unit 1) and 533.7°F (Unit 2).

Using a pressure of 1050 psia for these measurements, per Reference 9.8.2, the densities are determined as follows:

$\rho 1$(1050 psia and 531.2°F) = 47.2456 lbm/ft^3
$\rho 2$(1050 psia and 533.7°F) = 47.0788 lbm/ft^3

Therefore, flow rate is equal to the following:

$Flow_{RWCU}$ (vol) = Flow (mass) x (7.48052 gal / ft^3)/ (ρ x (60 min/hr))
$Flow1_{RWCU}$ (vol) = Flow1 (mass) x (7.48052 gal / ft^3)/ ($\rho 1$ x (60 min/hr))
$Flow1_{RWCU}$ (vol) = (100000 lbm / hr) x (7.48052 gal / ft^3)/ (47.2456 lbm / ft^3 x (60 min/hr))
$Flow1_{RWCU}$ (vol) = 263.8877 GPM

$Flow2_{RWCU}$ (vol) = Flow2 (mass) x (7.48052 gal / ft^3)/ ($\rho 2$ x (60 min/hr))
$Flow2_{RWCU}$ (vol) = (100000 lbm / hr) x (7.48052 gal / ft^3)/ (47.0788 lbm / ft^3 x (60 min/hr))
$Flow2_{RWCU}$ (vol) = 264.8227GPM

The differential pressure transmitters are calibrated to measure 0-300 GPM. Therefore, expressing each flow rate as in units of % Flow Span, and then in % DP Span,

RWCU Flow (U1) = (263.8877 GPM / 300 GPM) x 100% Flow Span
RWCU Flow (U1) = 87.9626% Flow Span
RWCU Flow (U1) = $(0.879626)^2$ x 100% DP Span
RWCU Flow (U1) = 77.3741% DP Span

RWCU Flow (U2) = (264.8227GPM / 300 GPM) x 100% Flow Span
RWCU Flow (U2) = 88.2742% Flow Span
RWCU Flow (U2) = $(0.882742)^2$ x 100% DP Span
RWCU Flow (U2) = 77.9234% DP Span

6.1.7 BASELINE CONDITIONS FOR REACTOR WATER CLEANUP (RWCU) SYSTEM INLET AND OUTLET TEMPERATURES

Per Figures 1.2-2 and 1.2-3 of Reference 9.8.1, the following values are obtained for 100% Power operating conditions.

RWCU Inlet Temperature	531.2°F (Unit 1) 533.7°F (Unit 2)
RWCU Outlet Temperature	434.0°F (Unit 1) 436.8°F (Unit 2)

6.1.8 BASELINE CONDITIONS FOR RECIRCULATION PUMP POWER

Unit 1

From Figure 1.2-3 of Reference 9.8.1, the Reactor Recirculation System Flow rate is 34.2E6 lbm/hr, with a delta H of 0.8 Btu/lbm. Computing the recirculation pump power released to the water,

Power Delivered = 34.2E6 lbm / hr x 0.8 BTU / lbm = 27.36E6 BTU / hr

Converting this term to units of Watts, we obtain the following:

Power Delivered = 27.36E6 BTU / hr x (1hr/60 min) x (17.5796 Watts /(BTU/min))
= 8.0163 MW

Using an efficiency of 93% for the pumps (per Reference 9.2.1), this would equate to continuous power outputs from each of the two pumps of:

Watt Transducer Output (Each Pump) = (8.0163MW / 0.93) / 2 = 4.3098 MW

Unit 2

From Figure 1.2-2 of Reference 9.8.1, the Reactor Recirculation System Flow rate is 34.3E6 lbm/hr, with a delta H of 0.8 Btu/lbm. Computing the recirculation pump power released to the water,

Power Delivered = 34.3E6 lbm / hr x 0.8 BTU / lbm = 27.44E6 BTU / hr

Converting this term to units of Watts, we obtain the following:

Power Delivered = 27.44E6 BTU / hr x (1hr/60 min) x (17.5796 Watts /(BTU/min))
= 8.0397 MW

Using an efficiency of 93% for the pumps (per Reference 9.2.1), this would equate to continuous power outputs from each of the two pumps of:

Watt Transducer Output (Each Pump) = (8.0397MW / 0.93) / 2 = 4.3224 MW.

6.2 DETERMINATION OF WEIGHTING FACTORS

In the determination of the weighting factors, 100% thermal power is computed based on a value of 2763 MW thermal, per Figures 1.2-2 and 1.2-3 of Reference 9.8.1. Each parameter in the equation is varied by a nominal value to determine these factors, per the methodology of Section 3.0.

6.2.1 FEEDWATER FLOW WEIGHTING FACTOR

For the Feedwater Flow measurement, all errors are expressed in terms of %DP Span, except for the Reference Accuracy and Installation Effect for the Flow Element itself, which are expressed in terms of % Actual Flow. All of the errors are random. The weighting factors for the errors expressed in % Actual Flow are determined in Section 6.2.9. The weighting factors for the errors expressed in % DP span are derived below.

Unit 1
Per Section 6.1.1, the nominal Feedwater Flow and differential pressure for Unit 1 are:

A(100% Power) = 51.7860% DP Span
C(100% Power) = 71.9625% Flow Span

A nominal ±5% uncertainty value results in a band as follows:

46.7860% DP Span ≤ A ≤ 56.7860% DP Span

The square root function produces the following in terms of % Flow Span.

68.4003% Flow Span ≤ C ≤ 75.3565% Flow Span.

The error in this value is as follows:

+ 3.3940/ -3.5622% Flow Span

Because of the very nearly equal values, for symmetry, the largest uncertainty value is used in both directions. Therefore, a 5% DP Span error for the feedwater flow signals results in the following:

± 3.5622% Flow Span

Converting this value to process units,

± 284976.0000 lbm/hr

The two loop flow rates are summed in the Plant Computer, with each of the loops having uncertainties as expressed above. This error is SRSS'ed to obtain the values shown.

$$\text{Total Flow Error} = ((284976.0000)^2 + (284976.0000)^2)^{1/2}$$
$$= \pm 403016.9242 \text{ lbm/hr}$$

Per Section 6.1.3 and Figure 1.2-3 of Reference 9.8.1, the difference in enthalpy from feedwater to steam in the reactor at 100% power is as follows:

$$DH = 1191 - 373.4 = 817.6 \text{ BTU/lbm}$$

Therefore, the error in flow rate indication would produce the following error in terms of the thermal power computation:

Error (MW) = Error (lbm/hr) x DH x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= ±403016.9242 lbm/hr x 817.6 BTU/lbm x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= ±96.5432 MW

Converting to a percentage,

Error (%) = (Error (MW) / 2763 MW thermal) x 100% RTP
Error (%) = ±3.4941% RTP

The weighting factor is therefore determined as follows:

WF_{FWF1} = Error (% RTP) / Error (% DP Span)
= 3.4941% RTP / 5% DP Span
= 0.6988% RTP / % DP Span

Unit 2

Per Section 6.1.1, the nominal feedwater flow and differential pressure for Unit 2 are:

A(100% Power) = 55.7822% DP Span
C(100% Power) = 74.6875% Flow Span

A nominal ±5% uncertainty value results in a band as follows:

50.7822% DP Span ≤ A ≤ 60.7822% DP Span

The square root function produces the following in terms of % Flow Span.

71.2616% Flow Span ≤ C ≤ 77.9629% Flow Span.

The error in this value is as follows:

+ 3.2754 / -3.4259% Flow Span

Because of the very nearly equal values, for symmetry, the largest uncertainty value is used in both directions. Therefore, a 5% DP Span error for the feedwater flow signals results in the following:

± 3.4259% Flow Span

Converting this value to process units,

± 274072.0000 lbm/hr

The two loop flow rates are summed in the Plant Computer, with each of the loops having uncertainties as expressed above. This error is SRSS'ed to obtain the values shown.

$$\text{Total Flow Error} = \pm((274072.0000)^2 + (274072.0000)^2)^{1/2}$$
$$= \pm 387596.3395 \text{ lbm/hr}$$

Per Section 6.1.3 and Figure 1.2-2 of Reference 9.8.1, the difference in enthalpy from feedwater to steam in the reactor at 100% power is as follows.

DH = 1191-403.2 = 787.8 BTU/lbm

Therefore, the error in flow rate indication would produce the following error in terms of the thermal power computation.

Error (MW) = Error (lbm/hr) x DH x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= ±387596.3395 lbm/hr x 787.8 BTU/lbm x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= ±89.4650 MW

Converting to a percentage,

Error (%) = ± (Error (MW) / 2763 MW thermal) x 100% RTP
Error (%) = ± 3.2380% RTP

The weighting factor is therefore determined as follows.

WF_{FWF2} = Error (% RTP) / Error (% DP Span)
= 3.2380% RTP / 5% DP Span
= 0.6476% RTP / % DP Span

6.2.2 FEEDWATER TEMPERATURE WEIGHTING FACTOR

The Feedwater Temperature measurement is only used in the Heat Balance equation for determining Feedwater enthalpy. A 5% error for the Feedwater Temperature measurement equates to an error of ±7.5°F, since the span of the instrument is 150°F.

Unit 1
Per Figure 1.2-3 of Reference 9.8.1, the Feedwater Temperature at 100% power conditions is 397.5°F, and the nominal Feedwater Flow is 11514000 lbm/hr. Per Design Input 4.1.2, the nominal upstream tap pressure for Unit 1 is as follows.

P_{noz1} = 1116 psia

The temperature range of concern is 397.5 ± 7.5°F, or

390°F ≤ T_{FW} ≤ 405°F

Assuming no change in pressure, the enthalpy computed for these temperature values are as shown, per Reference 9.8.2.

H(390°F, 1116psia) = 365.4224 BTU/lbm
H(397.5°F, 1116psia) = 373.4300 BTU/lbm
H(405°F, 1116psia) = 381.4726 BTU/lbm

The thermal power computation for the feedwater is performed by the following equation:

Q_{FW} = DH (BTU/lbm) x Flow (lbm/hr) x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)

The DH value is the difference between the steam enthalpy in the reactor and the feedwater enthalpy. For this exercise, steam enthalpy is constant, so the only change is in feedwater enthalpy. Therefore, the error in the power signal is determined by setting the DH term equal to the error in the enthalpy of the feedwater and solving for the resulting power error.

$DQ_{FWT(-)}$ = (365.4224-373.43)BTU/lbm x 11514000 lbm/hr (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= -27.0138 MW

$DQ_{FWT(+)}$ = (381.4726-373.43)BTU/lbm x 11514000 lbm/hr (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= +27.1319 MW

Due to the symmetry of the error, the error is conservatively established as the largest value, expressed in both directions.

Error (MW) = ± 27.1319 MW

Converting to a percentage,

Error (%) = (Error (MW) / 2763 MW thermal) x 100% RTP
Error (%) = ±0.9820% RTP

The weighting factor is therefore determined as follows:

WF_{FWT1} = Error (% RTP) / Error (°F)
= 0.9820% RTP / 7.5°F
= 0.1309% RTP / °F

Unit 2

Per Figure 1.2-2 of Reference 9.8.1, the Feedwater Temperature at 100% power conditions is 425.1°F, and the nominal Feedwater Flow is 11950000 lbm/hr. Per Design Input 4.1.2, the nominal upstream tap pressure for Unit 2 is as follows.

P_{noz2} = 1122 psia

The temperature range of concern is 425.1 ± 7.5°F, or

417.6°F ≤ T_{FW} ≤ 432.6°F

Assuming no change in pressure, the enthalpies computed for these temperature values are as shown, per Reference 9.8.2.

H(417.6°F, 1122psia) = 395.0752 BTU/lbm
H(425.1°F, 1122psia) = 403.2295 BTU/lbm

H(432.6°F, 1122psia) = 411.4183 BTU/lbm

The thermal power computation for the feedwater is performed by the following equation:

Q_{FW} = DH (BTU/lbm) x Flow (lbm/hr) x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)

The DH value is the difference between the steam enthalpy in the reactor and the feedwater enthalpy. For this evaluation, steam enthalpy is constant, so the only change is in feedwater enthalpy. Therefore, the error in the power signal is determined by setting the DH term equal to the error in the enthalpy of the feedwater and solving for the resulting power error.

$DQ_{FWT(-)}$ = (395.0752-403.2295)BTU/lbm x 11950000 lbm/hr (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= -28.5504 MW

$DQ_{FWT(+)}$ = (411.4183-403.2295)BTU/lbm x 11950000 lbm/hr (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= +28.6712 MW

Due to the symmetry of the error, the error is conservatively established as the largest value, expressed in both directions.

Error (MW) = ± 28.6712 MW

Converting to a percentage,

Error (%) = (Error (MW) / 2763 MW thermal) x 100% RTP
Error (%) = ±1.0377% RTP

The weighting factor is therefore determined as follows:

WF_{FWT2} = Error (% RTP) / Error (°F)
= 1.0377% RTP / 7.5°F
= 0.1384% RTP / °F

6.2.3 REACTOR PRESSURE WEIGHTING FACTOR

The Reactor Pressure measurement error is only considered in the Heat Balance computation for determining Steam enthalpy. (See Assumption 5.6.) A 5% error for the Reactor Pressure measurement equates to an error of ±60 psi, since the span of the instrument is 1200 psi. The Steam enthalpy is used both in the determination of power from feedwater and from the CRD system flow. Therefore, both these items are included in this assessment.

Unit 1

The steam enthalpy is figured from the saturation tables. Per Reference 9.8.2, the steam enthalpies for the different applicable values of steam pressure are as follows:

H(1110 psia) = 1188.68 BTU/lbm
H(1050 psia) = 1191.00 BTU/lbm
H(990 psia) = 1193.26 BTU/lbm

Therefore, a positive Reactor Pressure error causes a negative steam enthalpy error, because saturation conditions are assumed.

The thermal power computations for the Feedwater and CRD System are performed by the following equation:

Q_S = DH (BTU/lbm) x Flow (lbm/hr) x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)

The DH value is the difference between the steam enthalpy in the reactor and the feedwater enthalpy (or the CRD System water enthalpy). For this evaluation, feedwater and CRD enthalpies are constant, so the only change is in steam enthalpy. Therefore, the error in the thermal power measurements is determined by setting the DH term equal to the error in the enthalpy of the steam and solving for the resulting power error. Since the same enthalpy error exists for both systems, the total error due to the steam enthalpy error is computed by combining flow rates for the Feedwater and CRD systems. Per Figure 1.2-3 of Reference 9.8.1,

Flow = 11514000 lbm/hr + 30000 lbm/hr
= 11,544,000 lbm/hr

$DQ_{S(-)}$ = (1193.26-1191)BTU/lbm x 11,544,000lbm/hr (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= +7.6440 MW

$DQ_{S(+)}$ = (1188.68-1191)BTU/lbm x 11,544,000lbm/hr (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= -7.8470 MW

Due to the symmetry of the error, the error is conservatively established as the largest value, expressed in both directions.

$Error_S$ (MW) = ± 7.8470 MW

Converting to a percentage,

Error (%) = (Error (MW) / 2763 MW thermal) x 100% RTP
Error (%) = ±0.2840% RTP

The weighting factor is therefore determined as follows:

WF_{SP1} = Error (% RTP) / Error (% Span)
= 0.2840% RTP / 5 % Span
= 0.0568% RTP / % Span

Unit 2

The steam enthalpy is figured from the saturation tables. Per Reference 9.8.2, the steam enthalpies for the different applicable values of steam pressure are as follows:

H(1110 psia) = 1188.68 BTU/lbm
H(1050 psia) = 1191.00 BTU/lbm
H(990 psia) = 1193.26 BTU/lbm

Therefore, a positive Reactor Pressure error causes a negative steam enthalpy error at saturated conditions.

The thermal power computations for the Feedwater and CRD System are performed by the following equation:

Q_S = DH (BTU/lbm) x Flow (lbm/hr) x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)

The DH value is the difference between the steam enthalpy in the reactor and the feedwater enthalpy (or the CRD System water enthalpy). For this exercise, feedwater and CRD enthalpies are constant, so the only change is in steam enthalpy. Therefore, the error in the thermal power measurements is determined by setting the DH term equal to the error in the enthalpy of the steam and solving for the resulting power error. Since the same enthalpy error exists for both systems, the total error due to the steam enthalpy error is computed by combining flow rates for the Feedwater and CRD systems. Per Figure 1.2-2 of Reference 9.8.1,

Flow = 11950000 lbm/hr + 30000 lbm/hr
= 11,980,000 lbm/hr

$DQ_{S(-)}$ = (1193.26-1191)BTU/lbm x 11,980,000lbm/hr (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= +7.9327 MW

$DQ_{S(+)}$ = (1188.68-1191)BTU/lbm x 11,980,000 lbm/hr (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= -8.1433 MW

Due to the symmetry of the error, the error is conservatively established as the largest value, expressed in both directions.

$Error_S$ (MW) = ± 8.1433 MW

Converting to a percentage,

Error (%) = (Error (MW) / 2763 MW thermal) x 100% RTP
Error (%) = ±0.2947% RTP

The weighting factor is therefore determined as follows:

WF_{SP2} = Error (% RTP) / Error (% Span)
= 0.2947% RTP / 5 % Span
= 0.0589% RTP / % Span

6.2.4 CRD SYSTEM FLOW WEIGHTING FACTOR

For the CRD System Flow measurement, all errors are expressed in terms of %DP Span, except for the Reference Accuracy and Installation Effect for the Flow Element itself, which are expressed in terms of % Actual Flow. All of the errors are random. The weighting factors for each of these types of errors are derived below.

Weighting Factors for % DP Span Errors

Unit 1
Per Section 6.1.4, the nominal CRD System Flow at 100% Power operation is:

C (U1)= 60.4651% Flow Span
A (U1)= 36.5603% DP Span

A nominal ±5% uncertainty value results in a band as follows:

31.5603% DP Span ≤ A ≤ 41.5603% DP Span

The square root function produces the following in terms of % Flow Span.

56.1786% Flow Span ≤ C ≤ 64.4673% Flow Span.

The error in this value is as follows:

+ 4.0022 / -4.2865% Flow Span

Because of the very nearly equal values, for symmetry, the worst-case uncertainty value is used in both directions. Therefore, a 5% DP Span error for the feedwater flow signals results in the following:

$Error_{CRD}$ = ± 4.2865% Flow Span x (100 GPM)
$Error_{CRD}$ = ± 4.2865 GPM

Converting this value to process units, since the density is held constant during this exercise, the value is multiplied by the ratio of mass flow to volumetric flow at nominal 100% power conditions.

$Error_{CRD}$ = ± 4.2865 GPM x (30000 lbm/hr)/ 60.4651 GPM
$Error_{CRD}$ = ± 2126.7640 lbm/hr

Per Section 6.1.3 and Figure 1.2-3 of Reference 9.8.1, the difference in enthalpy from the CRD System to steam in the reactor at 100% power is as follows:

DH = 1191-94 = 1097 BTU/lbm

Therefore, the error in flow rate indication would produce the following error in terms of the thermal power computation:

Error (MW) = $Error_{CRD}$ (lbm/hr) x DH x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= ±2126.7640 lbm/hr x 1097 BTU/lbm x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= ±0.6836 MW

Converting to a percentage,

Error (%) = (Error (MW) / 2763 MW thermal) x 100% RTP
Error (%) = ±0.0247% RTP

The weighting factor is therefore determined as follows:

WF_{CRDF1} = Error (% RTP) / Error (% DP Span)
= 0.0247% RTP / 5% DP Span
= 0.0049% RTP / % DP Span

Unit 2
Per Section 6.1.4, the nominal CRD System Flow is:

C (U2)= 60.4706% Flow Span
A (U2)= 36.5669% DP Span

A nominal ±5% uncertainty value results in a band as follows:

$$31.5669\%\text{ DP Span} \leq A \leq 41.5669\%\text{ DP Span}$$

The square root function produces the following in terms of % Flow Span.

$$56.1844\%\text{ Flow Span} \leq C \leq 64.4724\%\text{ Flow Span.}$$

The error in this value is as follows:

+4.0018 / -4.2862% Flow Span

Because of the very nearly equal values, for symmetry, the worst case uncertainty value is used in both directions. Therefore, a 5% DP Span error for the feedwater flow signals results in the following:

$$Error_{CRD} = \pm 4.2862\%\text{ Flow Span x (100 GPM)}$$
$$Error_{CRD} = \pm 4.2862\text{ GPM}$$

Converting this value to process units, since the density is held constant during this exercise, the value is multiplied by the ratio of mass flow to volumetric flow at nominal 100% power conditions.

$$Error_{CRD} = \pm 4.2862\text{ GPM x (30000 lbm/hr)/ 60.4706 GPM}$$
$$Error_{CRD} = \pm 2126.4218\text{ lbm/hr}$$

Per Section 6.1.3 and Figure 1.2-2 of Reference 9.8.1, the difference in enthalpy from the CRD System to steam in the reactor at 100% power is as follows:

$$DH = 1191-94.3 = 1096.7\text{ BTU/lbm}$$

Therefore, the error in flow rate indication would produce the following error in terms of the thermal power computation:

$$\text{Error (MW)} = Error_{CRD}\text{ (lbm/hr) x DH x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)}$$
$$= \pm 2126.4218\text{ lbm/hr x 1097 BTU/lbm x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)}$$
$$= \pm 0.6833\text{ MW}$$

Converting to a percentage,

$$\text{Error (\%)} = \text{(Error (MW) / 2763 MW thermal) x 100\% RTP}$$
$$\text{Error (\%)} = \pm 0.0247\%\text{ RTP}$$

The weighting factor is therefore determined as follows:

WF_{CRDF2} = Error (% RTP) / Error (% DP Span)
= 0.0247% RTP / 5% DP Span
= 0.0049% RTP / % DP Span

Since the errors are equivalent to the significant digits considered by this study, the Weighting Factors for the Unit 1 CRD System Flow is considered equal to that of the Unit 2 CRD System.

WF_{CRDF} = 0.0049% RTP / % DP Span

Weighting Factors for % Actual Flow Errors

Unit 1

Per Section 6.1.4, the nominal CRD System Flow at 100% Power operation is:

C (U1)= 60.4651% Flow Span

A nominal ±5% Actual Flow uncertainty value results in a band as follows:

0.95*60.4651% Flow Span ≤ C ≤ 1.05*60.4651% Flow Span

57.4418% Flow Span ≤ C ≤ 63.4884% Flow Span.

The error in this value is as follows:

+ 3.0233 / -3.0233% Flow Span

$Error_{CRD}$ =. ± 3.0233% Flow Span x (100 GPM)
$Error_{CRD}$ = ± 3.0233 GPM

Converting this value to process units, since the density is held constant during this exercise, the value is multiplied by the ratio of mass flow to volumetric flow at nominal 100% power conditions.

$Error_{CRD}$ = ± 3.0233 GPM x 30000 lbm/hr/ 60.4651 GPM
$Error_{CRD}$ = ± 1500.0223 lbm/hr

Per Section 6.1.3 and Figure 1.2-3 of Reference 9.8.1, the difference in enthalpy from the CRD System to steam in the reactor at 100% power is as follows:

DH = 1191-94 = 1097 BTU/lbm

Therefore, the error in flow rate indication would produce the following error in terms of the thermal power computation:

Error (MW) = $Error_{CRD}$ (lbm/hr) x DH x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= ±1500.0223 lbm/hr x 1097 BTU/lbm x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= ±0.4821 MW

Converting to a percentage,

Error (%) = (Error (MW) / 2763 MW thermal) x 100% RTP
Error (%) = ±0.0174% RTP

The weighting factor is therefore determined as follows:

$WF_{CRDF1AF}$ = Error (% RTP) / Error (% Actual Flow)
= 0.0174% RTP / 5% Actual Flow
= 0.0035% RTP / % Actual Flow

<u>Unit 2</u>
Per Section 6.1.4, the nominal CRD System Flow is:

C (U2)= 60.4706% Flow Span

A nominal ±5% Actual Flow uncertainty value results in a band as follows:

0.95*60.4706% Flow Span ≤ C ≤ 1.05*60.4706% Flow Span

57.4471% Flow Span ≤ C ≤ 63.4941% Flow Span.

The error in this value is as follows:

+3.0235 / -3.0235% Flow Span

$Error_{CRD}$ = ± 3.0235% Flow Span x (100 GPM)
$Error_{CRD}$ = ± 3.0235 GPM

Converting this value to process units, since the density is held constant during this exercise, the value is multiplied by the ratio of mass flow to volumetric flow at nominal 100% power conditions.

$Error_{CRD}$ = ± 3.0235 GPM x (30000 lbm/hr)/ 60.4706 GPM
$Error_{CRD}$ = ± 1499.9851 lbm/hr

Per Section 6.1.3 and Figure 1.2-2 of Reference 9.8.1, the difference in enthalpy from the CRD System to steam in the reactor at 100% power is as follows:

$$DH = 1191-94.3 = 1096.7 \text{ BTU/lbm}$$

Therefore, the error in flow rate indication would produce the following error in terms of the thermal power computation:

$$\text{Error (MW)} = \text{Error}_{CRD} \text{ (lbm/hr)} \times DH \times (1\text{hr}/60 \text{ min}) \times (17.5796 \text{ Watts} /(\text{BTU/min})) \times (1 \text{ MW} / 1\text{E6 W})$$

$$= \pm 1499.9851 \text{ lbm/hr} \times 1096.7 \text{ BTU/lbm} \times (1\text{hr}/60 \text{ min}) \times (17.5796 \text{ Watts} /(\text{BTU/min})) \times (1 \text{ MW} / 1\text{E6 W})$$

$$= \pm 0.4820 \text{ MW}$$

Converting to a percentage,

$$\text{Error (\%)} = (\text{Error (MW)} / 2763 \text{ MW thermal}) \times 100\% \text{ RTP}$$

$$\text{Error (\%)} = \pm 0.0174\% \text{ RTP}$$

The weighting factor is therefore determined as follows:

$$WF_{CRDF2AF} = \text{Error (\% RTP)} / \text{Error (\% Actual Flow)}$$

$$= 0.0174\% \text{ RTP} / 5\% \text{ Actual Flow}$$

$$= 0.0035\% \text{ RTP} / \% \text{ Actual Flow}$$

Since the errors are equivalent to the significant digits considered by this study, the Weighting Factors for the Unit 1 CRD System Flow is considered equal to that of the Unit 2 CRD System.

$$WF_{CRDFAF} = 0.0035\% \text{ RTP} / \% \text{ DP Span}$$

6.2.5 CRD SYSTEM INLET TEMPERATURE WEIGHTING FACTOR

The CRD System Temperature measurement is only used to compute the enthalpy of the CRD System water, which is injected into the reactor during normal operation. The weighting factor is in terms of %RTP / °F, so a nominal variation of ±5°F is used to determine the weighting factor. Per Figures 1.2-2 and 1.2-3 of Reference 9.8.1, the inlet temperatures of the CRD System to the reactor are 123.2°F (Unit 1) and 123.5°F (Unit 2). Because of the closeness in values, a nominal value of 123.5°F is used to determine the corresponding error in the thermal power measurement. Per Reference 9.8.2,

H(1050 psia, 128.5°F) = 99.0990 BTU/lbm
H(1050 psia, 123.5°F) = 94.3000 BTU/lbm
H(1050 psia, 118.5°F) = 89.1575 BTU/lbm

The thermal power computations for the CRD System are performed by the following equation:

Q_{CRDT} = DH (BTU/lbm) x Flow (lbm/hr) x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)

The DH value is the difference between the steam enthalpy in the reactor and the CRD System water enthalpy. For this evaluation, the steam enthalpy is constant, so the only change is in CRD System water enthalpy. Therefore, the error in the thermal power measurements is determined by setting the DH term equal to the error in the enthalpy of the CRD System water and solving for the resulting power error. Per Figures 1.2-2 and 1.2-3 of Reference 9.8.1,

CRD System Flow = 30000 lbm/hr

$DQ_{CRDT(+)}$ = (99.099-94.3)BTU/lbm x 30000 lbm/hr (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= +0.0422 MW

$DQ_{CRDT(-)}$ = (89.1575-94.3)BTU/lbm x 30000 lbm/hr (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= -0.0452 MW

Due to the symmetry of the error, the error is conservatively established as the largest value, expressed in both directions.

$Error_{CRDT}$ (MW) = ± 0.0452 MW

Converting to a percentage,

Error (%) = (Error (MW) / 2763 MW thermal) x 100% RTP
Error (%) = ± 0.0016% RTP

The weighting factor is therefore determined as follows:

WF_{CRDT} = Error (% RTP) / Error (°F)
= 0.0016% RTP / 5 °F
= 0.0003% RTP / °F

6.2.6 RWCU SYSTEM FLOW WEIGHTING FACTOR

For the RWCU System Flow measurement, all errors are expressed in terms of %DP Span, except for the Reference Accuracy and Installation Effect for the Flow Element itself, which are expressed in terms of % Actual Flow. All of the errors are considered random. The weighting factors for each of these types of errors are derived below.

Weighting Factors for % DP Span Errors

Per Figures 1.2-2 and 1.2-3 of Réference 9.8.1, the nominal RWCU System Flow at 100% Power operating conditions is 100000 lbm/hr and the differential enthalpy is 112.6 BTU/lbm. The flow loops are of the same configuration and range. Therefore, both units are analyzed identically.

Per Section 6.1.6, the nominal flow rate at 100% power corresponds to the following values in terms of % Flow Span and % DP Span.

RWCU Flow (U1) = 87.9626% Flow Span
RWCU Flow (U1) = 77.3741% DP Span

RWCU Flow (U2) = 88.2742% Flow Span
RWCU Flow (U2) = 77.9234% DP Span

Because of the square root function, more effects are seen from DP errors at lower nominal flow rates. Therefore, the lowest (Unit 1) nominal flow rate is used, and the weighting factor is applied to both units.

C (U1)= 87.9626% Flow Span (263.8878 GPM)
A (U1)= 77.3741% DP Span

A nominal ±5% uncertainty value results in a band as follows:

72.3741% DP Span ≤ A+a ≤ 82.3741% DP Span

The square root function produces the following in terms of % Flow Span.

85.0730% Flow Span ≤ C+c ≤ 90.7602% Flow Span.

The error in this value is as follows:

+ 2.7976/ -2.8896% Flow Span

Because of the very nearly equal values, for symmetry, the worst case uncertainty value is used in both directions. Therefore, a 5% DP Span error for the feedwater flow signals results in the following:

$Error_{RWCU}$ = ± 2.8896% Flow Span x (300 GPM)
$Error_{RWCU}$ = ± 8.6688 GPM

Converting this value to process units, since the density is held constant during this exercise, the value is multiplied by the ratio of mass flow to volumetric flow at nominal 100% power conditions.

$Error_{RWCU}$ = ± 8.6688 GPM x (100000 lbm/hr)/ 263.8878 GPM
$Error_{RWCU}$ = ± 3285.0325 lbm/hr

Per Figures 1.2-2 and 1.2-3 of Reference 9.8.1, the difference in enthalpy from the RWCU System (inlet to outlet) at 100% power is as follows:

DH = 525.5-412.9 = 112.6 BTU/lbm

Therefore, the error in flow rate indication would produce the following error in terms of the thermal power computation:

Error (MW) = $Error_D$ (lbm/hr) x DH x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= ±3285.0325 lbm/hr x 112.6 BTU/lbm x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= ±0.1084 MW

Converting to a percentage,

Error (%) = (Error (MW) / 2763 MW thermal) x 100% RTP
Error (%) = ±0.0039% RTP

The weighting factor is therefore determined as follows:

WF_{CUF} = Error (% RTP) / Error (% DP Span)
= 0.0039% RTP / 5% DP Span
= 0.0008% RTP / % DP Span

Weighting Factors for % Actual Flow Errors

Per Figures 1.2-2 and 1.2-3 of Reference 9.8.1, the nominal RWCU System Flow at 100% Power operating conditions is 100000 lbm/hr and the differential enthalpy is 112.6 BTU/lbm. The flow loops are of the same configuration and range. Therefore, both units are analyzed identically.

Per Section 6.1.6, the nominal flow rate at 100% power corresponds to the following values in terms of % Flow Span.

RWCU Flow (U1) = 87.9626% Flow Span
RWCU Flow (U2) = 88.2742% Flow Span

Because a given % of Actual Flow is greater for larger flow rates, Unit 2 is used to establish the weighting factor.

C (U2)= 88.2742% Flow Span (264.8226 GPM)

A nominal ±5% Actual Flow uncertainty value results in a band as follows.

0.95*88.2742% Flow Span ≤ C+c ≤ 1.05*88.2742% Flow Span

83.8605% Flow Span ≤ C+c ≤ 92.6879% Flow Span

The error in this value is as follows.

+ 4.4137/ -4.4137% Flow Span

$Error_{RWCU}$ = ± 4.4137% Flow Span x (300 GPM)
$Error_{RWCU}$ = ± 13.2411 GPM

Converting this value to process units, since the density is held constant during this exercise, the value is multiplied by the ratio of mass flow to volumetric flow at nominal 100% power conditions.

$Error_{RWCU}$ = ± 13.2411 GPM x (100000 lbm/hr)/ 264.8226 GPM
$Error_{RWCU}$ = ± 4999.9887 lbm/hr

Per Figures 1.2-2 and 1.2-3 of Reference 9.8.1, the difference in enthalpy from the RWCU System (inlet to outlet) at 100% power is as follows:

DH = 528.6-416.0 = 112.6 BTU/lbm

Therefore, the error in flow rate indication would produce the following error in terms of the thermal power computation:

Error (MW) = Error_D (lbm/hr) x DH x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= ±4999.9887 lbm/hr x 112.6 BTU/lbm x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= ±0.1650 MW

Converting to a percentage,

Error (%) = (Error (MW) / 2763 MW thermal) x 100% RTP
Error (%) = ±0.0060% RTP

The weighting factor is therefore determined as follows:

WF_{CUFAF} = Error (% RTP) / Error (% DP Span)
= 0.0060% RTP / 5% DP Span
= 0.0012% RTP / % DP Span

6.2.7 RWCU SYSTEM INLET / OUTLET TEMPERATURE WEIGHTING FACTORS

With respect to the heat balance computation, the Inlet and Outlet Temperature measurements for the RWCU System are only used to compute the enthalpies of the RWCU System water at the inlet and outlet. The weighting factor is in terms of %RTP / °F, so a nominal variation of ±5°F is used to determine the weighting factor.

Unit 1
Per Figure 1.2-3 of Reference 9.8.1, the nominal temperatures and enthalpies of interest are as follows:

RWCU Inlet Temperature, Enthalpy	531.2°F, 525.5 BTU/lbm
RWCU Outlet Temperature, Enthalpy	434.0°F, 412.9 BTU/lbm

The enthalpies of the water in an error band around these nominal temperatures, assuming a pressure of 1050 psia are as follows, per Reference 9.8.2:

Inlet H(1050 psia, 536.2°F) = 531.8310 BTU/lbm
Inlet H(1050 psia, 526.2°F) = 519.3722 BTU/lbm

Outlet H(1050 psia, 439.0°F) = 418.3910 BTU/lbm
Outlet H(1050 psia, 429.0°F) = 407.4100 BTU/lbm

The thermal power computations for the RWCU System are performed by the following equation:

Q_{CRDT} = DH (BTU/lbm) x Flow (lbm/hr) x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)

The DH value is the difference between the inlet and outlet enthalpy values. For this exercise, the inlet and outlet temperature errors are assessed separately, with weighting factors determined for each. Therefore, only one of the enthalpies is varied at a time. Therefore, the error in the thermal power measurements is determined by setting the DH term equal to the error in the enthalpy and solving for the resulting power error. Per Figure 1.2-3 of Reference 9.8.1,

RWCU System Flow = 100,000 lbm/hr

$DQ_{RWCTI(-)}$ = (519.3722-525.5)BTU/lbm x 100,000 lbm/hr (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= -0.1795 MW

$DQ_{RWCTI(+)}$ = (531.831-525.5)BTU/lbm x 100,000 lbm/hr (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= +0.1855 MW

Due to the symmetry of the error, the error is conservatively established as the largest value, expressed in both directions.

$Error_{RWCTI}$ (MW) = ± 0.1855 MW

Converting to a percentage,

Error (%) = (Error (MW) / 2763 MW thermal) x 100% RTP
Error (%) = ±0.0067% RTP

The weighting factor is therefore determined as follows:

WF_{CUT1i} = Error (% RTP) / Error (°F)
= 0.0067% RTP / 5 °F
= 0.0013% RTP / °F

$DQ_{RWCTo(-)}$ = (407.41-412.9)BTU/lbm x 100,000 lbm/hr (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= -0.1609 MW

$DQ_{RWCTo(+)}$ = (418.391-412.9)BTU/lbm x 100,000 lbm/hr (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= +0.1609 MW

$Error_{RWCTo}$ (MW) = ± 0.1609 MW

Converting to a percentage,

Error (%) = (Error (MW) / 2763 MW thermal) x 100% RTP
Error (%) = ±0.0058% RTP

The weighting factor is therefore determined as follows:

WF_{CUT1o} = Error (% RTP) / Error (°F)
= 0.0058% RTP / 5 °F
= 0.0012% RTP / °F

Unit 2

Per Figure 1.2-2 of Reference 9.8.1, the nominal temperatures and enthalpies of interest are as follows:

RWCU Inlet Temperature, Enthalpy	533.7°F, 528.6 BTU/lbm
RWCU Outlet Temperature, Enthalpy	436.8°F, 416.0 BTU/lbm

The enthalpies of the water in an error band around these nominal temperatures, assuming a pressure of 1050 psia are as follows, per Reference 9.8.2:

Inlet H(1050 psia, 538.7°F) = 534.9685 BTU/lbm
Inlet H(1050 psia, 528.7°F) = 522.4497 BTU/lbm

Outlet H(1050 psia, 441.8°F) = 421.4662 BTU/lbm
Outlet H(1050 psia, 431.8°F) = 410.4782 BTU/lbm

The thermal power computations for the RWCU System are performed by the following equation:

Q_{CRDT} = DH (BTU/lbm) x Flow (lbm/hr) x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)

The DH value is the difference between the inlet and outlet enthalpy values. For this exercise, the inlet and outlet temperature errors are assessed separately, with weighting factors determined for each. Therefore, only one of the enthalpies is varied at a time. Therefore, the error in the thermal power measurements is determined by setting the DH term equal to the error in the enthalpy and solving for the resulting power error. Per Figure 1.2-2 of Reference 9.8.1,

RWCU System Flow = 100,000 lbm/hr

$DQ_{RWCTi(-)}$ = (522.4497-528.6)BTU/lbm x 100,000 lbm/hr (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= -0.1802 MW

$DQ_{RWCTi(+)}$ = (534.9685-528.6)BTU/lbm x 100,000 lbm/hr (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= +0.1866 MW

Due to the symmetry of the error, the error is conservatively established as the largest value, expressed in both directions.

$Error_{RWCTi}$ (MW) = ± 0.1866 MW

Converting to a percentage,

Error (%) = (Error (MW) / 2763 MW thermal) x 100% RTP
= ±0.0068% RTP

The weighting factor is therefore determined as follows:

WF_{CUT2i} = Error (% RTP) / Error (°F)
= 0.0068% RTP / 5 °F
= 0.0014% RTP / °F

$DQ_{RWCTo(-)}$ = (410.4782-416)BTU/lbm x 100,000 lbm/hr (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= -0.1618 MW

$DQ_{RWCTo(+)}$ = (421.4662-416)BTU/lbm x 100,000 lbm/hr (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= +0.1602 MW

Due to the symmetry of the error, the error is conservatively established as the largest value, expressed in both directions.

$Error_{RWCTo}$ (MW) = ± 0.1618 MW

Converting to a percentage,

Error (%) = (Error (MW) / 2763 MW thermal) x 100% RTP
Error (%) = ±0.0059% RTP

The weighting factor is therefore determined as follows:

WF_{CUT2o} = Error (% RTP) / Error (°F)
= 0.0059% RTP / 5 °F
= 0.0012% RTP / °F

Because of the similarity between Units 1 and 2 and the relatively small contribution to the heat balance computation, the weighting factors are assigned as the worst case for use in both units.

WF_{CUTi} = 0.0014% RTP / °F
WF_{CUTo} = 0.0012% RTP / °F

6.2.8 RECIRCULATION PUMP POWER WEIGHTING FACTOR

The range of the watt transducers for the recirculation pumps is 0-8.4 MW. The weighting factor for this parameter is merely a matter of expressing this term as a percentage of Rated Thermal Power.

100% Span = 8.4 MW

The 100% Rated Thermal Power for the Reactor is 2763 MW. Therefore, the weighting factor is determined as follows:

WF_{RPP}= 8.4 MW / 2763 MW = 0.0030% RTP / % Span

6.2.9 ULTRASONIC FEEDWATER FLOW AND FEEDWATER FLOW ELEMENT WEIGHTING FACTOR

The Ultrasonic Feedwater flow uncertainties and the Feedwater Flow Element uncertainties are listed in terms of % Actual Flow. Since each of these uncertainties are significantly less than 1% Actual Flow, a nominal value of 1% Actual Flow is used to determine the weighting factor, rather than the nominal

5% Span used for the majority of the parameters.

Unit 1

Per Figure 1.2-3 of Reference 9.8.1, the nominal Feedwater Flow rate is 11514000 lbm / hr. Therefore, a 1% Actual Flow uncertainty is computed.

Error (lbm/hr) = 0.01 x 11514000 lbm / hr
= 115140 lbm / hr

Per Section 6.1.3 and Figure 1.2-3 of Reference 9.8.1, the difference in enthalpy from feedwater to steam in the reactor at 100% power is as follows:

DH = 1191-373.4 = 817.6 BTU/lbm

Therefore, the error in flow rate indication would produce the following error in terms of the thermal power computation:

Error (MW) = Error (lbm/hr) x DH x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= ±115140 lbm / hr x 817.6 BTU/lbm x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= ±27.5819 MW

Converting to a percentage,

Error (%) = (Error (MW) / 2763 MW thermal) x 100% RTP
Error (%) = ±0.9983% RTP / % Actual Flow

The weighting factor is therefore determined as follows:

WF_{UFM1} = Error (% RTP) / Error (% Flow Span)
= 0.9983% RTP / 1% Actual Flow
= 0.9983% RTP / % Actual Flow

Unit 2

Per Figure 1.2-2 of Reference 9.8.1, the nominal Feedwater Flow rate is 11950000 lbm / hr. Therefore, a 1% Actual Flow uncertainty is computed.

Error (lbm/hr) = 0.01 x 11950000 lbm / hr
= 119500 lbm / hr

Per Section 6.1.3 and Figure 1.2-2 of Reference 9.8.1, the difference in enthalpy from feedwater to steam in the reactor at 100% power is as follows:

DH = 1191-403.2 = 787.8 BTU/lbm

Therefore, the error in flow rate indication would produce the following error in terms of the thermal power computation:

Error (MW) = Error (lbm/hr) x DH x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= ±119500 lbm / hr x 787.8 BTU/lbm x (1hr/60 min) x (17.5796 Watts /(BTU/min)) x (1 MW / 1E6 W)
= ±27.5830 MW

Converting to a percentage,

Error (%) = (Error (MW) / 2763 MW thermal) x 100% RTP
Error (%) = ±0.9983% RTP / % Flow Span

The weighting factor is therefore determined as follows:

WF_{UFM2} = Error (% RTP) / Error (% Flow Span)
= 0.9983% RTP / 1% Flow Span
= 0.9983% RTP / % Flow Span

Since the Unit 1 and Unit 2 weighting factors are equivalent, they are combined as one term.

WF_{UFM} = 0.9983% RTP / % Flow Span

Additionally, the Feedwater Flow Venturi Fouling bias terms are expressed in the same units. Therefore, the conversion factor is the same.

WF_{FWFB} = 0.9983% RTP / % Flow Span

Finally, the Reference Accuracy and Installation Effects for the Feedwater Flow Venturi are expressed in the same units. Therefore, the conversion factor is the same.

WF_{FWFE} = 0.9983% RTP / % Flow Span

6.2.10 CORRECTION FACTOR ERROR WEIGHTING FACTOR

The error in correction factor is in units of MW. Therefore, the weighting factor is merely determined using the conversion from MW to % RTP.

WF_{qrad} = 100% RTP/ 2763 MW
= 0.0362% RTP/ MW

6.2.11 WEIGHTING FACTOR SUMMARY

The following table is created from the values derived in Sections 6.2.1 through 6.2.10 above.

Parameter	Term	Value	Units
Feedwater Flow – Unit 1	WF_{FWF1}	0.6988	% RTP / % DP Span
Feedwater Flow – Unit 2	WF_{FWF2}	0.6476	% RTP / % DP Span
Feedwater Flow Venturi Fouling	WF_{FWFB}	0.9983	% RTP / % Actual Flow
Feedwater Flow Element Effects	WF_{FWFE}	0.9983	% RTP / % Actual Flow
Feedwater Temperature – Unit 1	WF_{FWT1}	0.1309	% RTP / °F
Feedwater Temperature – Unit 2	WF_{FWT2}	0.1384	% RTP / °F
Reactor Pressure – Unit 1	WF_{SP1}	0.0568	% RTP / % Span
Reactor Pressure – Unit 2	WF_{SP2}	0.0589	% RTP / % Span
CRD System Flow	WF_{CRDF}	0.0049	% RTP / % DP Span
CRD System Flow Element Effects	WF_{CRDFAF}	0.0035	% RTP / % Actual Flow
CRD Inlet Temperature	WF_{CRDT}	0.0003	% RTP / °F
RWCU Flow	WF_{CUF}	0.0008	% RTP / % DP Span
RWCU Flow Element Effects	WF_{CUFAF}	0.0012	% RTP / % Actual Flow
RWCU Inlet Temperature	WF_{CUTi}	0.0014	% RTP / °F
RWCU Outlet Temperature	WF_{CUTo}	0.0012	% RTP / °F
Recirc Pump Power	WF_{RPP}	0.0030	% RTP / % Span
UFM	WF_{UFM}	0.9983	% RTP / % Actual Flow
Correction Factor (Q_{RAD})	WF_{QRAD}	0.0362	% RTP / MW

Table 1 – Weighting Factor Summary Table

6.3 INDIVIDUAL INSTRUMENT LOOP UNCERTAINTY COMPUTATIONS

6.3.1 FEEDWATER FLOW UNCERTAINTY COMPUTATION

Case 1 – No UFM Correction

The following non-zero terms are derived in Section 4.2 and 4.10 for the Feedwater Flow instrument loops. These errors apply only to Case 1, since the continuous UFM Correction effectively eliminates all these error terms for Case 2.

RA_{FWFE} = ± 0.2500% Actual Flow
IE_{FWFE} = ± 0.5000% Actual Flow
PE_{FWFE1} = ± 0.0784% DP Span (Dependent with FW Temp)
PE_{FWFE2} = ± 0.0918% DP Span (Dependent with FW Temp)
PE_{bFWFE} = + 0.6000% Actual Flow (Bias, Treat Separately)
DA_{FWFT} = ± 1.4770% DP Span
ST_{FWFT1} = ± 0.2500% DP Span
ST_{FWFT2} = ± 0.1250% DP Span
SPE_{FWFT} = ± 0.2768% DP Span
PSE_{FWFT} = ± 0.0090% DP Span
TE_{FWFT} = ± 0.1260% DP Span

RA_{PC} = ± 0.0180% Span
RES_{PC} = ± 0.0244% Span

The Plant Computer uncertainties are expressed in generic percent span terms, which apply directly to this loop, since the DP signal feeds the Plant Computer directly.

Three random terms are computed herein, which are separately considered for the total heat balance uncertainty. The first term is the total of the random dependent loop errors that are expressed in terms of % DP Span. The second is the total of the random loop errors that are expressed in terms of % Actual Flow. The third is the Feedwater Flow element density error (PE_{FWFE}), which is expressed in terms of % DP Span, but which is a dependent term with the Feedwater Temperature uncertainty.

Therefore the terms combine in an SRSS fashion to produce Feedwater Flow uncertainties (TLU) for each single flow loop (A and B).

Unit 1

TLU_{FWF1} = SRSS(DA_{FWFT}, ST_{FWFT1}, SPE_{FWFT}, PSE_{FWFT}, TE_{FWFT}, RA_{PC}, RES_{PC})
= ± 1.5289% DP Span
TLU_{FWF1AF} = SRSS(RA_{FWFE}, IE_{FWFE})
= ± 0.5590% Actual Flow
PE_{FWFE1} = ± 0.0784% DP Span (Dependent with FW Temp)

In addition, there is a bias term, due to fouling of the feedwater flow elements, which must be considered.

PE_{bFWFE} = + 0.6000% Actual Flow (Bias, Treat Separately)

Unit 2

TLU_{FWF2} = SRSS(DA_{FWFT}, ST_{FWFT2}, SPE_{FWFT}, PSE_{FWFT}, TE_{FWFT}, RA_{PC}, RES_{PC})
= ± 1.5135% DP Span
TLU_{FWF2AF} = SRSS(RA_{FWFE}, IE_{FWFE})
= ± 0.5590% Actual Flow
PE_{FWFE2} = ± 0.0918% DP Span (Dependent with FW Temp)

PE_{bFWFE} = + 0.6000% Actual Flow (Bias, Treat Separately)

Case 2 - Continuous UFM Correction

Under this scenario, the UFM is used to automatically correct the FW flow indication in the Plant Computer on a continuous basis. Therefore, all uncertainty terms are eliminated from the flow venturi instrument loops. The only remaining uncertainty value is for the Westinghouse Crossflow UFMs. Therefore,

$TU_{UFMXFLO}$ = ± 0.4200% Actual Flow (95% Confidence Factor)

6.3.2 FEEDWATER TEMPERATURE UNCERTAINTY COMPUTATION

The following non-zero terms are derived in Section 4.3 and 4.10 for the Feedwater Temperature instrument loops.

RA_{FWTT} = ± 0.2000°F
ST_{FWTT} = ± 0.3001°F
$M\&TE_{FWTT}$ = ± 0.2000°F
DR_{FWTT} = ± 0.2000°F
PSE_{FWTT} = ± 0.0150°F
TE_{FWTT} = ± 2.5000°F

The span of the temperature indication is 150°F. The Plant Computer uncertainties are expressed in generic percent span terms, which apply directly to this loop, since the temperature signal feeds the Plant Computer directly. Therefore, the PC Conversions are made as shown below.

$RA_{PCFWT} = \pm RA_{PC} \times 150°F / 100\%$ Span
$= \pm 0.0180\%$ Span $\times 150°F / 100\%$ Span
$= \pm 0.0270°F$

$RES_{PCFWT} = \pm RES_{PC} \times 150°F / 100\%$ Span
$= \pm 0.0244\%$ Span $\times 150°F / 100\%$ Span
$= \pm 0.0366°F$

The terms combine in an SRSS fashion to produce a Feedwater Temperature uncertainty for each indication. Units 1 and 2 are identically configured.

$TU_{FWT} = SRSS(RA_{FWTT}, ST_{FWTT}, M\&TE_{FWTT}, DR_{FWTT}, PSE_{FWTT}, TE_{FWTT}, RA_{PCFWT}, RES_{PCFWT})$
$= \pm 2.5421°F$

The real parameter of concern is the average feedwater temperature between the loops. There are 4 feedwater temperature measurements, two on each feedwater loop, which are used in the determination of the average, and each sensor has the same configuration and range. Therefore, when the Plant Computer actually determines the value for average feedwater temperature, the Total Loop Uncertainty in the determination is shown as follows:

TLU (Average FW Temp) = SRSS (TUs of 4 FW Temp Signals) / No. Signals
$= (4\times(\text{TU of Single FW Temp Signal})^2)^{1/2}/4$
= TU of Single FW Temp Signal / 2

$TLU_{FWT} = TU_{FWT} / 2 = \pm 1.2711°F$

6.3.3 REACTOR PRESSURE UNCERTAINTY COMPUTATION

The following non-zero terms are derived in Section 4.4 and 4.10 for the Reactor Steam Pressure instrument loops.

$DA_{RPT} = \pm 1.4470\%$ Span
$ST_{RPT} = \pm 0.2500\%$ Span
$PSE_{RPT} = \pm 0.0188\%$ Span
$TE_{RPT} = \pm 0.4080\%$ Span

$RA_{PC} = \pm 0.0180\%$ Span
$RES_{PC} = \pm 0.0244\%$ Span

The uncertainties for this measurement are not changed for any of the analyzed scenarios, and the configuration is identical from Unit 1 to Unit 2. Therefore, only one set of Total Uncertainty is determined.

$$TU_{SP} = SRSS(DA_{RPT}, ST_{RPT}, PSE_{RPT}, TE_{RPT}, RA_{PC}, RES_{PC})$$
$$= \pm 1.5245\% \text{ Span}$$

There are 2 Reactor Pressure measurements that are averaged to determine Reactor Pressure, and each measurement loop has the same configuration and range. Therefore, when the Plant Computer actually determines the value, the Total Loop Uncertainty in the determination is shown as follows:

$$TLU_{SP} = \text{SRSS (TUs of 2 Rx Pressure) / No. Signals}$$
$$= (2x(\text{TU of Single RX Pressure Signal})^2)^{1/2}/2$$
$$= \text{TU of Single Rx Pressure} / (2)^{1/2}$$

$$TLU_{SP} = TU_{SP} / (2)^{1/2} = \pm 1.0780\% \text{ Span}$$

6.3.4 CONTROL ROD DRIVE (CRD) FLOW UNCERTAINTY COMPUTATION

The following non-zero terms are derived in Section 4.5 and 4.10 for the CRD System Flow instrument loops.

RA_{CRDFE} = ± 1.0000% Actual Flow
IE_{CRDFE} = ± 1.0000% Actual Flow
PE_{CRDFE} = ± 0.5560% DP Span

RA_{CRDFT} = ± 0.4000% DP Span
ST_{CRDFT} = ± 0.5000% DP Span
$M\&TE_{CRDFT}$ = ± 0.4000% DP Span
SPE_{CRDFT} = ± 2.0706% DP Span
TE_{CRDFT} = ± 0.6800% DP Span

RA_{PC} = ± 0.0180% Span
RES_{PC} = ± 0.0244% Span

The uncertainties for this measurement are not changed for any of the analyzed scenarios, and the configuration is identical from Unit 1 to Unit 2. Therefore, only one set of Total Loop Uncertainty is determined.

Two random terms are computed herein, which are separately considered for the total heat balance uncertainty. The first term is the total of the loop errors that are expressed in terms of % DP Span. The second is the total of the random loop errors that are expressed in terms of % Actual Flow.

The Plant Computer uncertainties are expressed in generic percent span terms, which apply directly to this loop, since the DP signal feeds the Plant Computer directly. Therefore the terms combine in an SRSS fashion to produce a CRD System Flow uncertainty (TLU).

$$TLU_{CRDF} = SRSS(PE_{CRDFE}, RA_{CRDFT}, ST_{CRDFT}, M\&TE_{CRDFT}, SPE_{CRDFT}, TE_{CRDFT}, RA_{PC}, RES_{PC})$$
$$= \pm 2.3727\% \text{ DP Span}$$
$$TLU_{CRDFAF} = SRSS(RA_{CRDFE}, IE_{CRDFE})$$
$$= \pm 1.4142\% \text{ Actual Flow}$$

6.3.5 CRD SYSTEM TEMPERATURE UNCERTAINTY COMPUTATION

The following non-zero terms are derived in Section 4.6 and 4.10 for the CRD System Temperature instrument loops.

$$RA_{CRDTE} = \pm 1.8000°F$$

Per Section 4.6.1, the span of these thermocouples is 0-752°F. Therefore, the PC uncertainty conversions are made as shown below.

$$RA_{PCCRDT} = \pm RA_{PC} \times 752°F / 100\% \text{ Span}$$
$$= \pm 0.0180\% \text{ Span} \times 752°F / 100\% \text{ Span}$$
$$= \pm 0.1354°F$$
$$RES_{PCCRDT} = \pm RES_{PC} \times 752°F / 100\% \text{ Span}$$
$$= \pm 0.0244\% \text{ Span} \times 752°F / 100\% \text{ Span}$$
$$= \pm 0.1835°F$$

The configuration of the CRD System Temperature measurement does not change for any of the scenarios analyzed, and Unit 1 is identically configured with Unit 2. Therefore, only one Total Loop Uncertainty (TLU) value is necessary.

$$TLU_{CRDT} = SRSS(RA_{CRDTE}, RA_{PCCRDT}, RES_{PCCRDT})$$
$$= \pm 1.8144°F$$

6.3.6 REACTOR WATER CLEANUP (RWCU) SYSTEM FLOW UNCERTAINTY COMPUTATION

The following non-zero terms are derived in Section 4.7 and 4.10 for the RWCU System Flow instrument loops.

RA_{CUFE} = ± 0.5000% Actual Flow
IE_{CUFE} = ± 0.5000% Actual Flow
PE_{CUFE1} = ± 0.5484% DP Span
PE_{CUFE2} = ± 0.5504% DP Span

PE_{b1CU} = -1.7864% DP Span (Bias, Treat Separately)
PE_{b2CU} = -1.5294% DP Span (Bias, Treat Separately)

DA_{CUFT} = ± 1.5770% DP Span
ST_{CUFT} = ± 0.5000% DP Span
SPE_{CUFT} = ± 0.5177% DP Span
PSE_{CUFT} = ± 0.2326% DP Span
TE_{CUFT} = ± 0.5000% DP Span

RA_{PC} = ± 0.0180% Span
RES_{PC} = ± 0.0244% Span

Two random terms are computed herein, which are separately considered for the total heat balance uncertainty. The first term is the total of the loop errors that are expressed in terms of % DP Span. The second is the total of the random loop errors that are expressed in terms of % Actual Flow.

The Plant Computer uncertainties are expressed in generic percent span terms, which apply directly to this loop, since the DP signal feeds the Plant Computer directly. Therefore the terms combine in an SRSS fashion to produce a RWCU System Flow uncertainty (TLU).

TLU_{CUF} = SRSS(PE_{CUFE}, DA_{CUFT}, ST_{CUFT}, SPE_{CUFT}, PSE_{CUFT}, TE_{CUFT}, RA_{PC}, ST_{PC}, $M\&TE_{PC}$, RES_{PC})
TLU_{CUFAF} = SRSS(RA_{CUFE}, IE_{CUFE})

<u>Unit 1</u>
TLU_{CUF1} = SRSS(PE_{CUFE1}, DA_{CUFT}, ST_{CUFT}, SPE_{CUFT}, PSE_{CUFT}, TE_{CUFT}, RA_{PC}, RES_{PC})
= ± 1.9002% DP Span

TLU_{CUF1AF} = SRSS(RA_{CUFE}, IE_{CUFE})
= ± 0.7071% Actual Flow

Unit 2

TLU_{CUF2} = SRSS(PE_{CUFE2}, DA_{CUFT}, ST_{CUFT}, SPE_{CUFT}, PSE_{CUFT}, TE_{CUFT}, RA_{PC}, RES_{PC})
= ± 1.9008% DP Span

TLU_{CUF2AF}= SRSS(RA_{CUFE}, IE_{CUFE})
= ± 0.7071% Actual Flow

For the RWCU flow uncertainty, an additional bias exists, for which the value is defined by the Process Error.

PE_{b1CU} = -1.7864% DP Span (Bias, Treat Separately)

PE_{b2CU} = -1.5294% DP Span (Bias, Treat Separately)

6.3.7 RWCU INLET / OUTLET TEMPERATURE UNCERTAINTY COMPUTATION

The following non-zero terms are derived in Section 4.8 and 4.10 for the RWCU Inlet and Outlet System Temperature instrument loops.

RA_{CUTE} = ± 3.0375°F

Per Section 4.8.1, the span of these thermocouples is 0-600°F. Therefore, the PC uncertainty conversions are made as shown below.

RA_{PCCUT} = ± RA_{PC} x 600°F / 100% Span
= ± 0.0180% Span x 600°F / 100% Span
= ± 0.1080°F

RES_{PCCUT} = ± RES_{PC} x 600°F / 100% Span
= ± 0.0244% Span x 600°F / 100% Span
= ± 0.1464°F

The configuration of the RWCU Inlet or Outlet Temperature measurement does not change for any of the scenarios analyzed, and Unit 1 is identically configured with Unit 2. Therefore, only one Total Loop Uncertainty (TLU) value is necessary.

TLU_{CUT} = SRSS(RA_{CUTE}, RA_{PCCUT}, RES_{PCCUT})
= ± 3.0429°F

6.3.8 RECIRCULATION PUMP POWER UNCERTAINTY COMPUTATION

The following non-zero terms are derived in Section 4.9 and 4.10 for the Recirculation Pump Power instrument loops.

RA_{RPWT} = $\pm$ 0.5000% Span
ST_{RPWT} = $\pm$ 0.5000% Span
$M\&TE_{RPWT}$ = $\pm$ 0.5000% Span
TE_{RPWT} = $\pm$ 1.0050% Span

RA_{PC} = $\pm$ 0.0180% Span
RES_{PC} = $\pm$ 0.0244% Span

The uncertainties for this measurement are not changed for any of the analyzed scenarios, and the configuration is identical from Unit 1 to Unit 2. Therefore, only one set of Total Loop Uncertainty is determined.

TLU_{RPP} = SRSS(RA_{RPWT}, ST_{RPWT}, $M\&TE_{RPWT}$, TE_{RPWT}, RA_{PC}, RES_{PC})
= $\pm$ 1.3270% Span

6.3.9 CORRECTION FACTOR UNCERTAINTY COMPUTATION

There is only one uncertainty term to be entered for the correction factor, so no computations are necessary.

$TU_{QRAD} = \pm 0.5500$ MW

6.3.10 INDIVIDUAL PARAMETER TOTAL LOOP UNCERTAINTY SUMMARY

The following table is created from the values derived in Sections 6.3.1 through 6.3.9 above.

Parameter	Term	Value	Units
Feedwater Flow – Unit 1	TLU_{FWF1}	± 1.5289	% DP Span
Feedwater Flow Elem Eff. – Unit 1	TLU_{FWF1AF}	± 0.5590	% Actual Flow
Dependent FW Flow - Unit 1	PE_{FWFE1}	± 0.0784	% DP Span
Feedwater Flow – Unit 2	TLU_{FWF2}	± 1.5135	% DP Span
Feedwater Flow Elem Eff. – Unit 2	TLU_{FWF2AF}	± 0.5590	% Actual Flow
Dependent FW Flow - Unit 2	PE_{FWFE2}	± 0.0918	% DP Span
Feedwater Venturi Fouling	PE_{bFWFE}	+ 0.6000	% Actual Flow
Feedwater Temperature	TLU_{FWT}	± 1.2711	°F
Reactor Pressure	TLU_{SP}	± 1.0780	% Span
CRD System Flow	TLU_{CRDF}	± 2.3727	% DP Span
CRD System Flow Element Effects	TLU_{CRDFAF}	± 1.4142	% Actual Flow
CRD Inlet Temperature	TLU_{CRDT}	± 1.8144	°F
RWCU Flow (Unit 1)	TLU_{CUF1}	± 1.9002	% DP Span
RWCU Flow Element Eff. (Unit 1)	TLU_{CUF1AF}	± 0.7071	% Actual Flow
RWCU Flow (Unit 2)	TLU_{CUF2}	± 1.9008	% DP Span
RWCU Flow Element Eff. (Unit 2)	TLU_{CUF2AF}	± 0.7071	% Actual Flow
RWCU Flow Bias (Unit 1)	PE_{b1CU}	-1.7864	% DP Span
RWCU Flow Bias (Unit 2)	PE_{b2CU}	-1.5294	% DP Span
RWCU Inlet / Outlet Temperature	TLU_{CUT}	± 3.0429	°F
Recirc Pump Power	TLU_{RPP}	± 1.3270	% Span
UFM – Westinghouse “Crossflow”	$TU_{UFMXFLOB}$	± 0.4200	% Actual Flow
Correction Factor	TU_{QRAD}	± 0.5500	MW

Table 2 – Individual Parameter Total Loop Uncertainty Summary Table

6.4 TOTAL HEAT BALANCE MEASUREMENT UNCERTAINTIES

The total heat balance measurement uncertainties are computed for 2 scenarios at 100% Power:

1. No Ultrasonic Flow Measurement (UFM) devices are installed. In this case, there is no correction to the venturi measurements, but operating in the current configuration, with accurate transmitter calibrations.
2. Westinghouse "Crossflow" Ultrasonic Flow Meters are used to correct the Feedwater Flow signals in the Plant Computer on a continuous basis.

The measurement uncertainty for each of these configurations is computed in the sub-sections to follow. NOTE: In addition to the random uncertainties computed in the sections below, there are two sets of bias terms needing consideration. The first is for the Feedwater Flow Venturi fouling, which is only a factor in Case 1, where UFMs are not used. This term may and may not be present, and could vary from a value of zero up to the value computed. This term is computed in Section 6.4.1.

The second bias is for the RWCU system flow measurement. Given the nature of this bias, which is negative, it is always present in the measurement, as performed, at 100% power heat balance conditions. This bias term is computed here and then repeated in each of the sections below.

$TLU_b \quad = \quad (WF_{CUF} \times PEb_{CU})$

<u>Unit 1</u>

$TLU_{b1} \quad = \quad (WF_{CUF} \times PEb1_{CU})$

$\quad = \quad -0.0014\%$ RTP

<u>Unit 2</u>

$TLU_{b2} \quad = \quad (WF_{CUF} \times PEb2_{CU})$

$\quad = \quad -0.0012\%$ RTP

6.4.1 CASE 1 – NO ULTRASONIC FLOW METERS USED FOR CORRECTION OF FEEDWATER FLOW

All random errors are combined in SRSS fashion, and bias terms are computed separately. The total measurement uncertainties of each parameter, which are derived in Section 6.3, are combined with weighting factors, which are derived in Section 6.2, in proportion to their total contribution to the calculation of uncertainties for the thermal power computation. Feedwater Temperature uncertainty and Feedwater Flow Element PE (due to density correction) are treated as dependent variables and are added prior to the SRSS computation.

$$TLU_{RTP(Case\ 1)} = \pm((WF_{FWF} \times TLU_{FWF})^2 + (WF_{FWFE} \times TLU_{FWFAF})^2 + (WF_{FWF} \times PE_{FWFE} + WF_{FWT} \times TLU_{FWT})^2 + (WF_{SP} \times TLU_{SP})^2 + (WF_{CRDF} \times TLU_{CRDF})^2 + (WF_{CRDFAF} \times TLU_{CRDFAF})^2 + (WF_{CRDT} \times TLU_{CRDT})^2 + (WF_{CUF} \times TLU_{CUF})^2 + (WF_{CUFAF} \times TLU_{CUFAF})^2 + (WF_{CUTi} \times TLU_{CUT})^2 + (WF_{CUTo} \times TLU_{CUT})^2 + (WF_{RPP} \times TLU_{RPP})^2 + (WF_{QRAD} \times TU_{QRAD})^2)^{1/2}$$

Unit 1

$$TLU_{RTP-U1C1} = \pm((WF_{FWF1} \times TLU_{FWF1})^2 + (WF_{FWFE} \times TLU_{FWF1AF})^2 + (WF_{FWF1} \times PE_{FWFE1} + WF_{FWT1} \times TLU_{FWT})^2 + (WF_{SP1} \times TLU_{SP})^2 + (WF_{CRDF} \times TLU_{CRDF})^2 + (WF_{CRDFAF} \times TLU_{CRDFAF})^2 + (WF_{CRDT} \times TLU_{CRDT})^2 + (WF_{CUF} \times TLU_{CUF1})^2 + (WF_{CUFAF} \times TLU_{CUF1AF})^2 + (WF_{CUTi} \times TLU_{CUT})^2 + (WF_{CUTo} \times TLU_{CUT})^2 + (WF_{RPP} \times TLU_{RPP})^2 + (WF_{QRAD} \times TU_{QRAD})^2)^{1/2}$$

$$= \pm 1.2273\%\ RTP$$

$$TLU_{b1} = (WF_{CUF} \times PEb1_{CU})$$
$$= -0.0014\%\ RTP$$

$$TLU_{FWFOUL} = (WF_{FWFB} \times PEb_{FWFE})$$
$$= +0.5990\%\ RTP$$

Unit 2

$$TLU_{RTP-U2C1} = \pm((WF_{FWF2} \times TLU_{FWF2})^2 + (WF_{FWFE} \times TLU_{FWF2AF})^2 + (WF_{FWF2} \times PE_{FWFE2} + WF_{FWT2} \times TLU_{FWT})^2 + (WF_{SP2} \times TLU_{SP})^2 + (WF_{CRDF} \times TLU_{CRDF})^2 + (WF_{CRDFAF} \times TLU_{CRDFAF})^2 + (WF_{CRDT} \times TLU_{CRDT})^2 + (WF_{CUF} \times TLU_{CUF2})^2 + (WF_{CUFAF} \times TLU_{CUF2AF})^2 + (WF_{CUTi} \times TLU_{CUT})^2 + (WF_{CUTo} \times TLU_{CUT})^2 + (WF_{RPP} \times TLU_{RPP})^2 + (WF_{QRAD} \times TU_{QRAD})^2)^{1/2}$$

$$= \pm 1.1542\%\ RTP$$

$$TLU_{b2} = (WF_{CUF} \times PEb2_{CU})$$
$$= -0.0012\%\ RTP$$

$$TLU_{FWFOUL} = (WF_{FWFB} \times PEb_{FWFE})$$

= +0.5990% RTP

6.4.2 CASE 2 – WESTINGHOUSE "CROSSFLOW" ULTRASONIC FLOW METERS USED FOR CORRECTION OF FEEDWATER FLOW ON A CONTINUOUS BASIS

All random errors are combined in SRSS fashion, and bias terms are computed separately. The total measurement uncertainties of each parameter, which are derived in Section 6.3, are combined with weighting factors, which are derived in Section 6.2, in proportion to their total contribution to the calculation of uncertainties for the thermal power computation.

$TLU_{RTP(Case\ 2)} = \pm((WF_{UFM} \times TU_{UFMXFLO})^2 + (WF_{FWT} \times TLU_{FWT})^2 + (WF_{SP} \times TLU_{SP})^2 + (WF_{CRDF} \times TLU_{CRDF})^2 + (WF_{CRDFAF} \times TLU_{CRDFAF})^2 + (WF_{CRDT} \times TLU_{CRDT})^2 + (WF_{CUF} \times TLU_{CUF})^2 + (WF_{CUFAF} \times TLU_{CUFAF})^2 + (WF_{CUTi} \times TLU_{CUT})^2 + (WF_{CUTo} \times TLU_{CUT})^2 + (WF_{RPP} \times TLU_{RPP})^2 + (WF_{QRAD} \times TU_{QRAD})^2)^{1/2}$

<u>Unit 1</u>

$TLU_{RTP-U1C2} = \pm((WF_{UFM} \times TU_{UFMXFLO})^2 + (WF_{FWT1} \times TLU_{FWT})^2 + (WF_{SP1} \times TLU_{SP})^2 + (WF_{CRDF} \times TLU_{CRDF})^2 + (WF_{CRDFAF} \times TLU_{CRDFAF})^2 + (WF_{CRDT} \times TLU_{CRDT})^2 + (WF_{CUF} \times TLU_{CUF1})^2 + (WF_{CUFAF} \times TLU_{CUF1AF})^2 + (WF_{CUTi} \times TLU_{CUT})^2 + (WF_{CUTo} \times TLU_{CUT})^2 + (WF_{RPP} \times TLU_{RPP})^2 + (WF_{QRAD} \times TU_{QRAD})^2)^{1/2}$

$TLU_{RTP-U1C2}$ = ± 0.4559% RTP (For Cross Flow Uncertainty of ±0.42%)

$TLU_{b1} = (WF_{CUF} \times PEb1_{CU})$
= -0.0014% RTP

<u>Unit 2</u>

$TLU_{RTP-U2C2} = \pm((WF_{UFM} \times TU_{UFMXFLO})^2 + (WF_{FWT2} \times TLU_{FWT})^2 + (WF_{SP2} \times TLU_{SP})^2 + (WF_{CRDF} \times TLU_{CRDF})^2 + (WF_{CRDFAF} \times TLU_{CRDFAF})^2 + (WF_{CRDT} \times TLU_{CRDT})^2 + (WF_{CUF} \times TLU_{CUF2})^2 + (WF_{CUFAF} \times TLU_{CUF2AF})^2 + (WF_{CUTi} \times TLU_{CUT})^2 + (WF_{CUTo} \times TLU_{CUT})^2 + (WF_{RPP} \times TLU_{RPP})^2 + (WF_{QRAD} \times TU_{QRAD})^2)^{1/2}$

$TLU_{RTP-U2C2}$ = ± 0.4598% RTP (For Cross Flow Uncertainty of ±0.42%)

$TLU_{b2} = (WF_{CUF} \times PEb2_{CU})$
= -0.0012% RTP

7.0 SUMMARY OF RESULTS

This evaluation analyzes the measurement uncertainty of the heat balance at E. I. Hatch Nuclear Plant, given 2 possible cases. Table 3 provides a summary of the total heat balance measurement uncertainties for each of the 2 analyzed cases.

Case	Bias Unit 1 (% RTP)	Random Uncert Unit 1 (%RTP)	Bias Unit 2 (% RTP)	Random Uncert Unit 2 (%RTP)
1. No UFM Correction	-0.001 / +0.599	± 1.227	-0.001 / +0.599	± 1.154
2. Westinghouse "Crossflow" UFM to Continuously Correct the Venturi Reading	-0.001	± 0.456	-0.001	± 0.460

Table 3 – Total Heat Balance Measurement Uncertainty Summary

8.0 CONCLUSIONS

This study evaluates the measurement uncertainty of the heat balance computation at E. I. Hatch Nuclear Plant under the following two conditions:

Case 1: current configuration, using feedwater flow venturis to measure feedwater flow, and
Case 2: configuration after installation of Westinghouse Crossflow Ultrasonic Flowmeters (UFMs), which will be used to automatically correct the venturi readings on a continuous basis within the Plant Computer.

The total heat balance measurement uncertainties of these two configurations are calculated and displayed in Table 3. These uncertainties only apply to approximately 100% power operating conditions. Although these uncertainties were computed for pre-power uprate conditions, due to the small amount of the power uprate, the uncertainties are still valid after the power uprate.

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9.7.5 Drawing H-43850, "Process Computer Replacement System 1C95 Elementary Diagram, Sheet 11 of 16," Rev. 2
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9.7.20 Drawing H-51557, "Process Computer Replacement System 2C95 Elementary Diagram Sheet 5 of 16," Rev. 2
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C
CG3SR01CTPSB
C*****************************************************************************
C
      SUBROUTINE G3SR01CTPSB (LU ,ERROR_CODE)
C
C     PURPOSE:
C
C     G3P6 (alias G3MCIL) performs heat balance calculation. It also
C
C     INPUT DESCRIPTION:
C
C       ARGUMENTS:
C
C         Lu        -     File code of error logging file
C
C       GLOBAL VARIABLES:
C
C         G3P6CONSTe      -     Plant constants Common Block
C         COMDAS          -     Common Block - PSC values and status
C
C     OUTPUT DESCRIPTION:
C
C       ARGUMENTS:
C
C         ERROR_CODE      -     Return error code; 0=Good, 1=Bad
C
C       GLOBAL VARIABLES:
C
C         SR1COM          -     Common Block with Heatbalance data
C
C     SUBROUTINES CALLED:
C
C     G3CONVERT
C     LWRWERR
C     LCGETERTM
C     LCERTOD
C     HGP
C     HFP
C     HPTL
C     HGSF
C     HSCF
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```
C
C     SPECIAL NOTES:
C
C (1) THE DATABASE OF PLANT DATA IS ASSUMED TO CONTAIN STATUS WORDS
C     FOR EACH THERMODYNAMIC SENSOR WHICH HAS THE VALUE 'GOOD',
C     'REMO', 'FAIL', OR 'SUBS' TO INDICATE STATUS OF THE SENSOR
C     SIGNAL TO BE RESPECTIVELY GOOD, REMOVED FROM SCANNING BY THE DAS,
C     FAILED, AND REMOVED FROM SCANNING WITH A SUBSTITUTE VALUE SUPPLIED
C     BY THE OPERATOR.
C
C (2) PLANT THERMODYNAMIC SENSOR DATA
C
C     THE FOLLOWING SCALARS AND ARRAYS ARE DEFINED TO CONTAIN THE
C     PLANT THERMODYNAMIC SENSOR READINGS RETURNED TO THE PROGRAM
C     FROM THE DAS IN THE "COMDAS" LABEL COMMON.
C
C     PSCDATA(I), I=1,NSC - PLANT THERMODYNAMIC SENSOR READINGS
C     PSCSTAT(I), I=1,NSC - PLANT THERMODYNAMIC SENSOR SCAN STATUS
C
C     PSCDATA / PSCSTAT ARRAY assignment for a plant with 2 clean-up
C     flow branches (NCUB=2), 2 feedwater  branches (NFWB=2),
c       2  recirculation  loops  (NPUMP=2) is as follows:
C
C            1.  WCR     Control rod system flow
C            2.  TCR     Control rod system flow temperature
C            3.  WCUA    Cleanup system flow, branch A
C            4.  WCUB    Cleanup system flow, branch B
C            5.  TCU1    Cleanup system inlet temperature
C            6.  TCU2    Cleanup system exit temperature
C            7.  MWPA    Recirc pump A motor power
C            8.  MWPB    Recirc pump B motor power
C            9.  PRG     Reactor pressure
C     10.  DPM     Core pressure drop
C     11.  RWL     Reactor water level
C     12.  TFWA1   Feedwater temperature  1, branch A
C     13.  TFWA2   Feedwater temperature  2, branch A
C     14.  TFWB1   Feedwater temperature  1, branch B
C     15.  TFWB2   Feedwater temperature  2, branch B
C     16.  GMWE    Generator gross power
C     17.  WT      Total core flow
C     18.  WDA1    Driving flow  1, loop A
C     19.  WDA2    Driving flow  2, loop A
C     20.  WDB1    Driving flow  1, loop B
C     21.  WDB2    Driving flow  2, loop B
C     22.  TDA1    Inlet temperature  1, loop A
C     23.  TDA2    Inlet temperature  2, loop A
C     24.  TDB1    Inlet temperature  1, loop B
C     25.  TDB2    Inlet temperature  2, loop B
C     26.  WFWA    Feedwater flow, branch A
C     27.  WFWB    Feedwater flow, branch B
C
C     WAVX(I), I=1,NFWB - Digitally Averaged
C                 Feedwater Branch Flows In Nfwb Branches
C     RAPDATA(I), I=1,NAP  - APRM Channel Readings
C                 For NAP APRM Channels, Scan Units
```

```
C      RAPSTAT(I), I=1,NAP  - Status Words For APRM
C                  Channel Sensors
C
C (3)  IT IS ASSUMED THAT IF ANY OF THE PLANT SENSORS ARE REMOVED FROM
C      SCANNING IT SHALL BE POSSIBLE FOR THE OPERATOR TO MANUALLY INSERT
C      A SUBSTITUTE VALUE FOR THE SENSOR READING INTO THE DBMS, THE
C      SUBSTITUTE VALUE OCCUPYING THE POSITION IN THE DATABASE WHERE
C      THE NORMAL VALUE WOULD BE STORED IF THE SENSOR WERE GOOD AND
C      BEING SCANNED.
C
C (4)  IT IS FURTHER ASSUMED THAT THE DAS SHALL MAINTAIN THE VALUES
C      IN THE DBMS IN THE UNITS SPECIFIED BY THE I/O LIST.
C      CONVERSION TO STANDARD INTERNAL UNITS WILL BE PERFORMED IN THE
C      THIS PROGRAM.
C
C (5)  IN ADDITION TO THE SENSORS ABOVE THE FOLLOWING STATUS WORDS ARE
C      ASSUMED TO EXIST IN THE DATABASE:
C
C      FWBA(I), I=1,NFWB - FEEDWATER BRANCH ACTIVE STATUS HAVING THE
C                          VALUE 'ACTI' IF ACTIVE AND THE VALUE 'PASS'
C                          IF NOT ACTIVE.  IF SIGNALS DO NOT EXIST, SET
C                          THE VALUE TO 'ACTI' AS AN ASSUMED VALUE.
C
C      RLA(I), I=1,NPUMP - RECIRC LOOP ACTIVE STATUS HAVING THE VALUE
C                          'ACTI' IF ACTIVE AND THE VALUE 'PASS' IF
C                          NOT ACTIVE.  IF THE STATUS SIGNALS DO NOT
C                          EXIST, SET THE VALUE TO 'ACTI' AS AN ASSUMED
C                          VALUE.
C
C      ELOC - EQUALIZER LINE OPEN/CLOSED STATUS HAVING THE VALUE 'OPEN'
C             IF THE EQUALIZER LINE IS OPEN AND HAVING THE VALUE 'SHUT'
C             IF THE EQUALIZER LINE IS NOT OPEN.  IF THE SIGNAL IS NOT
C             PRESENT, AND AN EQUALIZER LINE IS PRESENT, SET THE VALUE
C             TO 'OPEN' AS AN ASSUMED VALUE.  IF THE EQUALIZER LINE IS
C             NOT PRESENT, SET THE VALUE TO 'SHUT'.
C
C      PROCEDURE:
C
C      The procedure is outlined in the special note above. Refer
C      to 22A6701AA specification for more detail.
C
C      REQUIREMENTS REF:
C
C      This module was developed from and conforms to the functional
C      requirements in the General Electric specification 22A6701AA, rev. 0.
C
C***************************************************************************

       IMPLICIT NONE

!      INCLUDE 'PDL:G3SR01CTPSB.INC/LIST'

       INCLUDE '(DF_NSSIDB_NSSICLAS)/LIST'
       INCLUDE '(DF_NSSIDB_LIVEPD)/LIST'
       INCLUDE 'GPRM:G3NSSIPRM.GPM/LIST'
```

```
  INCLUDE 'GCMN:G3P6CONST.GMN/LIST'
INCLUDE 'Lcmn:G3SR1COM.cmn/list'
INCLUDE 'LCMN:G3COMDAS.CMN/LIST'

Character   TEXT*50             ! Error text
  Character*23    ascii_time   ! System Time in ASCII format
Integer*4   eristime(2)       ! System Clock Time in Eris Time Format

Integer*4   LU          ! File code of error logging file
Integer*4   ERROR_CODE  ! Return Error Code; 0=good, 1=bad

Real*4            G3CONVERT   ! Unit conversion
Real*4            TFWSUB(NFWBZ)      ! Feedwater temperature
Real*4            HFWSUB(NFWBZ)      ! Feedwater entholphy
Real*4            WFWSUB(NFWBZ)      ! Feedwater flow
Real*4            TDT(NPUMPZ) ! Recirc inlet temperature
Real*4            TEM         ! Local for limit comparision
Real*4            PUMP_POWER  ! Local variable for Pump Power
Real*4            FEED_FLOW   ! Local variable for Feedwater Flow
Real*4            delta       ! Local veriable
Parameter   (delta=1.0e-20) ! Small enough to test (.eq. 0)

Integer*4   ILFLAG(NSCZ)       ! PSC sensor status array
Integer*4   I, J, K            ! Loop counter
Integer*4   IP          ! Local variable
Integer*4   N3          ! Local variable
Integer*4   INDX        ! Local variable
Integer*4   LOC         ! Local variable
Integer*4   NUMP        ! No of recirc pump local counter
Integer*4   JLOOP       ! Loop counter
Integer*4   P_LOC       ! Local variable
Integer*4   WD_LOC             ! Local variable

C   PSC sensor status defination

   Byte         GOOD /0/,    ! PSC sensor status evluation
   1            FAIL /1/,
   1            SUBS /2/,
   1            REMO /3/

   Integer*4
   1            ACTI /'ACTI'/,
   1            PASS /'PASS'/,
   1            SHUT /'SHUT'/,
   1            OPEN /'OPEN'/

C   PSC sensor criticality code

   Integer*4   Critical     ! Critical Sensor, not use last value
   Integer*4   Use_lastgv   ! Non critical sensor, use last value
   Integer*4   Use_zero     ! Non critical sensor, use 0.0 value

   Parameter   (Critical   = 0)
   Parameter   (Use_lastgv = 1)
   Parameter   (Use_zero   = 2)
```

```
C  PSC array index for each type of PSC data

      Integer*4   iWCR        ! Control rod system flow
      Integer*4   iTCR        ! Control rod system flow temperature
      Integer*4   iWCU        ! Cleanup system flow, branch A
      Integer*4   iTCU        ! Cleanup system inlet temperature
      Integer*4   iMWP        ! Recirc pump A motor power
      Integer*4   iPR         ! Reactor pressure
      Integer*4   iDPM        ! Core pressure drop
      Integer*4   iRWL        ! Reactor water level
      Integer*4   iTFW              ! Feedwater temperature  1, branch A
      Integer*4   iGMWE       ! Generator gross power
      Integer*4   iWT         ! Total core flow
      Integer*4   iWD               ! Driving flow  1, loop A
      Integer*4   iTD               ! Inlet temperature  1, loop A
      Integer*4   iWFW        ! Feedwater flow, branch A

      Logical*4   FirstTime/ .true./

C  IREC (RECIRC LOOP ACTIVE FLAG) BITS SETTING

      Integer*4   BIT_VALUE(5)/1, 2, 4, 8, 16/  ! BIT 0, 1, 2, 3, 4 ON

C  Controlling Flags To send or Not to send the Warning Messages:

      Logical*4   ALL_LOOP_FLAG
      Logical*4   ALL_FWB_FLAG
      Logical*4   WD_LOOP_FLAG(NPUMPZ)
      Logical*4   TD_LOOP_FLAG(NPUMPZ)
      Logical*4   EPSWD3D_FLAG(NPUMPZ)
      Logical*4   EPSTD3D_FLAG(NPUMPZ)
      Logical*4   EPSWFW_FLAG(NFWBZ)

C  External (Heatbalance calculation)

      Real*4            HGP
      Real*4            HFP
      Real*4            HPTL
      Real*4            HGSF
      Real*4            HSCF

      External    HGP
      External    HFP
      External    HPTL
      External    HGSF
      External    HSCF

C***************************************************************************

C       +--------------------------------------------------+
C       | First Get System Time to stamp error log         |
C       +--------------------------------------------------+

        call lcgetertm (eristime)         ! Get system time in ERIS form
```

```
      call lcertod( eristime, ascii_time)     ! Convert ERIS time in ASCII

c       +--------------------------------------------------+
c      | If it is first time, perform some sanity check:  |
c       +--------------------------------------------------+

      if( FirstTime ) then

         FirstTime = .false.

         ! Set default values for these error messages falgs

         all_loop_flag = .true.      ! recirc loops availability flag
         all_fwb_flag  = .true.      ! feedwater branch availability flag

           do i = 1, npumpz
            wd_loop_flag(i)   = .true. ! driving flow not available flag
            td_loop_flag(i)   = .true. ! driving temp not available flag
            epswd3d_flag(i)   = .true. ! two driv. fl. differ more flag
            epstd3d_flag(i)   = .true. ! two driv temp differ more flag
         end do

           do i = 1, nfwbz
            epswfw_flag(i)    = .true. ! digital av and inst.fwf comp. flag
         end do

         ! Check Against Assumed Capacities For NFWB, NPUMP and NCUB

         IF(NCUB .LT.1  .OR. NCUB .GT. 3) THEN
            TEXT =' NUMBER OF CLEANUP BRANCHES MUST BE 1 TO 3'
              CALL LWRWERR (TEXT,'DUMY')
            CALL SEND LOG( '3DFMC028', TEXT )
            GO TO 9000 ! <<<<<<<<<<<<<  FATAL ERROR EXIT  >>>>>>>>>>>>>>>>>>
           END IF

         IF(NFWB .LT. 1 .OR.  NFWB .GT. 3) THEN
              TEXT = ' NUMBER OF FEEDWATER BRANCHES MUST BE 1 TO 3'
              CALL LWRWERR (TEXT,'DUMY')
            CALL SEND LOG( '3DFMC028', TEXT )
            GO TO 9000 ! <<<<<<<<<<<<<  FATAL ERROR EXIT  >>>>>>>>>>>>>>>>>>
         END IF

         IF(NPUMP .LT. 1  .OR.  NPUMP .GT. 5) THEN
              TEXT = ' NUMBER OF RECIRC LOOPS MUST BE 1 TO 5'
              CALL LWRWERR (TEXT,'DUMY')
            CALL SEND LOG( '3DFMC028', TEXT )
            GO TO 9000 ! <<<<<<<<<<<<<  FATAL ERROR EXIT  >>>>>>>>>>>>>>>>>>
           END IF

         ! calculate a PSC array index for each type of PSC data
         !-------------------------------------------------

         iWCR  = 1                     ! Control rod system flow
         iTCR  = 2               ! Control rod system flow temperature
         iWCU  = 3                     ! Cleanup system flow, branch A
```

```
      iTCU  = iWCU + ncub        ! Cleanup system inlet temperature
      iMWP  = iTCU + 2           ! Recirc pump A motor power
      iPR   = iMWP + npump       ! Reactor pressure
      iDPM  = iPR  + 1           ! Core pressure drop
      iRWL  = iDPM + 1           ! Reactor water level
      iTFW  = iRWL + 1           ! Feedwater temperature  1, branch A
      iGMWE = iTFW + 2*nfwb      ! Generator gross power
      iWT   = iGMWE + ngen       ! Total core flow
      iWD   = iWT + 1            ! Driving flow  1, loop A
      iTD   = iWD + 2*npump      ! Inlet temperature  1, loop A
      iWFW  = iTD + 2*npump      ! Feedwater flow, branch A

   end if

C  +--------------------------------------------+
C  | Start with Good CTP calculation status     |
C  +--------------------------------------------+

   KCTP = 0                   ! Init CTP calc status to GOOD
   CTP  = 0.0                 ! Initialize CTP to 0.0

C  +--------------------------------------------+
C  | First Check CONSTANTS.CED datasets values  |
C  +--------------------------------------------+

   DO I = 1, NFWB
      IF( FWNM(I) .EQ. 0.0 ) THEN          ! Bad Nominal FW Flow
           TEXT = 'FWNM('//char(48+i)//') = 0 in CONSTANTS.CED file'
         CALL LWRWERR (TEXT,'DUMY')
         CALL SEND LOG( '3DFMC028', TEXT )
         GO TO 9000 ! <<<<<<<<<<<<<  FATAL ERROR EXIT  >>>>>>>>>>>>>>>>>>>
      END IF
   END DO

   DO I = 1, NPUMP
      IF( WDNM(I) .EQ. 0.0 ) THEN      ! Bad nominal maximum driving flow
           TEXT = 'WDNM('//char(48+i)//') = 0 in CONSTANTS.CED file'
         CALL LWRWERR (TEXT,'DUMY')
         CALL SEND LOG( '3DFMC028', TEXT )
         GO TO 9000 ! <<<<<<<<<<<<<  FATAL ERROR EXIT  >>>>>>>>>>>>>>
      END IF
   END DO

C  +-----------------------------------------------------------+
C  | Convert the PSC data to the right units of measurement    |
C  +-----------------------------------------------------------+

   ! G3CONVERT converts the new thermodynamic data from DAS if
   ! necessary from metric to english units of measure.  All NSS
   ! calulations and data bank constants are in english units.
   !-------------------------------------------------------------

   PSCDATA( iWCR) = G3CONVERT(0,1,PSCDATA( iWCR) )

   ! P6OPTCRD NSSIDB item is set to TRUE if CRD temperature
```

```
! sensor exist in which case the plant DAS input is used.
! Otherwise, P6OPTCRD is FALSE and the CRD temperature input
! is obtained from the CT2 dataset value of CONSTANTS.CED
! file.
!--------------------------------------------------------------

if( P6OPTCRD ) then            ! plant sensor exist
   PSCDATA( iTCR) = G3CONVERT(0,5,PSCDATA( iTCR) )
else
   PSCDATA( iTCR) = CT2          ! plant sensor does not exist
   PSCSTAT( iTCR) = GOOD
end if

DO i = 0, NCUB-1
   PSCDATA( iWCU +i) = G3CONVERT(0,1,PSCDATA( iWCU +i))
END DO

  PSCDATA( iTCU) = G3CONVERT(0,5,PSCDATA( iTCU))
  PSCDATA( iTCU+1) = G3CONVERT(0,5,PSCDATA( iTCU+1))

! PR is gauge pressure; do NOT convert PR to absolute pressure
! here.
!--------------------------------------------------------------

PSCDATA( iPR)  = G3CONVERT(0,7,PSCDATA( iPR))

! DPM is a delta pressure.
!------------------------

PSCDATA( iDPM)  = G3CONVERT(0,7,PSCDATA( iDPM))
PSCDATA( iRWL)  = G3CONVERT(0,6,PSCDATA( iRWL))
PSCDATA( iWT)   = G3CONVERT(0,1,PSCDATA( iWT))

DO I=0,2*NPUMP -1
   PSCDATA( iWD +i) = G3CONVERT(0,1,PSCDATA( iWD +i))
   PSCDATA( iTD +i) = G3CONVERT(0,5,PSCDATA( iTD +i))
END DO


DO I=0, 2*NFWB -1
   PSCDATA( iTFW +i) = G3CONVERT(0,5,PSCDATA( iTFW +i))
END DO

DO I=0, NFWB -1
   PSCDATA( iWFW +i) = G3CONVERT(0,1,PSCDATA( iWFW +i))
   WAVX( i+1)        = G3CONVERT(0,1,WAVX( i+1))
END DO

C  +--------------------------------+
C  | Calculate ILFLAG and PSC arrays |
C  +--------------------------------+

   ! Load Sensors Reading and Sensor Status to PSC and ILFLAG arrays.
   ! Use PSC sensor criticality code in assigning last good value.
   !----------------------------------------------------------------
```

```
      do i = 1, nsc

         ilflag( i ) = pscstat( i )

         if(  (pscstat( i ) .eq. good) .and.
     1      (pscdata(i) .ge. rll(i)) .and.
     1      (pscdata(i) .le. rul(i))       ) then

            psc( i ) = pscdata( i )          ! good value, use it

         else if( (pscstat( i ) .eq. subs) .and.
     1      (pscdata(i) .ge. rll(i)) .and.
     1      (pscdata(i) .le. rul(i))       ) then

            psc( i ) = pscdata( i )          ! good sub value, use it
         else
            ! Use criticality code to assign last good value.

            if ( critical_psci(i) .eq. critical ) then
                 psc( i ) = -1.0          ! do not use last good value
            else if ( critical_psci(i) .eq. use_lastgv ) then
                 psc( i ) = ct(i)         ! use last good value
            else if ( critical_psci(i) .eq. use_zero ) then
                 psc( i ) = 0.0           ! set value to 0.0
            else
                 psc( i ) = -1.0          ! assign bad value.
            end if

            if ( ilflag (i) .eq. good ) then
               ilflag (i) = fail          !set status to fail
            end if

         end if

      end do

C  +--------------------------------------------------------------+
C  | Calculate the failed sensor list, IFSL, and update CT array. |
C  +--------------------------------------------------------------+

      nfsl = 0

      do i=1,nfsedz
         ifsl(i) = 0                    ! initialize to zero
      end do

      do i=1,nsc
             if( ilflag(i) .gt. good ) then     ! not good status
            nfsl = nfsl + 1
           if( nfsl .le. nfsedz ) ifsl(nfsl) = i
          else
           ct(i) = psc(i)               ! update latest good scan values
          end if
      end do
```

```
C  +------------------------------------------------------------------+
C  | Check aprm readings and add any failed APRM Identification to the |
C  | failed sensor list.                                               |
C  +------------------------------------------------------------------+

      do i=1,nap
         if(rapdata(i) .lt. rll(nsc+1) .or. rapdata(i) .gt. rul(nsc+1)
     1   .or. rapstat(i) .eq. fail .or. rapstat(i) .eq. remo) then
            rap(i) = 0.
            nfsl = nfsl + 1
            if( nfsl.le.nfsedz ) ifsl(nfsl) = nsc+i
         else
            rap(i) = rapdata(i)
         end if
      end do

C  +---------------------------------------+
C  | Calculate Recirc Loops active flags and |
C  | Feedwater Branches open/close Flags     |
C  +---------------------------------------+

      if(epspump  .eq. 0.0) epspump  = 0.1  !set default to 0.1 mw
      if(epswdflw .eq. 0.0) epswdflw = 0.05 !set default to 5% of wdnm

      ! Use Recirc Pump Power and drive flow in calculation of
      ! Recirc loop active flag
      !-------------------------------------------------------

      do i= 1, npump

           p_loc = imwp-1+i
         wd_loc = iwd + (i-1)*2

         if (eusclppw .ne. 0) then  !dvd by nssidb eu scaling constant
            pump_power = psc(p_loc)/eusclppw
         else
            pump_power = psc(p_loc)
         end if

         ppw(i) = pump_power

         if ( (ilflag(p_loc) .eq. good) .or.
     1        (ilflag(p_loc) .eq. subs)        ) then
           ! pump power signal is good, use pump power for testing
             if ( pump_power .gt. epspump ) then
              rla(i) = acti         ! recirc loop is active
           else
              rla(i) = shut         ! recirc loop is inactive
              ppw(i) = 0.0          ! set pump power to zero
           end if
         else if ( (psc(wd_loc) .gt. epswdflw*wdnm(i) ) .or.
     1              (psc(wd_loc+1) .gt. epswdflw*wdnm(i) )      ) then
             ! drive flow greater than minimum, loop is active.
           rla(i) = acti
```

```
   else
      rla(i) = shut
      ppw(i) = 0.0
   end if

end do

! Use instantaneous Feedwater Flow for Feedwater branch active flag
!-------------------------------------------------------------------

if(epsfwflw .eq. 0.0) epsfwflw = 0.01 !set default to 1% of fwnm

loc = iwfw - 1
do i= 1, nfwb
   feed_flow = psc(loc+i)
   if (feed_flow.gt.-1.1 .and.feed_flow .lt. -0.9)KCTP=2 !critical and
                                                          !FAIL or REMO
     fwba(i) = acti
   if (feed_flow .lt. epsfwflw * fwnm(i) ) then
      fwba(i) = shut    ! feedwater branch is closed
   end if
end do

! Calculate Number of Active Recirc Loops
! and Number of Active Feedwater Branches
!-------------------------------------------

! if all loops are active set irec with all bits off
! if loop 1 is inactive  set irec with bit # 0 on
! if loop 2 is inactive  set irec with bit # 1 on
! if loop 3 is inactive  set irec with bit # 2 on
! if loop 4 is inactive  set irec with bit # 3 on
! if loop 5 is inactive  set irec with bit # 4 on

irec         = 0        ! start with all pumps active
no_a_rc_loop = npump          ! start with all pumps active

do i=1,npump
   if(rla(i) .ne. acti) then
     irec = irec + bit_value(i)
     no_a_rc_loop = no_a_rc_loop - 1
   end if
end do

no_a_fw_br = nfwb       ! start with all fw branches active

do i=1, nfwb
   if(fwba(i) .ne. acti) then
     no_a_fw_br = no_a_fw_br - 1
   end if
end do

! Send Warning Message if Number of Active FW branches
! less than NFWB OR Number of Active Recirc Loops less than NPUMP
!----------------------------------------------------------------
```

```
      if(no_a_fw_br .lt. nfwb) then
        if ( all_fwb_flag ) then
             write(text, '(a,i3)')
      1    ' NO OF ACTIVE FEEDWATER BRANCHES LESS THAN ', NFWB
             CALL LWRWERR (TEXT,'DUMY')
           CALL SEND LOG( '3DFMC028', TEXT )
           all_fwb_flag = .false.
          end if
      else
        all_fwb_flag = .true.
        end if

      if(no_a_rc_loop .lt. npump) then
        if ( all_loop_flag ) then
             write(text, '(a,i3)')
      1    ' NO OF ACTIVE RECIRC LOOPS LESS THAN ', NPUMP
             CALL LWRWERR (TEXT,'DUMY')
           CALL SEND LOG( '3DFMC028', TEXT )
           all_loop_flag = .false.
          end if
      else
        all_loop_flag = .true.
        end if

C  +-----------------------------------------------------+
C  | Calculate Measured or  Operator Supplied Core Flow |
C  +-----------------------------------------------------+

      WTOPS = -1.0                              ! Operator supplied Core Flow
      WT    = -1.0                          ! Measured Core Flow

      LOC = iWT                     ! WT flow PSC base index
      IF( ILFLAG(LOC) .EQ. good ) WT    = PSC(LOC)
      IF( ILFLAG(LOC) .EQ. subs ) WTOPS = PSC(LOC)

C  +-----------------------------------------------------------------+
C  | Apply Engineering Unit Scaling Constants and Decode PSC array |
C  +-----------------------------------------------------------------+

        ! control rod system flow
      !------------------------

      IF (EUSCLWCR .NE. 0) THEN
           WCR = PSC(iWCR) / EUSCLWCR ! Dvd by NSSIDB EU Scaling Constant
      ELSE
         WCR = PSC(iWCR)
      ENDIF

        ! control rod system flow temperature
      !-----------------------------------

      TCR = PSC(iTCR)

        ! cleanup system flow
```

```
      !---------------------

      WCU = 0
      DO I=0,NCUB-1
         IF (EUSCLWCU .NE. 0) THEN
            WCU = WCU+PSC(iWCU+I)/EUSCLWCU !Dvd By NSSIDB EU Scaling Constant
         ELSE
            WCU = WCU+PSC(iWCU+I)
         END IF
      END DO

        ! cleanup system temperature
      !---------------------------

        TCU1 = PSC(iTCU)
        TCU2 = PSC(iTCU+1)

        ! reactor dome pressure, pressure drop and water level
      !-----------------------------------------------------

      PR = PSC(iPR) + 14.7     ! added 14.7 for abs. pressure (PSIA).
      DPM = PSC(iDPM)
      RWL = PSC(iRWL)

        ! generator power
      !----------------

      LOC = iGMWE
      IF( NGEN .EQ. 1)THEN
         GMWE(1) = PSC(LOC)
         GMWE(2) = 0.
      ELSE
         GMWE(1) = PSC(LOC)
         GMWE(2) = PSC(LOC+1)
      END IF

C  +--------------------------------+
C  | Set Equalizer OPEN/SHUT Flags |
C  +--------------------------------+

      IF (IEQLZR .EQ. 1 )THEN
         IEQL=1                !Equalizer Line Is Shut
      ELSE IF (IEQLZR .EQ. 2 )THEN
         IEQL=0                !Equalizer Line Is Open
      ELSE IF (IEQLZR .EQ. 0 )THEN
         IF (ELOC .EQ. OPEN )THEN
            IEQL=0
         ELSE
            IEQL=1
         END IF
      END IF

C  +----------------------------------+
C  | CALCULATE JET PUMP DRIVING FLOW |
C  +----------------------------------+
```

```
WD = 0.
DO I = 1, NPUMP              ! Number of Recirc Pump

     J = iWD +(I-1)*2          ! Drive Flow Index
   IF( RLA(I) .eq. ACTI ) THEN

      !Set the bad reading to the other good reading.
        !-------------------------------------------

      IF( (ILFLAG(J) .GT. 0) .AND. (ILFLAG(J+1) .EQ. 0) ) THEN
          PSC(J) = PSC(J+1)   ! next one is "good" status
      END IF

      IF( (ILFLAG(J+1).GT. 0) .AND. (ILFLAG(J) .EQ. 0) ) THEN
          PSC(J+1) = PSC(J)   ! previous one is "good" status
      END IF

      !If both readings are bad, set WD = -1.0
        !--------------------------------------

      IF( (PSC(J) .LE. 0.0) .AND. (PSC(J+1) .LE. 0.0) ) THEN
         IF ( WD_LOOP_FLAG(I) ) THEN
              WRITE(TEXT, '(A,I3,A)')
1           ' BOTH DRIVING FLOWS OF ACTIVE LOOP',I,' ARE BAD.'
              CALL LWRWERR (TEXT,'DUMY')
            CALL SEND LOG( '3DFMC028', TEXT )
            WD_LOOP_FLAG(I) = .false.
           END IF
       WD = -1.0          ! No Jetpump Driving Flow
       GO TO 1180         ! Bad WD value
      ELSE
         WD_LOOP_FLAG(I) = .true.
        END IF

      !Now compare both readings
        !------------------------

      TEM = ABS( PSC(J) - PSC(J+1) ) / WDNM(I)

      IF (EpsWD3D .eq. 0.0) EpsWD3D = 0.05      ! Set default to 0.05
      IF( TEM .GT. EpsWD3D ) THEN

      ! two readings are different to the level which
            ! exceeds the 5% range, so set to a bad reading
      !------------------------------------------------

        IF ( EPSWD3D_FLAG(I) ) THEN
              WRITE(TEXT, '(A,I3,A)')
1           ' DRIVE FLOWS OF LOOP',I,' DIFFER MORE THAN LIMIT'
              CALL LWRWERR (TEXT,'DUMY')
            CALL SEND LOG( '3DFMC028', TEXT )

              WRITE(TEXT, '(A,F6.4,A,F6.4)')
1           ' DIFFERNCE = ', TEM, ' LIMIT = ', EPSWD3D
```

```
              CALL LWRWERR (TEXT,'DUMY')
            CALL SEND LOG( '3DFMC028', TEXT )
            EPSWD3D_FLAG(I) = .false.
          END IF
      WD = -1.0
      GO TO 1180   ! Bad WD value
      ELSE
        EPSWD3D_FLAG(I) = .true.
        END IF

      ! If we are here, Both readings are good. Take the average
        !-------------------------------------------------------

      WD = WD + 0.5*( PSC(J) + PSC(J+1) )

     END IF

  END DO

1180 CONTINUE

C  +------------------------------------------------------+
C  |CALCULATE RECIRC FLOW INLET TEMPERATURE AND ENTHALPY |
C  +------------------------------------------------------+

      TD = 0.0
      HD = 0.0

      ! If the driving flow is bad, set Temperature TD
      ! and Enthalpy HD to bad

      IF(WD .LE. 0.0) THEN
         TD = -1.0      ! bad temp.
         HD = -1.0      ! bad enthalpy
         GO TO 1220
      END IF

      DO I = 1, NPUMP               ! Number of Recirc Pump

           J = iTD +(I-1)*2          ! Inlet Tempt. Index
         IF( RLA(I) .eq. ACTI ) THEN

           !Set the bad reading to the other good reading.
             !---------------------------------------------

           IF( (ILFLAG(J) .GT. 0) .AND. (ILFLAG(J+1) .EQ. 0) ) THEN
               PSC(J) = PSC(J+1)   ! next one is "good" status
           END IF

           IF( (ILFLAG(J+1).GT. 0) .AND. (ILFLAG(J) .EQ. 0) ) THEN
               PSC(J+1) = PSC(J)   ! previous one is "good" status
           END IF

           !If both readings are bad, set TD = -1.0
             !---------------------------------------
```

```
          IF( (PSC(J) .LE. 0.0) .AND. (PSC(J+1) .LE. 0.0) ) THEN
             IF ( TD_LOOP_FLAG(I) ) THEN
                  WRITE(TEXT, '(A,I3,A)')
     1    .     ' BOTH INLET TEMP OF ACTIVE LOOP ',I,' ARE BAD.'
                  CALL LWRWERR (TEXT,'DUMY')
                CALL SEND LOG( '3DFMC028', TEXT )
                TD_LOOP_FLAG(I) = .false.
               END IF
             TDT(I) = 0.0          ! Bad Inlet Temperature
           GO TO 1215
          ELSE
             TD_LOOP_FLAG(I) = .true.
            END IF

          !Now compare both readings
            !------------------------

          TEM = ABS( (PSC(J)/PSC(J+1)) - 1.0)

          IF (EpsTD3D .eq. 0.0) EpsTD3D = 0.03      ! Set default to 0.03
          IF( TEM .GT. EpsTD3D ) THEN

          ! two readings are different to the level which
                ! exceeds the 3% range, so set to a bad reading
          !------------------------------------------------

            IF ( EPSTD3D_FLAG(I) ) THEN
                  WRITE(TEXT, '(A,I3,A)')
     1          ' INLET TEMP OF LOOP',I,' DIFFER MORE THAN LIMIT'
                  CALL LWRWERR (TEXT,'DUMY')
                CALL SEND LOG( '3DFMC028', TEXT )

                  WRITE(TEXT, '(A,F6.4,A,F6.4)')
     1          ' DIFFERNCE = ', TEM, ' LIMIT = ', EPSTD3D
                  CALL LWRWERR (TEXT,'DUMY')
                CALL SEND LOG( '3DFMC028', TEXT )
                EPSTD3D_FLAG(I) = .false.
              END IF
            TDT(I) = 0.0           ! Bad Inlet Temperature
          GO TO 1215
          ELSE
            EPSTD3D_FLAG(I) = .true.
            END IF

          ! If we are here, Both readings are good. Take the average
            !----------------------------------------------------------

          TDT(I) = 0.5*(PSC(J)+PSC(J+1))
         ELSE
          TDT(I) = 0.0
       END IF

 1215  CONTINUE
```

```
  END DO                 ! End of Inlet Temp. Computation Loop

! Calculate Inlet Temp and Enthalpy as long as
! one loop has good reading
!----------------------------------------------

  JLOOP = 0
TD    = 0.0

DO I= 1, NPUMP
   IF (TDT(I) .GT. 0.0) THEN
        TD = TD + TDT(I)
        JLOOP = JLOOP +1
   END IF
END DO

! Test if all loops signal are bad
!-------------------------------

IF (JLOOP .EQ. 0) THEN

   ! All Inlet Termprature Readings aare bad.
   ! Set Tepmerature and Enthalpy to bad.
   !-----------------------------------------

   TD = -1.0
   HD = -1.0

ELSE

   TD = TD / JLOOP
         IF (IETCAL .EQ. 0) THEN
       HD = HSCF(PR,TD,HFT,TDIV,BTC)
     ELSE
       HD = HPTL(PR, TD)
     END IF

END IF

1220 CONTINUE

C  +---------------------------------------+
C  | Calculate Feedwater Temperature.       |
C  +---------------------------------------+

   ! If only one of the redundant feedwater temperature sensors is
   ! failed, set the failed sensor reading equal to the non-failed
   ! sensor reading.
   !-------------------------------------------------------------

   DO I=1, NFWB
      IF( FWBA(I) .EQ. ACTI ) THEN    ! Branch is Active
           J = iTFW +(I-1)*2          ! FW temperature PSC base index
         IF( (ILFLAG(J) .GT. 0) .AND. (ILFLAG(J+1) .EQ. 0) ) THEN
             PSC(J) = PSC(J+1)  ! next one is "good" status
```

```
        END IF

        IF( (ILFLAG(J+1).GT. 0) .AND. (ILFLAG(J) .EQ. 0) ) THEN
            PSC(J+1) = PSC(J)   ! previous one is "good" status
        END IF

        !If both readings are bad for any one of the active
        !branch, then set the CTP flag to unkown
          !----------------------------------------------------

        IF( (PSC(J) .LE. 0.0) .AND. (PSC(J+1) .LE. 0.0) ) THEN
          KCTP = 2                      ! 2 = CTP unknown
              TFWSUB(I) = 0.0                        ! No Good Data
        ELSE                            ! Branch is Inactive
              TFWSUB(I) = (PSC(J)+PSC(J+1))/2.  ! Take average value
        END IF
     ELSE                                ! Branch is Inactive
          TFWSUB(I) = 0.0                ! set 0.0 for inactive branch
     END IF
    END DO

C  +--------------------------------+
C  | Calculate feedwater flow rate. |
C  +--------------------------------+

      LOC = iWFW-1  ! = NCUB+5*NPUMP+2*NFWB+NGEN+8 ! FW flow PSC base index -1

      DO I = 1, NFWB

         IF( FWBA(I) .EQ. ACTI ) THEN

           !If the reading is bad for the active
           !branch, then set the CTP flag to unkown
             !----------------------------------------

           IF( PSC(LOC+I) .LT. 0.0 ) THEN        ! failed or removed
            KCTP = 2                          ! 2 = CTP unknown
           ELSE
              TEM = ABS( WAVX(I) - PSC(LOC+I) ) / FWNM(I)
            IF(TEM .GT. EPSWFW) THEN
              ILFLAG(LOC + I)    = 4           ! bad FW digital reading
              KCTP = 2                ! 2 = CTP unknown
              NFSL = NFSL + 1
              IF (NFSL .LE. NFSEDZ) IFSL(NFSL) = NSC - NFWB + I
                IF ( EPSWFW_FLAG(I) ) THEN       ! Send Warning Message
                      WRITE(TEXT, '(A,I3,A)')
     1               ' FEEDWATER FLOW BRANCH ',I,
     2               ' DIFFER MORE THAN LIMIT'
                      CALL LWRWERR (TEXT,'DUMY')
                   CALL SEND LOG( '3DFMC028', TEXT )

                      WRITE(TEXT, '(A,F6.4,A,F6.4)')
     1               ' DIFFERNCE = ', TEM, ' LIMIT = ', EPSWFW
                      CALL LWRWERR (TEXT,'DUMY')
                   CALL SEND LOG( '3DFMC028', TEXT )
```

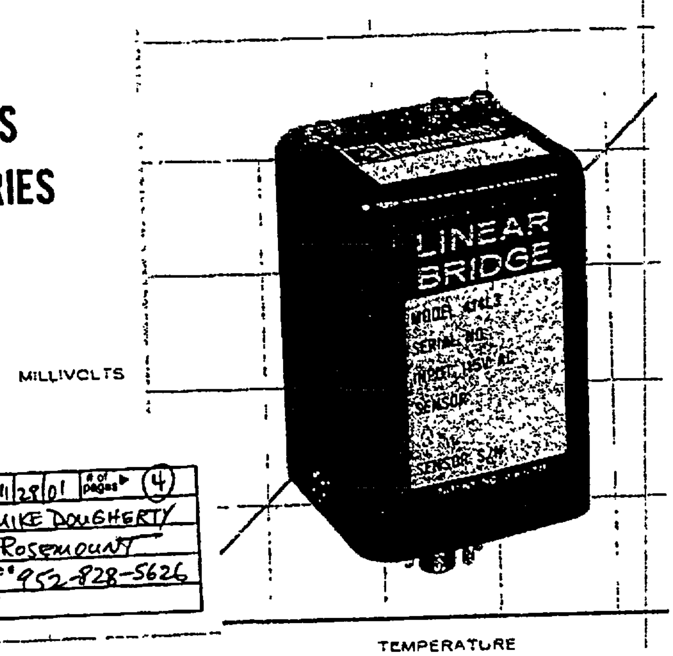
```
                EPSWFW_FLAG(I) = .FALSE.
              END IF
          ELSE
            EPSWFW_FLAG(I) = .TRUE.
          END IF
       END IF

     ELSE

       WAVX(I) = 0.0

       END IF

     WFWSUB(I) = WAVX(I)

    END DO

C  +-----------------------------------------------------+
C  | Evaluate the status of other sensors required for  |
C  | Heat balance calculation. If bad, set KCTP = 2     |
C  +-----------------------------------------------------+

      ! Check that the following PSC data required for CTP
      ! calculation is available: WCR, TCR, WCU( ncub ), TCU1, TCU2,
      ! PPW( npump ), PRG. Note, PSC data for TFW1/2( nfwb ) and
      ! WFW( nfwb ) have all ready been checked as reflected by
      ! KCTP = 2 if they are unavailable.
        !-------------------------------------------------------------

      DO I= 1, iPR
         IF (PSC(i) .EQ. -1.0 )  KCTP = 2        ! 2 = CTP unknown
      END DO

C  +--------------------------------------------------------------------+
C  | Set CTP calculations to default values for unknown CTP condition |
C  +--------------------------------------------------------------------+

      IF (KCTP .EQ. 2) THEN

         CTP          =  0.0     ! RP6( 2 )
         HG      =  0.0  ! RP6( 10 )
         HS      =  0.0  ! RP6( 11 )
         HF      =  0.0  ! RP6( 12 )
         HFG     =  0.0  ! RP6( 13 )
         WFW     =  0.0  ! RP6( 16 )
         TFW     =  0.0  ! RP6( 17 )
         HFW     =  0.0  ! RP6( 18 )
         QFW     =  0.0  ! RP6( 19 )
         QP      =  0.0  ! RP6( 23 )
         HCU1    =  0.0  ! RP6( 32 )
         HCU2    =  0.0  ! RP6( 33 )
         QCU     =  0.0  ! RP6( 34 )
         HCR     =  0.0  ! RP6( 37 )
         QCR     =  0.0  ! RP6( 38 )
```

```
         GO TO 8000      ! Rturn with good status

      END IF

C  +---------------------------------------------------------------+
C  |  If we are here, we got good status and reading of scan data.|
C  +---------------------------------------------------------------+

      ! Calculate Feedwater flow by adding all active branches.
      ! Use Degital Average Feedwater flow.
      !----------------------------------------------------------

        WFW = 0.0
      DO I=1,NFWB
         IF( FWBA(I) .EQ. ACTI ) WFW = WFW + WAVX(I)
      END DO

C  +----------------------------------+
C  |  Calculate energy balance terms.  |
C  +----------------------------------+

      ! If IETCAL .EQ. 0 then use old STEAM TABLE which is based on FITS to
      ! either KEENAN and KEYES or ASME data; otherwise use new STEAM TABLE
      ! which is based on the ASME (or PANACEA model) data.
      !-------------------------------------------------------------------

      ! saturated steam enthalpy
      !------------------------

        IF (IETCAL .EQ. 0) THEN
          HG = HGSF(PR,HGC,PLHG)                    ! saturated steam
        ELSE
          HG = HGP(PR)
        END IF

      ! saturated liquid steam enthalpy
      !-------------------------------

        IF (IETCAL .EQ. 0) THEN
          HF = HFC (1) + (HFC(2) + HFC(3)*PR)*PR  ! saturated liquid
        ELSE
          HF = HFP(PR)
        END IF

      HFG = HG - HF                            ! vaporization

      ! Subcooled water (Feedwater) enthalpy
      !--------------------------------------

        DO I = 1, NFWB
          IF (FWBA(I) .EQ. ACTI) THEN
           IF (IETCAL .EQ. 0) THEN
               HFWSUB(I) = HSCF (PR, TFWSUB(I), HFT, TDIV, BTC)
             ELSE
               HFWSUB(I) = HPTL (PR, TFWSUB(I))    ! subcool liquid
```

```
      END IF
   ELSE
      HFWSUB(I) = 0.0                        ! inctive branch
   END IF
 END DO

! Control Rod Drive Flow enthalpy
!--------------------------------

IF (IETCAL .EQ. 0) THEN
   HCR = HSCF (PR,TCR,HFT,TDIV,BTC)        ! Cont. Rod Driv
 ELSE
   HCR = HPTL(PR, TCR)
 END IF

! Cleanup loop inlet enthalpy
!-----------------------------

IF (IETCAL .EQ. 0) THEN
   HCU1 = HSCF (PR,TCU1,HFT,TDIV,BTC)      ! Cleanup loop inlet
 ELSE
   HCU1 = HPTL(PR, TCU1)
 END IF

! Cleanup loop exit enthalpy
!-----------------------------

IF (IETCAL .EQ. 0) THEN
   HCU2 = HSCF (PR,TCU2,HFT,TDIV,BTC)      ! Cleanup loop exit
 ELSE
   HCU2 = HPTL(PR, TCU2)
 END IF

HS = HG - FM*HFG
IF (C1 .EQ. 0.0) C1 = 3.413           !  MBTU/MWH CONVERSION FACTOR

QCR = WCR*(HS-HCR)/C1
QCU = WCU*(HCU1-HCU2)/C1

! Energy added to Recirc Pumps
!-----------------------------

QP = 0.
DO I=1,NPUMP
   QP = QP + PPW(I)*ETA1
END DO

! Feedwater water
!----------------

JLOOP = 0
  TFW = 0.
  HFW = 0.

  IF (SR1OPT1) THEN    ! simple averaging
```

```
          DO I = 1, NFWB
               IF (FWBA(I) .EQ. ACTI) THEN
                   TFW = TFW + TFWSUB(I)
                   HFW = HFW + HFWSUB(I)
                   JLOOP = JLOOP + 1
               END IF
            END DO
          IF ( JLOOP .GT. 0 ) THEN    ! Avoid devid by zero
               TFW = TFW/JLOOP
               HFW = HFW/JLOOP
          ELSE
               TFW = 0.0
               HFW = 0.0
          END IF
         ELSE
            DO I = 1, NFWB     ! wfwsub(i) = 0 for inactive branches
               TFW = TFW + TFWSUB(I)*WFWSUB(I)
               HFW = HFW + HFWSUB(I)*WFWSUB(I)
            END DO

          IF (WFW .GT. 0.001) THEN    ! Avoid devid by zero
               TFW = TFW / WFW
               HFW = HFW / WFW
          ELSE
               TFW = 0.0
               HFW = 0.0
          END IF
         END IF

        QFW = WFW*(HS-HFW)/C1

C   +------------------------------------+
C   |  Now calculate Core Thermal Power  |
C   +------------------------------------+

        CTP = QFW+QCR+QCU+QRADX-QP

C   +-----------------+
C   |  Return Status  |
C   +-----------------+

 8000 continue

        ERROR_CODE = 0

        RETURN                  ! NORMAL RETURN

 9000 CONTINUE

        ERROR_CODE = 1          ! G3P6 WILL TERMINATE

        RETURN                  ! FATAL ERROR RETURN

        END
```

MODEL 414L LINEAR BRIDGES AND ACCESSORIES



Post-it® Fax Note 7671	Date 11/28/01 # of pages ▸ (4)
To KIRK MELSON	From MIKE DOUGHERTY
Co./Dept	Co. ROSEMOUNT
Phone #	Phone # 952-828-5626
Fax # 864-962-5920	Fax #

Linear mv/degree output for computer input or digital indication

Accurate to 0.1% with platinum RTD's

DESCRIPTION

The Model 414L Linear Bridge* converts the resistance of a platinum resistance temperature sensor to a millivolt per degree output signal. The output is zero millivolts at zero degrees (F or C). The slope of the output is one millivolt per degree within the non-linearity tolerance shown in the ordering information. When the output of a linear bridge is interfaced with a millivolt readout device, that device becomes a direct reading temperature indicator.

The millivolt/degree output is ideal for use in computer systems because the signal does not require storage space for correction factors.

Differential temperature measurements can be made by using two linear bridges as shown on page 2.

Rosemount

*U.S. PATENT NO. 3,406,331

NOV-28-2001 12:24 ROSEMOUNT NUCLEAR 6128288280 P.02

ORDERING INFORMATION

Available from stock except as noted.

MODEL	
414L	LINEAR BRIDGE

CODE	INPUT VOLTAGE
2	28 VDC
3	115 VAC

CODE	SENSOR R_o
A	100 Ω
**B	200 Ω
*C	400 Ω
*D	500 Ω
*E	1000 Ω
*H	50 Ω

Bridges are properly trimmed to mate with sensors purchased on the same order. Provide model and serial numbers for Rosemount sensors purchased on a different order. Provide complete R vs T information for platinum sensors not manufactured by Rosemount.
Calibration data sheets accompanying each bridge completely identify the mating sensors.

CODE	LOAD RESISTANCE
A	10 KΩ
B	25 KΩ
C	50 KΩ
D	100 KΩ
E	500 KΩ
F	1 megΩ
G	10 megΩ

Load resistance means the input resistance of your DVM, DPM, A/D convertor or recorder. (Note: Slide wire recorders are usually infinite ohms at null. Specify 10 megohms as the load.)

CODE	RANGE	NON-LINEARITY (MAX.)
A	-100 to +500° F	±0.03%
B	0 to +1000° F	±0.06%
D	-350 to +1000° F	±0.17%
*E	0 to +1350° F	±0.10%
F	-200 to +500° C	±0.17%
G	-100 to +200° C	±0.03%
H	0 to +200° C	±0.03%
J	0 to +500° C	±0.06%
*K	0 to +750° C	±0.10%

414L— 3— A— G— A ← TYPICAL MODEL NUMBER

ACCESSORIES

ITEM	SPECIFY MODEL NO
Socket	420-8
Single Channel Chassis	420S
Six Channel Chassis	420L
Selector Switch Kit	420-14
420L with Selector Switch Kit Installed (5 Channel Capacity)	420L-14

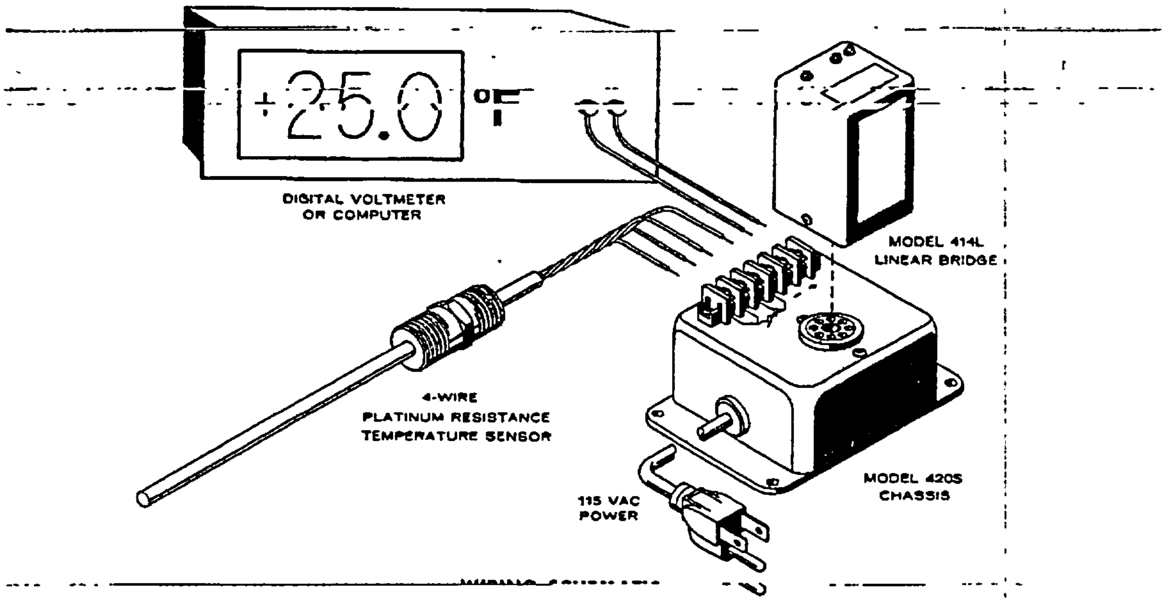
* These options are not stocked.

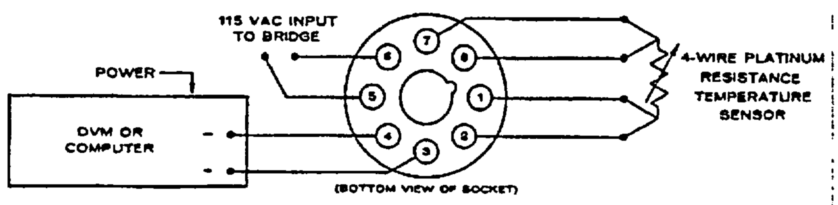
** 200Ω R_o stocked for temperature range "A" only.

Rosemount Inc.

POST OFFICE BOX 35129 MINNEAPOLIS MINNESOTA 55435
PHONE: (612) 941 5560 TWX 910-576-3103 TELEX: 29-0183 CABLE: ROSEMOUNT

TYPICAL INSTALLATION





SPECIFICATIONS

ACCURACY ±0.1% of span

OUTPUT 1 mv/°F or °C

INPUT POWER

115 VAC, ±10%, 50/60 Hz or 28 VDC.

EFFECT OF INPUT POWER VARIATIONS

Output will not shift by more than 0.01% for a ±10% line change.

AMBIENT TEMPERATURE 40° to 140°F.

EFFECT OF AMBIENT TEMPERATURE

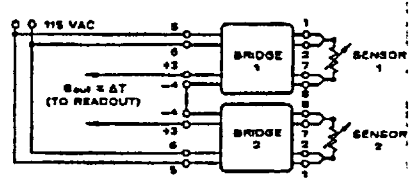
±0 005°/°F change in ambient temperature

LEADWIRE EFFECT

Output will not change by more than 0 05° for a ±2Ω change in 3Ω of balanced sensor leadwires.

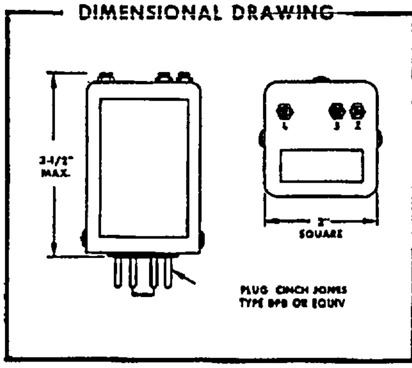
DIFFERENTIAL OPERATION

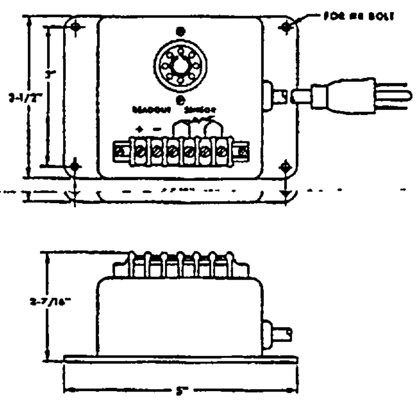
Differential Temperatures can be measured by connecting the negative output terminals of two 414L3's and connecting the readout between their positive terminals.



NOTE: The readout device must have one megohm or greater input impedance for ΔT operation. The absolute temperature readings from each bridge are not affected by the ΔT connection.

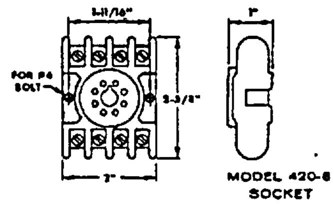
DIMENSIONAL DRAWING





MODEL 420S CHASSIS

ACCESSORIES



MODEL 420-8 SOCKET

MODEL 420-8 SOCKET

The Model 420-8 Socket offers a simple way to mount the Model 414L in cabinets or on the back of panels. A protective strip, marked with a connection diagram, covers the power terminals.

MODEL 420S CHASSIS

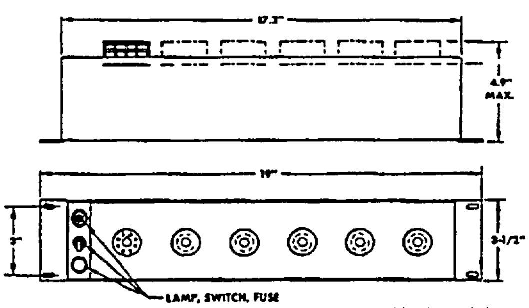
The Model 420S Chassis includes a line cord and fully-enclosed 115 volt power connection for bench or panel mounting one Model 414L3 bridge. A terminal strip provides connection points for the sensor and signal leadwires.

MODEL 420L CHASSIS

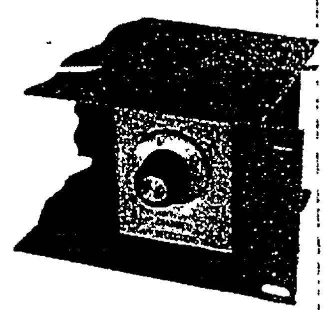
The Model 420L Chassis holds up to six 414L3 bridges and has a three-wire line cord, switch, fuse and pilot light. The chassis fits in a standard 19-inch relay rack and has rear-mounted terminal strips.

MODEL 420-14 SWITCH KIT

A modification kit for the 420L Chassis, the Model 420-14 replaces the 6th socket and provides switch selected output of the other five bridges to a common pair of output terminals. Available as a kit or factory installed.



MODEL 420L CHASSIS



MODEL 420-14 SWITCH

Feedwater Flow Differential Pressure Transmitter Calibration Computations

Unit 1 Transmitter A Tap Set 1

Feedwater Temp	397.5	deg F
Total FW Flow	1.15140E+07	lbm/hr
FW Flow per Loop	5.75700E+06	lbm/hr
Upstream Tap Pressure	1116	psia
vf1	0.0185018	lbm/ft^3
D1	54.04879525	ft^3/lbm
vt	0.0185018	lbm/ft^3
qr	5.75700E+06	lbm/hr
g	32.137	ft/sec^2
Alpha	9.16900E-06	in/in/deg F
Fa	1.006051499	
d	7.737	inches
Beta	0.4999	
mu	2.77800E-06	lbf-sec/ft^2
Rr	3.53321E+07	
Cavg	0.9918	
Ravg	4.21910E+06	
Cr	0.994339104	
hr	1245.816943	inWC
hs	2405.70	inWC
SPE	1.45	%/1000psi
CF	0.01596885	
hsc	2367.889084	inWC

Unit 1 Transmitter B Tap Set 1

Feedwater Temp	397.5	deg F
Total FW Flow	1.15140E+07	lbm/hr
FW Flow per Loop	5.75700E+06	lbm/hr
Upstream Tap Pressure	1116	psia
vf1	0.0185018	lbm/ft^3
D1	54.04879525	ft^3/lbm
vt	0.0185018	lbm/ft^3
qr	5.75700E+06	lbm/hr
g	32.137	ft/sec^2
Alpha	9.16900E-06	in/in/deg F
Fa	1.006051499	
d	7.7405	inches
Beta	0.4999	
mu	2.77800E-06	lbf-sec/ft^2
Rr	3.53161E+07	
Cavg	0.9933	
Ravg	4.90260E+06	
Cr	0.99562174	
hr	1240.363154	inWC
hs	2395.17	inWC
SPE	1.45	%/1000psi
CF	0.01596885	
hsc	2357.523221	inWC

Unit 2 Transmitter A Tap Set 2

Feedwater Temp	425.1	deg F
Total FW Flow	1.19500E+07	lbm/hr
FW Flow per Loop	5.97500E+06	lbm/hr
Upstream Tap Pressure	1122	psia
vf2	0.018909356	lbm/ft^3
D2	52.88387399	ft^3/lbm
vt	0.018909356	lbm/ft^3
qr	5.97500E+06	lbm/hr
g	32.137	ft/sec^2
Alpha	9.22600E-06	in/in/deg F
Fa	1.006600064	
d	7.775	inches
Beta	0.5161	
mu	2.57500E-06	lbf-sec/ft^2
Rr	3.93675E+07	
Cavg	0.9968	
Ravg	4.41140E+06	
Cr	0.999376607	
hr	1317.869158	inWC
hs	2362.53	inWC
SPE	1.45	%/1000psi
CF	0.01605585	
hsc	2325.19226	inWC

Unit 2 Transmitter B Tap Set 2

Feedwater Temp	425.1	deg F
Total FW Flow	1.19500E+07	lbm/hr
FW Flow per Loop	5.97500E+06	lbm/hr
Upstream Tap Pressure	1122	psia
vf2	0.018909356	lbm/ft^3
D2	52.88387399	ft^3/lbm
vt	0.018909356	lbm/ft^3
qr	5.97500E+06	lbm/hr
g	32.137	ft/sec^2
Alpha	9.22600E-06	in/in/deg F
Fa	1.006600064	
d	7.775	inches
Beta	0.515	
mu	2.57500E-06	lbf-sec/ft^2
Rr	3.93675E+07	
Cavg	1.0003	
Ravg	4.18720E+06	
Cr	1.002952824	
hr	1309.336864	inWC
hs	2347.23	inWC
SPE	1.45	%/1000psi
CF	0.01605585	
hsc	2310.138243	inWC

Attachment D

Tabulation of On-Line Plant Computer Heat Balance Parameters

Date/Time	B015	B016	B018	B019	B020	B023	B024	B025	B030	B031	B032	B033	ACRDTEMP	B014
11/1 0·00	5.957	6 062	0.09	3.326	3 387	536 404	438.673	1034.619	426.889	426.413	426.786	427.089	125.247	0.026
11/1 0.01	5.91	6 026	0.091	3 313	3.391	536.404	438 589	1034.802	426.986	426 511	426.942	427.206	125.355	0.026
11/1 0 02	5 876	5.986	0 09	3.313	3.413	536.404	438 673	1034.802	426.869	426.433	426.766	427.011	125.247	0.026
11/1 0.03	5.904	6.1	0 09	3.33	3.409	536.404	438.673	1034.435	426.928	426.433	426 825	427.069	125.355	0.026
11/1 0 04	5.928	6 04	0 09	3.329	3 394	536.324	438.673	1034.435	426.791	426.374	426.688	426.972	125.355	0.026
11/1 0:05	5.938	6 032	0.09	3 314	3 4	536.404	438.504	1034 619	426.732	426.374	426.649	426.933	125.355	0 026
11/1 0.06	5.925	6 077	0.091	3 326	3 377	536.324	438.589	1034.435	426.908	426 433	426.805	427.089	125.247	0.026
11/1 0.07	5.975	6.053	0 09	3.314	3.391	536 404	438 504	1034.802	426.928	426.511	426.864	427.089	125.355	0 026
11/1 0 08	5.938	6.055	0.09	3.335	3.4	536.404	438.673	1034.802	427.025	426 55	426 962	427.225	125.355	0 026
11/1 0 09	5.958	6.056	0 09	3 314	3.388	536.404	438.589	1034.619	426 83	426.452	426.766	427.05	125.247	0.026
11/1 0:10	5.884	6 051	0.091	3.314	3 397	536.404	438.589	1034.802	426.791	426.413	426.727	427.011	125 247	0.026
11/1 0·11	5.91	6.027	0 09	3.308	3 392	536 404	438.673	1034.802	427.006	426.491	426.922	427.167	125.247	0.026
11/1 0:12	5.949	6 075	0 09	3 343	3.388	536.404	438.589	1034 985	427.006	426.491	426.922	427.206	125.247	0.026
11/1 0:13	5.971	6 004	0.09	3.36	3 4	536.404	438.589	1034.802	427.045	426 55	426.942	427.186	125.247	0.026
11/1 0:14	5.949	6.054	0.09	3.359	3.377	536.404	438.673	1034.802	427.006	426 53	426.922	427.225	125.247	0.026
11/1 0:15	5.906	6.032	0.09	3 343	3.393	536.485	438 673	1034.985	426.928	426.472	426.805	427.069	125.355	0 026
11/1 0:16	5.929	6.057	0 09	3.361	3 402	536.404	438.758	1034.985	426 869	426.452	426.786	427.03	125 247	0.026
11/1 0:17	5.952	6.054	0 09	3.353	3.394	536.404	438.589	1034.802	427.025	426.55	426.903	427.186	125.355	0.026
11/1 0:18	5.914	6 024	0.09	3.346	3.408	536.404	438.504	1034.985	426.791	426 413	426.747	427.05	125.355	0 026

Parameter	FW Flow Loop A, Mlbm/hr	FW Flow Loop B, Mlbm/hr	RWCU Flow Mlbm/hr	Recirc PP Mtr A Pow MW	Recirc PP Mtr B Pow MW	RWCU Inlt Tmp Deg F	RWCU Outl Tmp Deg F	Rx Pressure PSIG	FW Temp A1 Deg F	FW Temp A2 Deg F	FW Temp B1 Deg F	FW Temp B2 Deg F	All 4 FW Temps Deg F	CRD Syst Temp, Deg F	CRD Flow Mlbm/hr
Mean	5.930158	6 045526	0.090158	3.331632	3.394789	536.3998	438 6198	1034.754	426.9133	426.4656	426.8278	427.0981	426.8262	125.2981579	0.026
St Dev	0 027811	0.026364	0.000375	0 018133	0.009641	0.032517	0 070163	0.18168	0.09523	0.057547	0 093708	0.089824	0.246183	0 055402831	0
2 Std Devs	0.055623	0.052727	0.000749	0 036266	0 019282	0.065034	0.140325	0.36336	0.190459	0.115095	0.187417	0.179648	0.492366	0.110805662	0
Min	5.876	5 986	0.09	3.308	3.377	536 324	438.504	1034.435	426.732	426.374	426.649	426.933	426.374	125.247	0 026
Max	5.975	6.1	0 091	3.361	3 413	536.485	438.758	1034.985	427.045	426 55	426.962	427.225	427.225	125.355	0.026
Range	0 099	0 114	0.001	0 053	0 036	0.161	0.254	0.55	0.313	0.176	0 313	0 292	0.851	0.108	0
No. Readings	19	19	19	19	19	19	19	19	19	19	19	19	76	19	19
Heat Bal Value	5.975	5.975	0.1	4.3224	4.3224	533.7	436.8	1035	425.1	425.1	425.1	425.1	425.1	123 5	0.03

Attachment E

Hatch Feedwater Flow Correction and Digital Filtering Algorithms

The equation for calculating Feedwater Flow for a single loop is

$$FWLoopNFlow\_corrected = [1 + C1 * (\Delta T) + C2 * (\Delta T) ** 2] * FWLoopNFlow$$

Output point ID's are C51C7001 for Loop A and C51C7002 for Loop B (used later)

where

N = Loop Identifier (A or B)

$$\Delta T = (FWLoopTempN - RatedFWTemp)$$

$$FWLoopTempN = (FWLoopTemp1N + FWLoopTemp2N)/2$$ Average FW Temperature

C1 and C2 are constants based on the expansion properties of the venturi throat.

INPUT Point ID's for the algorithm are

$FWLoopTemp1A = B030$
$FWLoopTemp2A = B031$ FOR LOOP A

$FWLoopTemp1B = B032$
$FWLoopTemp2B = B033$ FOR LOOP A

$FWLoopAFlow = B015$
$FWLoopBFlow = B016$ B015 and B016 are RAW Feedwater Flows in mlb/hr

UNIT CONSTANTS FROM THE POINT DEFINITION DATABASE

UNIT	C1	C2	Rated FW Temp
1	-0.3485E-03	-0.4156E-06	393.0
2	-0.3858E-03	-0.4481E-06	424.0

Each Corrected FW Loop Flow is "composed" once every 4 seconds. On the same frequency, the each corrected FW Loop Flow is "smoothed"/digitally filtered according to the following algorithm*:

$$C51C7001\_sm = [prevC51C7001\_sm * (Sm\_factor - 1)] + C51C7001\_sm] / Sm\_factor$$

Smoothing factor is 15 for both units.

*(database algorithm ID "N20" – GE Doc # 23A5250, sheet 184 section 30.4.1.12)

 RL Miller 12/16/2002