Enclosure 14

Calculation SC-BB-0525, "Hope Creek Heat Balance Uncertainty Calculation", Revision 5

Design Analysis Major Revision Cover Sheet

Design Analysis (Major Revision)		**Last Page No.** [6] Attachment 8 page 1	
Analysis No.: [1]	SC-BB-0525	**Revision:** [2]	5
Title: [3]	Hope Creek Heat Balance Uncertainty Calculation		
DCP No(s)./ Revision: [4]	80116312 R0	**AD No(s)./ Revision:** [5]	I50 R0

Station(s): [7]	Hope Creek	**Component(s):** [14]	
Unit No.: [8]	1		
Discipline: [9]	I		
Safety/QA Class: [11]	Important to Safety		
System Code: [12]	BB		
Structure: [13]			

CONTROLLED DESIGN INPUTS AND OUTPUTS [15]

Document No.:	From/To	Document No.:	From/To
SC-AE-0540	From	SC-AE-0541	From
SC-BB-0355	From	SC-BG-0516	From
SC-BF-0511	From	SC-BB-0526	From
SC-BG-0515	From	432792 Sheet 001	From

Is this Design Analysis Safeguards Information? [16] Yes ☐ No ☒ If yes, see SY-AA-101-106

Does this Design Analysis contain Unverified Assumptions? [17] Yes ☐ No ☒ If yes, Order#:

This Design Analysis SUPERCEDES: [18] 4 **in its entirety.**

Description of Revision (list affected pages for partials): [19]
This revision is to increase the thermal power level from 3840 to 3902 in response to the MUR uprate per Appendix K. Attachments have been added for the various mode of operation of the LEFM. The attachments have been reordered as follows:
Attachment 1 is now the Heat Balance Calculation with a Normally Operating LEFM
Attachment 2 is the Heat Balance Calculation with a LEFM in Maintenance Mode (new attachment)
Attachment 3 is the Heat Balance Calculation without Taking Credit for the Operation of the LEFM
Attachment 4 is the FFWTR Heat Balance Calculation with a Normally Operating LEFM (new attachment)
Attachment 5 is the FFWTR Heat Balance Calculation with a LEFM In Maintenance Mode (new attachment)
Attachment 6 is the FFWTR Heat Balance Calculation without Taking Credit for the Operation of the LEFM (previously attachment 4)
Attachment 7 is the General Electric Reactor Heat Balance Power Uprate (previously attachment 2)
Attachment 8 is the General Electric Reactor Heat Balance For Final Feedwater Temperature Reduction Operation (previously attachment 5)
Note that the revision bars in the attachments identify the content change from the previous attachment and does not identify the formatting changes with the rearrangement of the calculation.

Preparer: [20]	Michael Miller (S&L)		3/16/17
	Print Name	Sign Name	Date
Method of Review: [21]	**Detailed Review** ☒	**Alternate Calculations (attached)** ☐	**Testing** ☐
Reviewer: [22]	John Wilkens (S&L)		3/16/17
	Print Name	Sign Name	Date
Review Notes: [23]	Independent review ☒ Peer review ☐		
	Performed detailed line-by-line review.		
(For External Analyses Only) **External Approver:** [24]	R. Master (S&L)		3/16/17
	Print Name	Sign Name	Date
PSEG Reviewer: [26]	S. Brahma		3/17/17
	Print Name	Sign Name	Date
Independent 3rd Party Review Reqd? [26]	Yes ☐ No ☒		
PSEG Approver: [27]	Shawn Madden		3/17/17
	Print Name	Sign Name	Date

Attachment 1, General Review Questions

DESIGN ANALYSIS NO. SC-BB-0525 **REV:** 5

		Yes	No	N/A
1.	Does the Design Analysis conform to design requirements?	☒	☐	☐
2.	Does the Design Analysis conform to applicable codes, standards, and regulatory requirements?	☒	☐	☐
3.	Have applicable design and safety limits been identified?	☒	☐	☐
4.	Is the analysis method appropriate?	☒	☐	☐
5.	Are the methods used and recommendations given conservative relative to the design and safety limits?	☒	☐	☐
6.	Are assumptions/Engineering Judgments explained and appropriate?	☒	☐	☐
7.	Have appropriately verified Computer Program and versions been identified, when applicable?	☐	☐	☒
8.	Does the Computer Program conform with the NRC SER or similar document when applicable?	☐	☐	☒
9.	Has the input been correctly incorporated into the Design Analysis?	☒	☐	☐
10.	Has the input been reviewed by all cognizant design authorities?	☒	☐	☐
11.	Are the analysis outputs and conclusions reasonable compared to the inputs and assumptions?	☒	☐	☐
12.	Are the recommendations/results/conclusions reasonable based on previous experience?	☒	☐	☐
13.	Has a verification of the Design Analysis been performed by alternate methods?	☐	☐	☒
14.	Has all input data been used correctly and is it traceable?	☒	☐	☐
15.	Has the effect on plant drawings, procedures, databases, and/or plant simulator been addressed?	☒	☐	☐
16.	Has the effect on other systems been addressed?	☒	☐	☐
17.	Have any changes in other controlled documents (e.g. UFSAR, Technical Specifications, Core Operating Limits Report (COLR), etc.) been identified and tracked?	☒	☐	☐
18.	When applicable, are the analysis results consistent with the proposed license amendment?	☒	☐	☐
19.	Have other documents that have used the calculation as input been reviewed and revised as appropriate?	☒	☐	☐
20.	Have all affected design analyses been documented on the Affected Documents List (ADL) for the associated Configuration Change?	☒	☐	☐
21.	Do the sources of inputs **and** analysis methodology used meet current technical requirements and regulatory commitments? (If the input sources **or** analysis methodology are based on an out-of-date methodology or code, additional reconciliation may be required if the site has since committed to a more recent code)	☒	☐	☐
22.	Have supporting technical documents and references been reviewed when necessary?	☒	☐	☐

Attachment 2, Owners Acceptance Review Checklist for External Design Analysis
SAP Standard Text Key "NDAEXT"

DESIGN ANALYSIS NO. SC-BB-0525 **REV:** 5

		Yes	No	N/A
1.	Do assumptions have sufficient rationale?	☒	☐	☐
2.	Are assumptions compatible with the way the plant is operated and with the licensing basis?	☒	☐	☐
3.	Do the design inputs have sufficient rationale?	☒	☐	☐
4.	Are design inputs correct and reasonable?	☒	☐	☐
5.	Are design inputs compatible with the way the plant is operated and with the licensing basis?	☒	☐	☐
6.	Are Engineering Judgments clearly documented and justified?	☐	☐	☒
7.	Are Engineering Judgments compatible with the way the plant is operated and with the licensing basis?	☐	☐	☒
8.	Do the results and conclusions satisfy the purpose and objective of the Design Analysis?	☒	☐	☐
9.	Are the results and conclusions compatible with the way the plant is operated and with the licensing basis?	☒	☐	☐
10.	Does the Design Analysis include the applicable design basis documentation?	☒	☐	☐
11.	Have any limitations on the use of the results been identified and transmitted to the appropriate organizations?	☒	☐	☐
12.	Are there any unverified assumptions?	☐	☒	☐
13.	Do all unverified assumptions have a tracking and closure mechanism in place?	☐	☐	☒
14.	Have all affected design analyses been documented on the Affected Documents List (ADL) for the associated Configuration Change?	☒	☐	☐
15.	Do the sources of inputs **and** analysis methodology used meet current technical requirements and regulatory commitments? (If the input sources **or** analysis methodology are based on an out-of-date methodology or code, additional reconciliation may be required if the site has since committed to a more recent code)	☒	☐	☐
16.	Have vendor supporting technical documents and references (including GE DRFs) been reviewed when necessary?	☒	☐	☐
17.	Has the Vendor supplied the **native** electronic file(s)?	☐	☐	☒

PSEG REVIEWER: S. Brahma / Sbrahma **DATE:** 3/17/17
Print / Sign

CALC. No.: SC-BB-0525			REFERENCE:				
ORIGINATOR, DATE:	REV	MTM 02/14/17	5				
REVIEWER/VERIFIER, DATE		JW 02/28/17					

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ATTACHMENTS	Number of Pages
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1.0 PURPOSE

The purpose of this calculation is to determine the uncertainty in the heat balance calculation performed by the plant computer taking credit for the operation of the LEFM Check Plus in Attachment 1. The calculation without the LEFM Check Plus is provided in Attachment 3 and the calculation with the LEFM in maintenance mode is provided in Attachment 2. In each mode of operation, this calculation shows that margin exists for the calculated measurement uncertainty between the power levels defined in the Operating License and the accident analyses performed at 2% above the pre-MUR uprate power. This calculation also provides the basis for the Maintenance mode power level, which is set at the highest whole MWt power level which produces positive margin.

2.0 FUNCTIONAL DESCRIPTION/ DESIGN BASIS

2.1 Functional Description

The Core Thermal Power is determined by a heat balance calculation performed in the secondary system. The heat balance accounts for heat added and lost into the "system" as depicted in the loop diagram in Section 4.0. The calculated power by the secondary heat balance is utilized to calibrate the Neutron Monitoring System.

2.2 Design Basis

Hope Creek current design basis, for the most part, is based on reactor power greater than or equal to 102% of the licensed reactor thermal power for the Nuclear Steam Supply System (NSSS) and Emergency Core Cooling System (ECCS) design and 105% steam flow for the Balance of Plant (BOP) design (UFSAR Chapter 1.1, 5.4, 6.2, 6.3, 10 and 15). The plant has been licensed to operate at less than 2% total uncertainty based on installation of an LEFM CheckPlus ultrasonic flow meter. Two uprated power levels are defined; one is based on a fully functional flow meter with two operable measurement planes, the second is based on the LEFM flow meter operating with one plane out of service (maintenance mode). In the event of a failure of both LEFM measurement planes or other system-level failure, the plant will operate using venturi measurements for flow with an allowance for 2% total uncertainty.

3.0 REFERENCES

3.1 Updated Final Safety Analysis Report

3.1.1 Figure 1.1-1, UFSAR Rev. 10 September 30, 1999, Heat Balance at Rated Power
3.1.2 Table 4.4-1, UFSAR Rev. 0 April 11, 1988, Thermal Hydraulic Design Characteristics of the Reactor Core
3.1.3 Section 5.1.11, Reactor Water Cleanup System
3.1.4 Section 5.4.8, Reactor Water Cleanup System
3.1.5 Section 4.1.1, Information for the CRD System
3.1.6 Section 7.5.1.3.3, Plant Computer System
3.1.7 Section 7.7.13, Feedwater Control System
3.1.8 Section 7.7.1.6, Reactor Water Cleanup System
3.1.9 Section 10.4.7, Condensate and Feedwater

3.2 Technical Specifications

3.2.1 Section 2.1, Safety Limits
3.2.2 Section 2.2, Limiting Safety Limits Settings
3.2.3 Technical Specifications Amendment 131
3.2.4 Technical Specifications Amendment for EPU
3.2.5 Hope Creek Generating Station Renewed Facility Operating License No. NPF-57

3.3 Drawings

3.3.1 M-44-1, Rev. 27, Reactor Water Clean-up P&ID
3.3.2 M-41-1, Sht. 1, Rev. 29, Nuclear Boiler P&ID
3.3.3 M-42-1, Sht. 1, Rev. 38, Nuclear Boiler Vessel Instrumentation P&ID
3.3.4 M-43-1, Sht. 1, Rev. 26, Reactor Recirculation System P&ID
3.3.5 M-46-1, Rev. 21, Control Rod Drive Hydraulic Part A

3.4 Support Documents

3.4.1 H-1-RJ-ECS-0190(07), Rev. 1, Software Design Specification NSSS Process Computer Replacement Heat Balance Program
3.4.2 PN0-A41-5050-0009, Rev. 3, GE Reactor System Heat Balance Rated
3.4.3 HC.RE-RA.ZZ-0001, Core Thermal Power Evaluation Application Results 11/22/99
3.4.4 SC-BB-0355, Rev. 2, Reactor Vessel Pressure 1BBPT-N005-C32
3.4.5 SC-BF-0511, Rev. 1, Control Rod Drive 1BFFT-N004-C11
3.4.6 SC-BG-0515, Rev. 1, Reactor Water Cleanup Temperature
3.4.7 SC-AE-0540, Rev 5, Feedwater Line A&B Flow
3.4.8 SC-AE-0541, Rev. 3, Feedwater Temperature 1AETT-N602A-D-C32

3.4.9 Fluid Meters their Theory and Application, Sixth Edition (ASME)
3.4.10 SC-BG-0516, Rev. 0, Reactor Water Cleanup System Inlet Flow 1BGFT-N036A-G33
3.4.11 SC-BB-0526, Rev. 0, Reactor Recirculation Pump Motor Power
3.4.12 ISA-RP67.04, Par II, Methodologies for the Determination of Setpoints for Nuclear Safety-Related Instrumentation, September 1994
3.4.13 Regulatory Guide 1.105, Rev. 3, Setpoints for Safety-Related Instrumentation
3.4.14 NEDC-31336, Class III, October 1986, General Electric Instrument Setpoint Methodology
3.4.15 ASME Steam Tables, Sixth Edition
3.4.16 Deleted
3.4.17 VTD 430003 (002), GE Nuclear Energy Project Task Report for Task T0100: Reactor Heat Balance
3.4.18 Deleted
3.4.19 DCP 80100455 FFWTR
3.4.20 LEFM Bounding Uncertainty Analysis VTD 432792

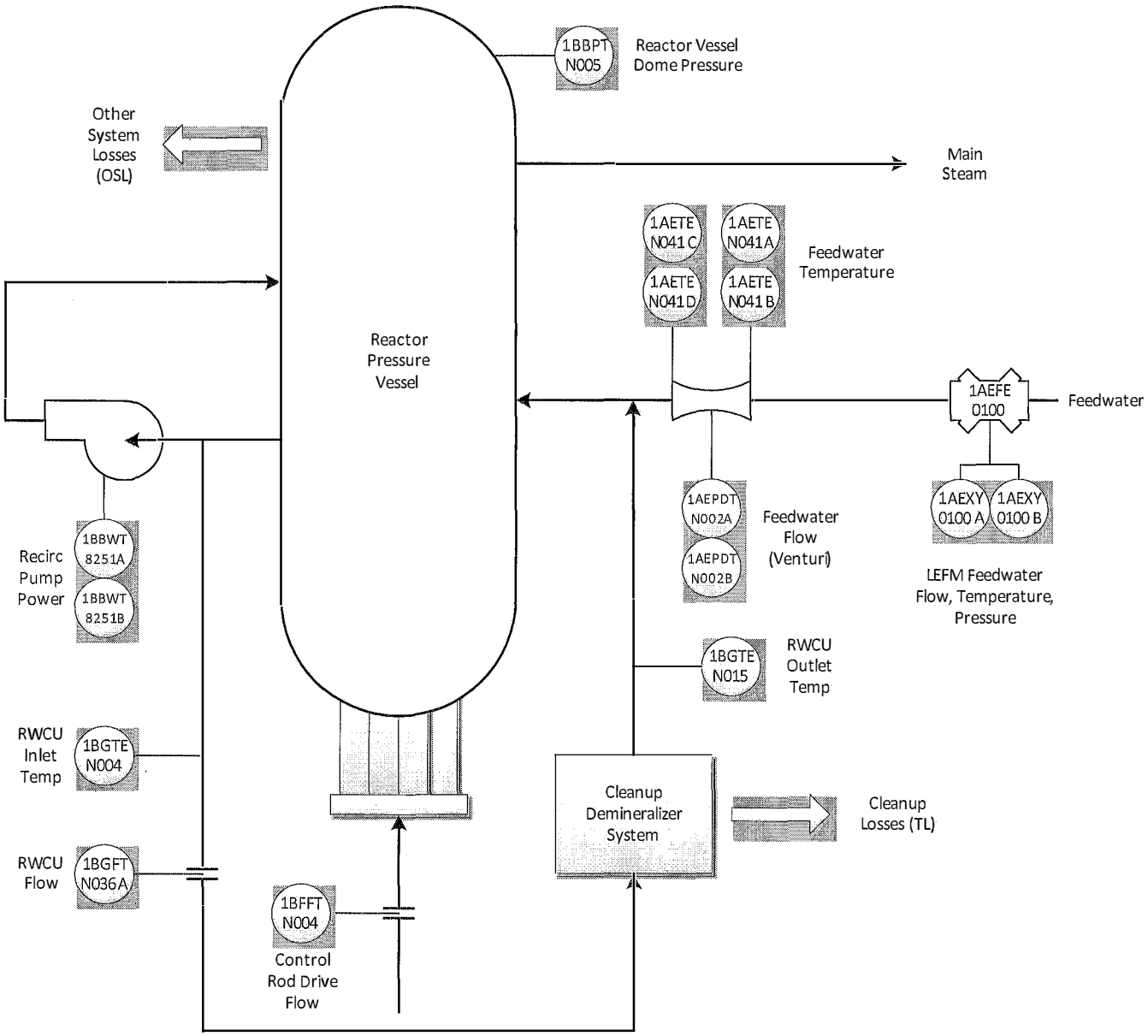
3.5 Procedures

3.5.1 HC.RE-RA.ZZ-0001, Rev. 10 -Core Thermal Power Evaluation

3.6 Computer Programs

3.6.1 STMFUNC v2.0, Steam Table Function Dynamic Link Library, S&L Program Number STM 03.7.598 - 2.0 was used as an Excel add-in. This program uses the 1967 ASME Steam Tables.

4.0 Loop Diagram



5.0 Design Inputs

See attachments 1 through 6

6.0 Assumptions

See attachments 1 through 6

7.0 Calculations

See attachments 1 thought 6

8.0 Summary

See attachments 1 through 6

9.0 Results

Summary of results

The total uncertainty is the calculated uncertainty contained within attachments 1 through 6. The margin is defined by the following:

Margin= 3840 * 102% – Rated Thermal Power – Total uncertainty

There remains a positive margin between the 2% design basis and the combined rated thermal power and total uncertainty for each operating condition; therefore, the results are acceptable.

Plant Condition	LEFM Status	Rated Thermal Power	Total Uncertainty (%)	Total Uncertainty (MWt)	Margin (%)	Margin (MWt)
Normal Feedwater Temperature	Normal (Attachment 1)	3902	0.374%	14.59	0.005%	0.21
	Maintenance (Attachment 2)	3889*	0.694%	26.99	0.021%	0.81
	Fail (Attachment 3)	3840	0.919%	35.29	1.081%	41.51
Feedwater Temperature Reduction (102 Deg F)	Normal (Attachment 4)	3902	0.373%	14.55	0.006%	0.25
	Maintenance (Attachment 5)	3889*	0.693%	26.95	0.022%	0.85
	Fail (Attachment 6)	3840	1.095%	42.05	0.905%	34.75

*Note that the Thermal Power in Maintenance Mode operation is calculated as described in section 1 by attachments 2 and 5. This power level is not identified in Reference 3.2.5

(NC.DE-AP.ZZ-0002(Q), Rev. 12, Form 2)		CALCULATION CONTINUATION SHEET			SHEET: 1
CALC NO.: SC-BB-0525 Attachment 1	REV: 5	REF:			CONT'D ON SHEET: 2
ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	2/14/2017	John Wilkens	3/13/2017	N/A	N/A

Sections 1 through 4 have been replaced with the main body of the calculation

5.0 DESIGN INPUTS

5.1 Rated Power Conditions

100% rated Power Conditions are listed below. Actual 100% operation values might be used in lieu of rated nominal values, for other than Rated MWt, Feedwater Flow and Main Steam parameters as deemed appropriate. This is found acceptable, since for the purpose of error determination to rated MWt "heat differential errors", actual heat contribution deviation from measured/calculated heat to rated MWt due to instrumentation uncertainties, is required not the actual deviation value.

Rated MWt =	**3902MW**	(Ref. 3.4.17, 3.2.5)	Rev 5
Rated FW flow =	**1.7054E+07lbm/hr**	(Ref. 3.4.17)	
Rated FW temperature =	**433.5 F**	(Ref. 3.4.17)	
Rated MS flow =	**17086000**	(Ref. 3.4.17)	
Rated MS pressure =	**1020 psia**	(Ref. 3.4.17)	
Rated MS quality =	**100.000**	(Ref. 3.4.1)	
Rated RWCU flow =	**148000.0 lb/hr**	(Ref. 3.4.17)	Rev 5
Rated RWCU temperature =	**530.7 F**	(Ref. 3.4.17)	
Rated RWCU return temperature =	**433.8 F**	(Ref. 3.4.17)	
Rated CRD flow =	**32000.0 lb/hr**	(Ref. 3.4.3)	
CRD Calibration pressure =	**1474.0 psia**	(Ref. 3.4.5)	
Rated CRD temperature =	**77 F**	(Ref. 3.4.17)	Rev 5
Radiation Loses =	**1.10MW**	(Ref. 3.4.2, 3.4.17)	
Other System Loses =	**1.18MW**	(Ref. 3.4.2, 3.4.17) These loses are not included in UFSAR Heat Balance, Ref. 3.1.1	Rev 5
MWt/BTU/hr =	**2.9300E-07**	(Ref. 3.4.1)	

Power = MFW(MSh-FWh)-CRDF(hin-hout)+RWCU(hout-hin)-RRP+HL+Miscellaneous

Notes:

1) This calculation uses rated MS quality of 100.0%, which will produce a more conservative number with respect to the actual plant MS quality. This parameter may be revised when the actual MS quality is measured after the implementation of EPU.
2) This calculation specifies radiation loses as 1.10 MW and other loses as 0.84 MW for the total lose of 1.94 MW. Reference 3.4.17 stated "other system loses" as 1.9 MW without specifically accounting for Radiation loses. Since the two total numbers are almost identical and the difference would have negligible affect on the Power Error, radiation loses of 1.10 MW and the other loses of 0.84 MW will be maintained.

6.0 ASSUMPTIONS

See sections 7.2.3, 7.2.4, 7.2.6 and 7.2.7 for specific assumptions. Rev 5

7.0 CALCULATIONS

7.1 Methodology

The methodology used to combine the uncertainties for the different contributors to the heat balance calculation is the square root of the sum of the squares of those uncertainties which are statistically independent. Then algebraically combined with the those errors that are systematic, or bias. The uncertainties are considered to be random, two sided distributions. This methodology has been utilized before, and has been endorsed by the NRC and various industry standards (Ref. 3.4.12-3.4.14).

The uncertainty calculation combines the different errors from the different parameters contributing to the heat balance in accordance to the heat balance equation. The contributing parameters errors are taken from the specific system uncertainty calculation.

These errors are generally classified in two groups:

a) Instrument loop(s) uncertainty
b) Process effects

The individual uncertainties affecting the heat balance calculation are determined by the application of the corresponding process algorithm, as described below:

a) the appropriate algorithm for the specific process parameter is set in the form to its specific contribution to the heat balance at specified rated conditions,
b) subsequently, the instrumentation loop error is factored in the process algorithm to calculate the corresponding process parameter with the error built-in,
c) the difference of the calculated contributed process parameter heat, with error, to the rated process rated heat is then calculated,
d) the resultant heat error contribution is then divided by the rated 100% power thermal megawatts. The result is the error contribution by the specific process to the total heat balance uncertainty,
e) finally, all the calculated heat errors are combined in accordance to their parameter function in the heat balance equation. The resultant combination of all contributing errors is the Heat Balance Uncertainty.

7.2 Uncertainties Calculation

Rev 5

7.2.1 Main Feedwater Uncertainty(ies)

The Main Feedwater uncertainties are included in the total thermal power uncertainty provided by the LEFM is 0.34% per Reference 3.4.20. This includes the Main Feedwater mass flow error, main feedwater heat enthalpy error, and the Main Steam mass flow error

7.2.1.1 Main Feedwater Mass Flow Heat Error due to Flow Element Uncertainty (**FWm**)

Deleted

7.2.1.2 Main Feedwater Heat Enthalpy Error due to Pressure Loop Uncertainty (**FWhp**)

Deleted

7.2.1.3 Main Feedwater Heat Enthalpy Error due to Temperature Loop Uncertainty (**FWht**)

Deleted

7.2.2 Main Steam Flow Uncertainty(ies)

Referring to the schematic drawing in section 4.0, It can be seen that the Main Steam heat contribution is affected by the following parameters:

a) Main Steam Enthalpy determination is affected by the pressure instrumentation loop error, documented in calculation: Rev 5

Ref. 3.4.4

7.2.2.1 Main Steam Mass Flow Heat Error due to Main Feedwater Flow Uncertainty (**MSm**) Rev 5

Deleted

7.2.2.2 Main Steam Heat Enthalpy Error due to Pressure Loop Uncertainty (**MShp**)

This Section calculates the Main Heat Steam enthalpy error due to the loop pressure uncertainty, documented in:

Ref.: 3.4.4

The heat error is the difference in the Main Steam flow heat content at rated flow and enthalpy conditions minus the heat content at rated flow with enthalpy at rated pressure plus pressure induced error:

MShp = [Flow (hrated - hrated+err)] x 2.93E-07 / 3902 x 100% Rev 5

P Rtd	P+err	Moist Rtd	Moist+err	h rated	h+err	Flow
1020	1026.1	100	100.000	1192.19	1191.96	17,086,000
Error (psi) =	6.1		0			

Rev 5

TTL MS Heat
20,365,884,863 BTU/hr Rev 5

20,369,812,105 BTU/hr at rated conditions Rev 5

Error
3,927,242 BTU/hr error at rated main feedwater flow Rev 5

Error in Rated MWt
MShp = 0.0295% Rev 5

7.2.2.3. Main Steam Moisture Heat Enthalpy Error due to Steam Moisture Uncertainty (**MSmoist**)

This section calculates the Main Steam enthalpy error due to MS moisture uncertainty. The uncertainty is conservatively set to 50% of rated moisture content of 0.0%.

The heat error is the difference in the Main Steam flow heat content at rated flow and moisture conditions minus the heat content at rated moisture conditions plus moisture error:

MSmoist = [Flowrated hrated (hmoist-rated - hmoist-rated+err)] x 2.93E-07 / 3902 x 100% | Rev 5

P Rtd	P+err	Moist Rtd	Moist+err	h rated	h+err	Flow	
1020	1020	100	100.0000	1192.19	1192.19	17,086,000	Rev 5
	0.00000	0.00%	0				

TTL MS Heat
20,369,812,105 BTU/hr | Rev 5

20,369,812,105 BTU/hr at rated conditions | Rev 5

Error
- BTU/hr error at rated main feedwater flow

Error in Rated MWt
MSmoist = 0.0000%

7.2.3 Control Rod Drive Flow

Referring to the schematic drawing in section 4.0, it can be seen that CRD flow is not monitored for pressure or temperature.

The CRD calculated heat is affected by the following effects:

a) Mass Flow Measurement affected by: 1) flow, instrumentation loop effect and 2) temperature, and 3) pressure deviation from calibration values

b) The CRD Enthalpy determination is affected by: 1) temperature, from applied constants, and 2) pressure, from reactor pressure loop error

The CRD flow loop errors are documented in calculation:

Ref. 3.4.5

The flow formula is derived from the ASME (Ref. 3.4.9) as follows:

Flow = C*Fa*K*(DP*r)^0.5

where K is calculated below:

K = Calib Flow/(Calib inWC * Calib r)^0.5

7.2.3.1 Control Rod Drive Flow Heat Error due to Flow Element and Fluid Specific Weight Uncertainty due to Temperature Error (**CRDt**)

The uncertainty is dependent for the following variables:

Fa = FE Thermal Expansion **r =** Fluid Specific Weight

The plant computer calculates the CRD flow with a constant flow K factor. However, the actual temperature could vary as much as 43F from the expected 77F, and this impacts the Fa and r impacting the calculated flow; therefore, the effect due to this temperature deviation is:

CRDt = [(hs rated - CRDh rated) (Flowrated - Flowrated+err)] x 2.93E-07 / 3902 x 100% Rev 5

Ref.: 3.4.5

K = 448.48
Calib Flow = 50154 lb/hr 100 GPM
Calib inWC = **200**
Calib Temp = **77**
Calib Press = **1474.7**
r = 62.529
Assumed Rated Flow = **32000.0 lb/hr**
Rated Press = 1020 psia
Rated Temp = **77 F**
Rated h = 47.83 btu/lb

Fa Error	
Rated 77F	1.0003
@140 F	1.0013
@40 F	0.9995
Fa/F	1.8E-05

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	81.3694	81.3694	1.0003	1.0011	77	120
0.00%	0	0.00%	0				43

Temp error = Calib Temp - Min Temp

P Rtd	r	h Rtd	Flow	hs Rtd
1020	61.9029	47.83	31,863.902	1192.19

TTL CRD Heat
36,463,826 BTU/hr

36,619,571 BTU/hr at rated conditions

Error
(155,745) BTU/hr error at rated CRD flow

Error in Rated MWt
CRDt = -0.0012% This error is a bias, not a random instrument induced uncertainty.

7.2.3.2 Control Rod Drive Flow Heat Error due to Flow Element Uncertainty (**CRDc**)

The CRD contributed heat is affected by the FE error that is assigned to the flow element expansion coefficient.

C

The FE uncertainty is determined based in calculation:

Ref.: 3.4.5

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

CRDc = [(hs rated - CRDh rated) (Flowrated - Flowrated+err)] x 2.93E-07 / 3902 x 100% | Rev 5

Fa Error		**K =** 448.48		
Rated 77F	1.0003	Calib Flow = 50154	100.00	
@140 F	1.0013	Calib inWC = 200.00		
@60 F	0.9995	Assumed Calib Temp = 77.00		
Fa/F	1.8E-05	Assumed Calib Press = 1474.00		
		r = 62.529		0.0159925
		Assumed Rated Flow = 32000.0 lb/hr		
		Rated Press = 1020 psia		
		Rated Temp = 77 F		
		Rated h = 47.83 btu/lb		

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0200	81.3694	81.3694	1.0003	1.0003	77	77
2.00%	200	0.00%	0				0

P Rtd	r	h Rtd	Flow	hs Rtd
1020.00	62.4433	47.83	32,617.500	1192.19

Rev 5

TTL MFW Heat
37,326,215 BTU/hr | Rev 5

36,619,571 BTU/hr at rated conditions

Error
706,644 BTU/hr error at rated CRD flow | Rev 5

Error in Rated MWt
CRDc = 0.0053% | Rev 5

7.2.3.3 Control Rod Drive Heat Error due to Differential Pressure (DP) Loop Uncertainty (**CRDdp**)

This error is calculated in calculation:

Ref.: 3.4.5

The loop is comprised of 1) flow transmitter, FT, 2) resistor, REST, 3) computer analog to digital card, A/D.
The uncertainties are in % DP span:

Accuracy: **Loop Drift:**

CRD_AFT	CRD_AREST	CRD_AA/D	CRD_VDFT	CRD_VDA/D
1.154%	0.100%	0.188%	1.450%	0.000%

Rev 5

Loop Calibration:

CRD_CEFT	CRD_CEA/D
0.140%	0.188%

Rev 5

The uncertainties are random and independent and combined by the SRSS method:

1.88%	span DP

(NC.DE-AP.ZZ-0002(Q), Rev. 12, Form 2)		CALCULATION CONTINUATION SHEET			SHEET: 11
CALC NO.: SC-BB-0525 Attachment 1	REV: 5	REF:			CONT'D ON SHEET: 12
ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	2/14/2017	John Wilkens	3/13/2017	N/A	N/A

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

CRDdp = [(hs rated - CRDh rated) (Flowrated - Flowrated+err)] x 2.93E-07 / 3902 x 100% | Rev 5

Fa Error

Rated 77F	1.0003	**K =**	448.51	
@140 F	1.0013	Calib Flow =	50157.2 lb/hr	100 GPM
@60 F	0.9995	Calib inWC =	200	
Fa/F	1.8E-05	Assumed Calib Temp =	77	
		Assumed Calib Press =	1474	
		r =	62.529	
		Assumed Rated Flow =	32000.0 lb/hr	
		Rated Press =	1020.0 lb/hr	
		Rated Temp =	77 F	
		CRDh rated =	47.83 btu/lb	

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	81.3584	85.1183	1.0003	1.0003	77	77
0.00%	0	1.88%					0

P Rtd	r	CRDh rated	Flowrated+err	hs Rtd
1020	62.4433	47.83	32,708.537	1192.19

TTL MFW Heat
37,430,393 BTU/hr

36,619,571 BTU/hr at rated conditions

Error
810,822 BTU/hr at rated CRD flow

Error in Rated MWt
CRDdp = 0.0061%

Rev 5

7.2.3.4 Control Rod Drive Flow Enthalpy Heat Error due to Temperature Calibration Deviation (**CRDht**)

The plant computer calculates the CRD fluid enthalpy at a constant 77F and reactor pressure. However, the actual temperature varies and it is assumed to vary as much as 43F from the expected 77F; therefore, the effect due to this temperature deviation in the calculated enthalpy is:

Ref. 3.4.5

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

CRDht = [Flow (hs rated - CRDh rated) - Flow (hs rated - CRDh rated+err)] x 2.93E-07 / 3902 x 100% | Rev 5

TRtd	T Max/Min	T+err	P Rtd	h rated	h+err	hs rated	Flow
77	40	37	1020	47.83	8.05	1192.19	32,000

TTL RWCU Heat
37,892,585 BTU/hr

36,619,571 BTU/hr at rated conditions

Error
(1,273,014) BTU/hr at rated CRD flow

Uncertainty in Rated MWt
CRDht = -0.0096%

This error is a bias, not a random instrument induced uncertainty. | Rev 5

7.2.3.5 Control Rod Drive Flow Enthalpy Heat Error due to Pressure Loop Uncertainty (**CRDhp**)

The plant computer calculates the CRD fluid enthalpy at a constant 77Fand reactor loop pressure, that is affected by the loop uncertainty.
The pressure loop uncertainty is documented in:

Ref.: 3.4.4

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

CRDhp = [Flow (hs rated - CRDh rated) - Flow (hs rated+err - CRDh rated)] x 2.93E-07 / 3902 x 100% Rev 5

P Rtd	P+err	TRtd	CRDh rated	hs rated	hs rated+err	Flow
1020	1026.1	77	47.83	1192.19	1191.96	32,000

Rev 5

Error (psi) = 6.1

TTL MFW Heat
36,612,216 BTU/hr

Rev 5

36,619,571 BTU/hr at rated conditions Rev 5

Error
(7,355) BTU/hr at rated CRD flow Rev 5

Uncertainty in Rated MWt
CRDhp = -0.00006%

Rev 5

7.2.4 Reactor Water Cleanup Uncertainty(ies)

Referring to the schematic drawing in section 4.0, it can be seen that RWCU flow is measured and mass calculated by a "NUMAC" process unit. Differential pressure, temperature, by dedicated thermocouples, and reactor pressure are an input to the instrument. Therefore, the RWCU contributed heat is affected by the following parameters:

a) Mass Flow Measurement affected by: 1) flow, 2) temperature, and 3) pressure induced factors/instrumentation loops errors

b) The RWCU Enthalpy determination is affected by: 1) temperature instrumentation loop error (see discussion for pressure)

The flow formula is derived from the ASME (Ref. 3.4.9) as follows:

Flow = C*K*(DP)^0.5

where K is:

K = Calib Flow / [C*(Calib inWC)^0.5]

7.2.4.1 RWCU Inlet/Outlet Flow Heat Error due to Flow Element Expansion deviation from Calibration (**RWCUFa**)

The Numac computer calculating the mass flow has a built-in Fa constant different than the flow element Fa provided at the calculated venturi rated temperature of 533F. This induces a bias error. Furthermore, the plant NUMAC normalizes the flow mass signal to a specific weight of 47.0 lbm/cuft for pressure and temperature conditions, back calculated below; therefore, the rated conditions are set at 530.7F. Rev 5

Pressure Density Compensated to :	47.19 lb/cuft	530.7 F	**908 psia**	Rev 5
The Fa used in the calculation is fixed to:		1.0045		
The correct Fa at rated 533 F is:		1.0087		

Based on the Fa differences the induced flow error is calculated below:

Fa = FE Thermal Expansion

Ref.: 3.4.10

Flow+err = C x Fa+err / Fa x K x (DP)^0.5

K = 9449.90 Rev 5

Calib Flow = 189823.1 lb/hr **500 GPM** (Note)

Calib inWC = **403.5**

Assumed Calib Temp = **530.7** Rev 5

Assumed Calib Press = **1114.7**

r = 47.332 Rev 5

Assumed Rated Flow = 148021 lb/hr **389 GPM**

Rated h = 524.83 btu/lb

Fa Error

Rated 533F **1.0087**

Calibrated **1.0045**

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	245.3520	245.3520	1.0087	1.0045	530.7	530.7
0.00%	0	0.00%	0				0

P Rtd	P+err	r	h Rtd	Flow+err
1114.7	1114.7	47.3324	524.83	147,404
	0			

Rev 5

Uncertainty
RWCUFa -616.3 lb/hr

This a bias and the actual contributed Heat is Higher than indicated Rev 5

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.2 RWCU Inlet/Outlet Flow Heat Error due to Fluid Specific Weight deviation (**RWCUPMA**)

This error is the combination of several uncertainties calculated below:

7.2.4.2.1 RWCU Inlet/Outlet Flow Error due to Fluid Specific Weight Numac Lookup Tables Error (**RWCUPMA1**)

The Numac performs the fluid specific weight determination with an error of 0.1 specific weight, this effect in the flow is calculated below.

r = Fluid Specific Weight

Ref.: 3.4.10

Flow+err = C x K x (DP x r+err / r)^0.5

The flow error is the difference between the rated flow at rated specific weight minus the flow at specific weight plus error:

RWCUPMA1 = Flowrated - Flowrated+error

		K = 9449.90			Rev 5
		Calib Flow = 189823.1 lb/hr	500 GPM	(Note)	
Fa Error		Calib inWC = 403.5			
Rated 533F	1.0087	Assumed Calib Temp = 530.7			Rev 5
Calibrated	1.0045	Assumed Calib Press = 1114.7			
		r = 47.332			Rev 5
		Assumed Rated Flow = 148021 lb/hr	388.8 GPM		
		Rated hout = 524.83 btu/lb			

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	
1.0000	1.0000	245.3520	245.3520	1.0087	1.0087	530.7	Rev 5
0.00%	0	0.00%	0				

P Rtd	P+err	r	Numac err	r+perr+Numac	h Rtd	Flow	
1114.7	1114.7 psi	47.332	0.1	47.432	524.83	148,177	Rev 5
	0 psi						

Uncertainty
RWCUPMA1 = 156.3 lb/hr

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.2.2 RWCU Inlet/Outlet Flow Error due to Fluid Specific Weight Numac 0.75 Factor Pressure Correction Factor Error (**RWCUPMA2**)

The Numac computer introduces a 0.75 factor to the input pressure raw value and calculates the specific weight for saturated conditions, which bias the actual flow.

Ref.: 3.4.10

Flow+err = C x K x (DP x r+err / r)^0.5

The flow error is the difference between the rated flow at rated specific weight minus the flow at specific weight plus error:

$RWCU_{PMA2} = Flow_{rated} - Flow_{rated+error}$

r = Fluid Specific Weight

K = 9449.90 Rev 5

Calib Flow = 189823.1 lb/hr 500 GPM (Note)

Calib inWC = 403.5

Fa Error		
Rated 533F	1.0087	Assumed Calib Temp = 530.7 Rev 5
Calibrated	1.0045	Assumed Calib Press = 1114.7

r = 47.332 Rev 5

Assumed Rated Flow = 148021 lb/hr 388.8 GPM

Rated = 524.83 btu/lb

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	
1.0000	1.0000	245.3520	245.3520	1.0087	1.0087	530.7	Rev 5
0.00%	0	0.00%	0				

P Rtd	P+err	T Sat	r+perr	Numac rerr	r+perr+Numac	h Rtdout	h Rtd return	Flow
1114.7	840 psi	523.8	47.5905	0	47.5905	524.83	412.64	148,424
	75%	75						

Uncertainty
$\dot{W}_{RWCUPMA2}$ = -403 lb/hr

This a bias and the actual contributed Heat is Higher than indicated Rev 5

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	2/14/2017	John Wilkens	3/13/2017	N/A	N/A

7.2.4.2.3 RWCU Inlet/Outlet Flow Heat Error due to Fluid Specific Weight Pressure Loop Uncertainty (**RWCUP_SW**)

Pressure is utilized as an input to the Numac to determine the specific weight of the fluid. The pressure loop uncertainty combined with the Numac computer uncertainty introduces an error in the calculated specific weight.

The loop error is comprised of 1) pressure loop, PT, 2) NUMAC computer uncertainties. The combined uncertainties are:

RWCUpress error= 21 psi

Ref.: 3.4.10

Flow+err = C x K x (DP x r+err / r)^0.5

The flow error is the difference between the rated flow at rated specific weight minus the flow at specific weight plus error:

RWCUp_SW = [Flowrated (h_in - h_out) - Flowrated+error (h_in - h_out)] x 2.93E-07 / 3902 x 100% Rev 5

r = Fluid Specific Weight

K = 9449.90 Rev 5

Calib Flow = 189823.1 lb/hr 500 GPM (Note)

Fa Error		Calib inWC = 403.5
Rated 533F	1.0087	Assumed Calib Temp = 530.7 Rev 5
Calibrated	1.0045	Assumed Calib Press = 1114.7

r = 47.332 Rev 5

Assumed Rated Flow = 148021 lb/hr 388.8 GPM

Rated h = 524.83 btu/lb

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd in	T Rtd out
1.0000	1.0000	245.3520	245.3520	1.0087	1.0087	530.7	433.8
0.00%	0	0.00%	0				

P Rtd	P+err	r+perr	Numac rerr	r+perr+Numac	h Rtd in	h Rtd out	Flow	
1020	1041 psi	47.2821	0	47.2821	524.96	412.64	147,942	Rev 5

TTL MFW Heat
16,616,340 BTU/hr Rev 5

16,625,169 BTU/hr at rated conditions Rev 5

Error
8,829 Rev 5

Uncertainty in Rated MWt
RWCUp_sw = 0.0001%

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.3 Reactor Water Cleanup Flow Error due to Flow Element Uncertainty (**RWCUc**)

The RWCU flow is affected by the FE error that is assigned to the flow element expansion coefficient.

C

The FE uncertainty is determined based in calculation:

Ref.: 3.4.10

Flow+err = C+err x K x (DP)^0.5

The flow error is the difference between the rated flow minus the flow with the C coefficient error:

RWCUc = Flowrated - Flowrated+error

Fa Error		**K =** 9449.90			Rev 5
Rated 533F	1.0087	Calib Flow = 189823.1 LB/HR	500 GPM	(Note)	
Calibrated	1.0045	Calib inWC = 403.50			
		Assumed Calib Temp = 530.70			Rev 5
		Assumed Calib Press = 1114.70			
		r = 47.332			Rev 5
		Assumed Rated Flow = 148021 lb/hr	389 GPM		
		Rated h = 524.83 btu/lb			

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0150	245.3520	245.3520	1.0087	1.0087	530.7	530.7
1.50%	150	0.00%	0				0

P Rtd	r	h	Flow
1114.7	47.3324	524.8	150,241

Rev 5

Uncertainty
RWCUc = 2220.3 lb/hr

Rev 5

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.4 Reactor Water Cleanup Flow Error due to Differential Pressure (DP) Loop Uncertainty (**RWCUdp**)

This error is introduced by the differential pressure instrument loop. The uncertainties in the loop are found in: Ref.: 3.4.10

The loop is comprised of 1) flow transmitter, FT, 2) NUMAC computer. The uncertainties are in % DP span:

The flow error is the difference between the rated flow minus the flow with the C coefficient error:

RWCUdp = Flowrated - Flowrated+error

Accuracy: **Loop Drift:**

RWCU_AFT	RWCU_ANU_IE	RWCU_ANU_A/D	RWCU_VDFT	RWCU_VDNU_IE	RWCU_VDNU_A/D
0.503%	0.100%	0.233%	0.900%	0.127%	0.127%

Loop Calibration:

RWCU_CEFT	RWCU_CENU_A/D
0.139%	0.02%

The uncertainties are random and independent and combined by the SRSS method:

1.09%	span DP

Flow+err = C x K x (DP+err)^0.5

Fa Error
Rated 533F 1.0087
Calibrated 1.0045

K = 9449.90
Calib Flow = 189823.1 LB/HR 500 GPM (Note)
Calib inWC = 403.50
Assumed Calib Temp = 530.70 Rev 5
Assumed Calib Press = 1114.70
r = 47.332 Rev 5
Assumed Rated Flow = 148021 LB/HR 389 GPM
Rated h = 524.83 btu/lb

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	245.3520	249.7338	1.0087	1.0087	530.7	530.7
0.00%	0						0

P Rtd	r	h	Flow
1114.7	47.3324	524.83	149,336

Rev 5

Uncertainty
RWCUdp = 1315.9 lb/hr Rev 5

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.5 Reactor Water Cleanup Flow Error due to Signal Conditioning/NSSS Computer Loop Uncertainty **(RWCUNSSS_cptr)**

The differential pressure is converted to flow by the Numac computer and retransmitted as flow signal to the plant computer for heat balance calculations.

This portion of the loop is comprised of 1) NUMAC computer output, 2) NSSS computer uncertainty. The uncertainties are in % flow span:

Accuracy:

RWCU_ANU_D/A	RWCU_AA/D
0.233%	0.188%

Loop Drift:

RWCU_VDNU_D/A	RWCU_VNA/D
0.13%	0.000%

Rev 5

Loop Calibration:

RWCU_CENU_D/A	RWCU_CEA/D
0.02%	0.188%

Rev 5

The uncertainties are random and independent and combined by the SRSS method:

0.38%	span FLOW

The flow error is the difference between the rated flow at without loop error minus the flow plus loop error:

RWCUNSSS_cptr = Flowrated - Flowrated+error

Fa Error
Rated 533F 1.0087
Calibrated 1.0045

K = 9449.90
Calib Flow = 189823.1 lb/hr 500 GPM (Note)
Calib inWC = 403.50
Assumed Calib Temp = 530.70
Assumed Calib Press = 1114.70
r = 47.332
Assumed Rated Flow = 148021 lb/hr 389 GPM
Rated h = 524.83 btu/lb

Rev 5

Rev 5

Rev 5

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	245.3520	245.3520	1.0087	1.0087	530.7	530.7
0.00%	0						0

P Rtd	r	h	Flowrated+err
1114.7	47.3324	524.83	148,733.9

Rev 5

Uncertainty
RWCUNSSS_cptr= 713.3 lb/hr

Rev 5

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.6 Reactor Water Cleanup Total Flow due to Flow Loop Uncertainties (**RWCUf)**

RWCU Inlet h - Outlet h.

The total RWCU Flow Uncertainty is calculated below:

RWCUfu =+/-SQRT(RWCUPMA1^2+RWCUc^2+RWCUdp^2+RWCUNSSS_cptr^2)-RWCUFa-RWCUPMA2

Notice that the bias PMAs are factored with both signs, since the negative uncertainty is the one that has impact in the heat balance calculations, that is, that (-) less indication means that power is higher; however, it will be factored in both directions for simplicity.

RWCUfu = 3710 lb/hr

Then, the heat error contribution is the calculated inlet flow heat error minus the outlet flow heat error:

RWCUh_in = 524.96 btu/lb
RWCUh_out = 412.64 btu/lb

Rev 5

And the RWCU heat error contribution is calculated by the following expression:

RWCU = [RWCUfu (RWCUh_in - RWCUh_out) x MWt_BTU_hr (conversion factor)] / Rated MWt 100%

RWCUf = 0.0031% This total error will be treated as bias in the total heat balance error

Rev 5

7.2.4.7 Reactor Water Cleanup Flow Enthalpy Heat Error due to Temperature Uncertainty (RWCUht)

This error is the error resultant of temperature measurement errors by the inlet/outlet RWCU thermocouple loops factored into the fluid enthalpy determination. The thermocouples are instruments with good repeatability and stability. However, fabrication errors can amount to several farenheit degrees. The fabrication errors can be calibrated out, since essentially it is a bias, systematic error. The temperature loops for RWCU are not calibrated out. Finally, since most of the thermocouples loop error is a bias, the conservative and safe way to apply the error, is for the two temperature error to be set in the same direction; therefore, the effect is additive, bias. The temperature loops error is found in:

Ref. 3.4.6

The heat error is the difference between the inlet flow heat error minus the outlet flow heat error:

RWCUht = [Flow [(hin - hin+error) + (hout - hout+error)]] x 2.93E-07 / 3902 x 100% | Rev 5

In flow heat

TRtd	T+err	P Rtd	h rated	h+err	Flow	
530.7	541.6	1020	524.96	538.69	148,021	Rev 5
Error (F)	**10.9**					

Out flow heat

TRtd	T+err	P Rtd	h rated	h+err	Flow	
433.8	444.7	1020	412.64	424.67	148,021	Rev 5
Error (F)	10.9					

Error		
3,813,151	**BTU/hr error at rated reactor water cleanup flow**	Rev 5

Uncertainty in Rated MWt		
RWCUht = 0.0286%	This error is a bias	Rev 5

7.2.4.8 Reactor Water Cleanup Flow Enthalpy Heat Error due to Pressure Loop Uncertainty (**RWCUhp**)

The reactor water cleanup enthalpy determination is affected by the loop pressure error. The pressure has a very small effect in the water enthalpy, however, it is determined in this calculation. The loop uncertainty is documented in:

Ref.: 3.4.4

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

RWCUhp = [Flow [(hin - hin+error) - (hout - hout+error)]] x 2.93E-07 / 3902 x 100% | Rev 5

In flow heat

P Rtd	P+err	TRtd	h rated	h+err	Flow
1020	1040.2	530.7	524.96	524.93	148,000
Error (psi)	20.2				

| Rev 5

Out flow heat

P Rtd	P+err	TRtd	h rated	h+err	Flow
1020	1040.2	433.8	412.64	412.66	148,000
Error (psi)	20.2				

| Rev 5

Error

6,672 BTU/hr at rated reactor water cleanup flow | Rev 5

Uncertainty in Rated MWt
RWCUhp = 0.00005%

7.2.5 Recirculation Pumps Heat Error due to Watts Loop Uncertainty (**RRPw**)

This section calculates the uncertainty due to RRP watts loop error, calculated in:

Ref.: 3.4.11

The rated power for the pump-motor and the motor efficiency (0.93) is from reference:

(Ref. 3.4.3)

There are two recirculation pumps, the calculated error below is per pump. The actual total MW for the 2 pumps is taken from above reference.

W 2 pump = 7.33

The Watt error contribution is calculated as follows:

RRPw = [(W Rtd/pump + MW Loop Span x Span err) x Mottor eff] - W Rtd/pump x Motor eff] / 3902 x 100% | Rev 5

W Rtd/pmp+err	Motor Eff	W+err
3.823	0.93	3.55
	Error =	1.50 % span
	Span =	10.5 Mwatt

TTL Mwatt
3.41 Mwatt

Error
0.1465 Mwatt

Uncertainty in Rated MWT
RRPw = 0.0038%

7.2.6 Thermal Loses (TL)

This section calculates the uncertainty due to TL error. This error will be treated as a bias error since the estimated value is larger or smaller than assumed, i.e. it is a fixed error not a random error. Rev 5

An assumed error equal to 20% of the specified loses is used.

The rated Heat Loss is from reference:

(Ref. 3.4.2)

W Rtd	W+err
1.1	1.32
Error =	20.00%

TTL Mwatt Heat
1.32

MW

1.10 MW at rated conditions

Error

0.2200 MW error at rated radiated loses

Uncertainty in Rated MWT
TL = 0.0056%

This error is treated as bias. Rev 5

Note: The computer utilizes this value combined with Other System Loses (Section 7.2.7) as Radiative power loses, QRAD = 1.94

7.2.7 Other System Loses (**OSL**)

The rated value includes Rod Drive seal purge flow to recirculation pumps. An assumed error equal to 20% of the specified loses is used.
This error will be treated as a bias error since if the estimated value is larger or smaller than assumed, i.e. it is a fixed error not a random error.

The rated Losses figure is from reference:

(Ref. 3.4.2)

W Rtd	W+err
1.18	1.416
Error =	**20%**

Rev 5

TTL Mwatt Heat		
1.42	MW	Rev 5
1.18	MW at rated conditions	Rev 5
Error		
0.2360	**MW error at rated radiated loses**	Rev 5
Uncertainty in Rated MWT	This error is treated as bias.	
OSL = 0.0060%		Rev 5

Note: The computer utilizes this value combined with Thermal Loses (Section 7.2.6) as Radiative power loses, QRAD = 1.94

7.2.8 Heat Balance Calculation Power Uncertainty (**Power U**)

The calculated heat balance uncertainty is the algebraic combination of the bias errors with the independent/random errors statistically combined, that contribute into the heat balance calculation, in accordance with the heat balance formula:

Power = MFW(MSh-FWh)-CRDF(hin-hout)+RWCU(hout-hin)-RRP+HL+Miscellaneous

Summary of Heat Balance Calculation Contributing Errors:

Random Errors:	MSmoist = 0.0000%	
	CRDc = 0.0053%	
	CRDdp = 0.0061%	
	RRPw = 0.0038%	
	RWCUp_sw = 0.0001%	
Dependent Errors:	Errors	Variable
	FWhp = **	Rated MS pressure = 1020 psia
	FWm = **	
	FWht = **	
	MSm = **	
	MShp = 0.0295%	
	CRDhp = -0.00006%	
	RWCUhp = 0.00005%	
Bias Errors:	CRDt = -0.0012%	
	CRDht = -0.0096%	
	RWCUf = 0.0031%	
	RWCUht = 0.0286%	
	TL = 0.0056%	
	OSL = 0.0060%	

Rev 5

** Note that these terms are combined in reference 3.4.20 for an over all uncertainty of 0.34% for FWm, FWht and FWhp

Heat Balance Calculation Power Error (U):

Power Error = SQRT[((0.0034)^2+(MShp+CRDhp+RWCUhp)^2+MSmoist^2+CRDc^2+CRDdp^2+
+RWCUp_sw^2+RRPw^2x2]+CRDt+CRDht+RWCUf+RWCUht+TL+OSL

Rev 5

Power Error = **0.374%**

Rev 5

To ensure operation margin exist, due to possible instrumentation loops miss-calibration, actual drift (to be determined by history), etc., a margin is added:

Power U = Power Error + Margin

where margin is defined as 3840 * 102% –Rated Thermal Power – Power Error

Margin = 3916.8 - 3902 - Power Error
Margin = 0.005% and **Power U = 0.379%**

Rev 5

8.0 SUMMARY

The calculated Heat Balance Error performed in this calculation is applicable to fully operational LEFM. The Power Uncertainty is the difference between the 2% design basis and the rated termal power for the current LEFM mode of operation. Positive margin is maintained between the Power Uncertainty and the Power Error. The Heat Balance calculation error (Section 7.0) is: Rev 5

Power U = 0.379% Rev 5

Sections 1 through 4 have been replaced with the main body of the calculation

5.0 DESIGN INPUTS

5.1 Rated Power Conditions

100% rated Power Conditions are listed below. Actual 100% operation values might be used in lieu of rated nominal values, for other than Rated MWt, Feedwater Flow and Main Steam parameters as deemed appropriate. This is found acceptable, since for the purpose of error determination to rated MWt "heat differential errors", actual heat contribution deviation from measured/calculated heat to rated MWt due to instrumentation uncertainties, is required not the actual deviation value.

Rated MWt =	**3889MW**	This power level is set at the highest whole MWt power level which produces positive margin	Rev 5
Rated FW flow =	**1.7054E+07lbm/hr**	(Ref. 3.4.17)	
Rated FW temperature =	**433.5 F**	(Ref. 3.4.17)	
Rated MS flow =	**17086000**	(Ref. 3.4.17)	
Rated MS pressure =	**1020 psia**	(Ref. 3.4.17)	
Rated MS quality =	**100.000**	(Ref. 3.4.1)	
Rated RWCU flow =	**148000.0 lb/hr**	(Ref. 3.4.17)	Rev 5
Rated RWCU temperature =	**530.7 F**	(Ref. 3.4.17)	
Rated RWCU return temperature =	**433.8 F**	(Ref. 3.4.17)	
Rated CRD flow =	**32000.0 lb/hr**	(Ref. 3.4.3)	
CRD Calibration pressure =	**1474.0 psia**	(Ref. 3.4.5)	
Rated CRD temperature =	**77 F**	(Ref. 3.4.17)	Rev 5
Radiation Loses =	**1.10MW**	(Ref. 3.4.2, 3.4.17)	
Other System Loses =	**1.18MW**	(Ref. 3.4.2, 3.4.17) These loses are not included in UFSAR Heat Balance, Ref. 3.1.1	Rev 5
MWt/BTU/hr =	**2.9300E-07**	(Ref. 3.4.1)	

Power = MFW(MSh-FWh)-CRDF(hin-hout)+RWCU(hout-hin)-RRP+HL+Miscellaneous

Notes:

1) This calculation uses rated MS quality of 100.0%, which will produce a more conservative number with respect to the actual plant MS quality. This parameter may be revised when the actual MS quality is measured after the implementation of EPU.
2) This calculation specifies radiation loses as 1.10 MW and other loses as 0.84 MW for the total lose of 1.94 MW. Reference 3.4.17 stated "other system loses" as 1.9 MW without specifically accounting for Radiation loses. Since the two total numbers are almost identical and the difference would have negligible affect on the Power Error, radiation loses of 1.10 MW and the other loses of 0.84 MW will be maintained.

6.0 ASSUMPTIONS

The Main Feedwater uncertainties is included in the total termal power uncertainty provided by the LEFM while in mantenance mode is 0.66% per Reference 3.4.20 is provided based on a power level of 3902MWt. This is not interpolated based on a 3889MWt since the uncertainty provided by Reference 4.1.20 is only provided in two significant digits and the impact is neglible. Rev 5

The design inputs from reference 3.4.17 are used as bounding design inputs and a 3889MWt heat balance is not included in reference 3.4.17. The difference between the operating region of the steam tables between the inputs of 3902MWt and 3889MWt are considered to be minimal and the impact is neglible. Rev 5

See sections 7.2.3, 7.2.4, 7.2.6 and 7.2.7 for specific assumptions. Rev 5

7.0 CALCULATIONS

7.1 Methodology

The methodology used to combine the uncertainties for the different contributors to the heat balance calculation is the square root of the sum of the squares of those uncertainties which are statistically independent. Then algebraically combined with the those errors that are systematic, or bias. The uncertainties are considered to be random, two sided distributions. This methodology has been utilized before, and has been endorsed by the NRC and various industry standards (Ref. 3.4.12-3.4.14).

The uncertainty calculation combines the different errors from the different parameters contributing to the heat balance in accordance to the heat balance equation. The contributing parameters errors are taken from the specific system uncertainty calculation.

These errors are generally classified in two groups:

a) Instrument loop(s) uncertainty
b) Process effects

The individual uncertainties affecting the heat balance calculation are determined by the application of the corresponding process algorithm, as described below:

a) the appropriate algorithm for the specific process parameter is set in the form to its specific contribution to the heat balance at specified rated conditions,
b) subsequently, the instrumentation loop error is factored in the process algorithm to calculate the corresponding process parameter with the error built-in,
c) the difference of the calculated contributed process parameter heat, with error, to the rated process rated heat is then calculated,
d) the resultant heat error contribution is then divided by the rated 100% power thermal megawatts. The result is the error contribution by the specific process to the total heat balance uncertainty,
e) finally, all the calculated heat errors are combined in accordance to their parameter function in the heat balance equation. The resultant combination of all contributing errors is the Heat Balance Uncertainty.

7.2 Uncertainties Calculation

Rev 5

7.2.1 Main Feedwater Uncertainty(ies)

The Main Feedwater uncertainties are included in the total thermal power uncertainty provided by the LEFM while in mantenance mode is 0.66% per Reference 3.4.20. This includes the Main Feedwater mass flow error, main feedwater heat enthalpy error, and the Main Steam mass flow error

7.2.1.1 Main Feedwater Mass Flow Heat Error due to Flow Element Uncertainty (**FWm**)

Deleted

7.2.1.2 Main Feedwater Heat Enthalpy Error due to Pressure Loop Uncertainty (**FWhp**)

Deleted

7.2.1.3 Main Feedwater Heat Enthalpy Error due to Temperature Loop Uncertainty (**FWht**)

Deleted

7.2.2 Main Steam Flow Uncertainty(ies)

Referring to the schematic drawing in section 4.0, It can be seen that the Main Steam heat contribution is affected by the following parameters:

a) Main Steam Enthalpy determination is affected by the pressure instrumentation loop error, documented in calculation: Rev 5

Ref. 3.4.4

7.2.2.1 Main Steam Mass Flow Heat Error due to Main Feedwater Flow Uncertainty (**MSm**) Rev 5

Deleted

7.2.2.2 Main Steam Heat Enthalpy Error due to Pressure Loop Uncertainty (**MShp**)

This Section calculates the Main Heat Steam enthalpy error due to the loop pressure uncertainty, documented in:

Ref.: 3.4.4

The heat error is the difference in the Main Steam flow heat content at rated flow and enthalpy conditions minus the heat content at rated flow with enthalpy at rated pressure plus pressure induced error:

MShp = [Flow (hrated - hrated+err)] x 2.93E-07 / 3889 x 100% | Rev 5

P Rtd	P+err	Moist Rtd	Moist+err	h rated	h+err	Flow	
1020	1026.1	100	100.000	1192.19	1191.96	17,086,000	Rev 5
Error (psi) =	6.1		0				

TTL MS Heat
20,365,884,863 BTU/hr | Rev 5

20,369,812,105 BTU/hr at rated conditions | Rev 5

Error
3,927,242 BTU/hr error at rated main feedwater flow | Rev 5

Error in Rated MWt
MShp = 0.0296% | Rev 5

7.2.2.3. Main Steam Moisture Heat Enthalpy Error due to Steam Moisture Uncertainty (**MSmoist**)

This section calculates the Main Steam enthalpy error due to MS moisture uncertainty. The uncertainty is conservatively set to 50% of rated moisture content of 0.0%.

The heat error is the difference in the Main Steam flow heat content at rated flow and moisture conditions minus the heat content at rated moisture conditions plus moisture error:

MSmoist = [Flowrated hrated (hmoist-rated - hmoist-rated+err)] x 2.93E-07 / 3889 x 100% | Rev 5

P Rtd	P+err	Moist Rtd	Moist+err	h rated	h+err	Flow	
1020	1020	100	100.0000	1192.19	1192.19	17,086,000	Rev 5
	0.00000	0.00%	0				

TTL MS Heat
20,369,812,105 BTU/hr | Rev 5

20,369,812,105 BTU/hr at rated conditions | Rev 5

Error
- BTU/hr error at rated main feedwater flow

Error in Rated MWt
MSmoist = 0.0000%

7.2.3 Control Rod Drive Flow

Referring to the schematic drawing in section 4.0, it can be seen that CRD flow is not monitored for pressure or temperature.

The CRD calculated heat is affected by the following effects:

a) Mass Flow Measurement affected by: 1) flow, instrumentation loop effect and 2) temperature, and 3) pressure deviation from calibration values

b) The CRD Enthalpy determination is affected by: 1) temperature, from applied constants, and 2) pressure, from reactor pressure loop error

The CRD flow loop errors are documented in calculation:

Ref. 3.4.5

The flow formula is derived from the ASME (Ref. 3.4.9) as follows:

Flow = C*Fa*K*(DP*r)^0.5

where K is calculated below:

K = Calib Flow/(Calib inWC * Calib r)^0.5

7.2.3.1 Control Rod Drive Flow Heat Error due to Flow Element and Fluid Specific Weight Uncertainty due to Temperature Error (**CRDt**)

The uncertainty is dependent for the following variables:

Fa = FE Thermal Expansion **r =** Fluid Specific Weight

The plant computer calculates the CRD flow with a constant flow K factor. However, the actual temperature could vary as much as 43F from the expected 77F, and this impacts the Fa and r impacting the calculated flow; therefore, the effect due to this temperature deviation is:

CRDt = [(hs rated - CRDh rated) (Flowrated - Flowrated+err)] x 2.93E-07 / 3889 x 100% Rev 5

Ref.: 3.4.5

K = 448.48
Calib Flow = 50154 lb/hr 100 GPM
Calib inWC = **200**
Calib Temp = **77**
Calib Press = **1474.7**
r = 62.529
Assumed Rated Flow = **32000.0 lb/hr**
Rated Press = 1020 psia
Rated Temp = **77 F**
Rated h = 47.83 btu/lb

Fa Error	
Rated 77F	1.0003
@140 F	1.0013
@40 F	0.9995
Fa/F	1.8E-05

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	81.3694	81.3694	1.0003	1.0011	77	120
0.00%	0	0.00%	0				43

Temp error = Calib Temp - Min Temp

P Rtd	r	h Rtd	Flow	hs Rtd
1020	61.9029	47.83	31,863.902	1192.19

TTL CRD Heat
36,463,826 BTU/hr

36,619,571 BTU/hr at rated conditions

Error
(155,745) BTU/hr error at rated CRD flow

Error in Rated MWt
CRDt = -0.0012% This error is a bias, not a random instrument induced uncertainty.

7.2.3.2 Control Rod Drive Flow Heat Error due to Flow Element Uncertainty (**CRDc**)

The CRD contributed heat is affected by the FE error that is assigned to the flow element expansion coefficient.

C

The FE uncertainty is determined based in calculation:

Ref.: 3.4.5

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

CRDc = [(hs rated - CRDh rated) (Flowrated - Flowrated+err)] x 2.93E-07 / 3889 x 100% | Rev 5

Fa Error				
Rated 77F	1.0003	**K =** 448.48		
@140 F	1.0013	Calib Flow = 50154	100.00	
@60 F	0.9995	Calib inWC = 200.00		
Fa/F	1.8E-05	Assumed Calib Temp = 77.00		
		Assumed Calib Press = 1474.00		
		r = 62.529	0.0159925	
		Assumed Rated Flow = 32000.0 lb/hr		
		Rated Press = 1020 psia		
		Rated Temp = 77 F		
		Rated h = 47.83 btu/lb		

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0200	81.3694	81.3694	1.0003	1.0003	77	77
2.00%	200	0.00%	0				0

P Rtd	r	h Rtd	Flow	hs Rtd
1020.00	62.4433	47.83	32,617.500	1192.19

Rev 5

TTL MFW Heat
37,326,215 BTU/hr | Rev 5

36,619,571 BTU/hr at rated conditions

Error
706,644 BTU/hr error at rated CRD flow

Rev 5

Error in Rated MWt
CRDc = 0.0053% | Rev 5

7.2.3.3 Control Rod Drive Heat Error due to Differential Pressure (DP) Loop Uncertainty (**CRDdp**)

This error is calculated in calculation:

Ref.: 3.4.5

The loop is comprised of 1) flow transmitter, FT, 2) resistor, REST, 3) computer analog to digital card, A/D.
The uncertainties are in % DP span:

Accuracy: **Loop Drift:**

CRD_AFT	CRD_AREST	CRD_AA/D	CRD_VDFT	CRD_VDA/D
1.154%	0.100%	0.188%	1.450%	0.000%

Loop Calibration:

CRD_CEFT	CRD_CEA/D
0.140%	0.188%

The uncertainties are random and independent and combined by the SRSS method:

1.88%	span DP

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

CRDdp = [(hs rated - CRDh rated) (Flowrated - Flowrated+err)] x 2.93E-07 / 3889 x 100% | Rev 5

Fa Error

Rated 77F	1.0003
@140 F	1.0013
@60 F	0.9995
Fa/F	1.8E-05

K = 448.51
Calib Flow = 50157.2 lb/hr 100 GPM
Calib inWC = 200
Assumed Calib Temp = 77
Assumed Calib Press = 1474
r = 62.529
Assumed Rated Flow = 32000.0 lb/hr
Rated Press = 1020.0 lb/hr
Rated Temp = 77 F
CRDh rated = 47.83 btu/lb

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	81.3584	85.1183	1.0003	1.0003	77	77
0.00%	0	1.88%					0

P Rtd	r	CRDh rated	Flowrated+err	hs Rtd
1020	62.4433	47.83	32,708.537	1192.19

TTL MFW Heat
37,430,393 BTU/hr

36,619,571 BTU/hr at rated conditions

Error
810,822 BTU/hr at rated CRD flow

Error in Rated MWt
CRDdp = 0.0061% | Rev 5

7.2.3.4 Control Rod Drive Flow Enthalpy Heat Error due to Temperature Calibration Deviation (**CRDht**)

The plant computer calculates the CRD fluid enthalpy at a constant 77F and reactor pressure. However, the actual temperature varies and it is assumed to vary as much as 43F from the expected 77F; therefore, the effect due to this temperature deviation in the calculated enthalpy is:

Ref. 3.4.5

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

CRDht = [Flow (hs rated - CRDh rated) - Flow (hs rated - CRDh rated+err)] x 2.93E-07 / 3889 x 100% | Rev 5

TRtd	T Max/Min	T+err	P Rtd	h rated	h+err	hs rated	Flow
77	40	37	1020	47.83	8.05	1192.19	32,000

TTL RWCU Heat
37,892,585 BTU/hr

36,619,571 BTU/hr at rated conditions

Error
(1,273,014) BTU/hr at rated CRD flow

Uncertainty in Rated MWt
CRDht = -0.0096%

This error is a bias, not a random instrument induced uncertainty. | Rev 5

7.2.3.5 Control Rod Drive Flow Enthalpy Heat Error due to Pressure Loop Uncertainty (**CRDhp**)

The plant computer calculates the CRD fluid enthalpy at a constant 77Fand reactor loop pressure, that is affected by the loop uncertainty.
The pressure loop uncertainty is documented in:

Ref.: 3.4.4

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

CRDhp = [Flow (hs rated - CRDh rated) - Flow (hs rated+err - CRDh rated)] x 2.93E-07 / 3889 x 100% | Rev 5

P Rtd	P+err	TRtd	CRDh rated	hs rated	hs rated+err	Flow
1020	1026.1	77	47.83	1192.19	1191.96	32,000

Rev 5

Error (psi) = 6.1

TTL MFW Heat
36,612,216

BTU/hr | Rev 5

36,619,571 BTU/hr at rated conditions | Rev 5

Error
(7,355) BTU/hr at rated CRD flow | Rev 5

Uncertainty in Rated MWt
CRDhp = -0.00006% | Rev 5

7.2.4 Reactor Water Cleanup Uncertainty(ies)

Referring to the schematic drawing in section 4.0, it can be seen that RWCU flow is measured and mass calculated by a "NUMAC" process unit. Differential pressure, temperature, by dedicated thermocouples, and reactor pressure are an input to the instrument. Therefore, the RWCU contributed heat is affected by the following parameters:

a) Mass Flow Measurement affected by: 1) flow, 2) temperature, and 3) pressure induced factors/instrumentation loops errors

b) The RWCU Enthalpy determination is affected by: 1) temperature instrumentation loop error (see discussion for pressure)

The flow formula is derived from the ASME (Ref. 3.4.9) as follows:

Flow = C*K*(DP)^0.5

where K is:

K = Calib Flow / [C*(Calib inWC)^0.5]

7.2.4.1 RWCU Inlet/Outlet Flow Heat Error due to Flow Element Expansion deviation from Calibration (**RWCU$_{Fa}$**)

The Numac computer calculating the mass flow has a built-in Fa constant different than the flow element Fa provided at the calculated venturi rated temperature of 533F. This induces a bias error. Furthermore, the plant NUMAC normalizes the flow mass signal to a specific weight of 47.0 lbm/cuft for pressure and temperature conditions, back calculated below; therefore, the rated conditions are set at 530.7F. Rev 5

Pressure Density Compensated to :	47.19 lb/cuft	530.7 F	**908 psia**	Rev 5
The Fa used in the calculation is fixed to:		1.0045		
The correct Fa at rated 533 F is:		1.0087		

Based on the Fa differences the induced flow error is calculated below:

Fa = FE Thermal Expansion

Ref.: 3.4.10

Flow+err = C x Fa+err / Fa x K x (DP)^0.5

K = 9449.90 Rev 5

Calib Flow = 189823.1 lb/hr **500 GPM** (Note)

Calib inWC = **403.5**

Assumed Calib Temp = **530.7** Rev 5

Assumed Calib Press = **1114.7**

r = 47.332 Rev 5

Assumed Rated Flow = 148021 lb/hr **389 GPM**

Rated h = 524.83 btu/lb

Fa Error

Rated 533F	**1.0087**
Calibrated	**1.0045**

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	245.3520	245.3520	1.0087	1.0045	530.7	530.7
0.00%	0	0.00%	0				0

P Rtd	P+err	r	h Rtd	Flow+err
1114.7	1114.7	47.3324	524.83	147,404
	0			

Rev 5

Uncertainty
RWCUFa -616.3 lb/hr

This a bias and the actual contributed Heat is Higher than indicated Rev 5

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.2 RWCU Inlet/Outlet Flow Heat Error due to Fluid Specific Weight deviation (**RWCUPMA**)

This error is the combination of several uncertainties calculated below:

7.2.4.2.1 RWCU Inlet/Outlet Flow Error due to Fluid Specific Weight Numac Lookup Tables Error (**RWCUPMA1**)

The Numac performs the fluid specific weight determination with an error of 0.1 specific weight, this effect in the flow is calculated below.

r = Fluid Specific Weight

Ref.: 3.4.10

Flow+err = C x K x (DP x r+err / r)^0.5

The flow error is the difference between the rated flow at rated specific weight minus the flow at specific weight plus error:

RWCUPMA1 = Flowrated - Flowrated+error

		K = 9449.90			Rev 5
		Calib Flow = 189823.1 lb/hr	500 GPM	(Note)	
Fa Error		Calib inWC = 403.5			
Rated 533F	1.0087	Assumed Calib Temp = 530.7			Rev 5
Calibrated	1.0045	Assumed Calib Press = 1114.7			
		r = 47.332			Rev 5
		Assumed Rated Flow = 148021 lb/hr	388.8 GPM		
		Rated hout = 524.83 btu/lb			

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	
1.0000	1.0000	245.3520	245.3520	1.0087	1.0087	530.7	Rev 5
0.00%	0	0.00%	0				

P Rtd	P+err	r	Numac err	r+perr+Numac	h Rtd	Flow	
1114.7	1114.7 psi	47.332	0.1	47.432	524.83	148,177	Rev 5
	0 psi						

Uncertainty
RWCUPMA1 = 156.3 lb/hr

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.2.2 RWCU Inlet/Outlet Flow Error due to Fluid Specific Weight Numac 0.75 Factor Pressure Correction Factor Error (**RWCUPMA2**)

The Numac computer introduces a 0.75 factor to the input pressure raw value and calculates the specific weight for saturated conditions, which bias the actual flow.

Ref.: 3.4.10

Flow+err = C x K x (DP x r+err / r)^0.5

The flow error is the difference between the rated flow at rated specific weight minus the flow at specific weight plus error:

RWCUPMA2 = Flowrated - Flowrated+error

r = Fluid Specific Weight

		K = 9449.90			Rev 5
		Calib Flow = 189823.1 lb/hr	500 GPM	(Note)	
Fa Error		Calib inWC = 403.5			
Rated 533F	1.0087	Assumed Calib Temp = 530.7			Rev 5
Calibrated	1.0045	Assumed Calib Press = 1114.7			
		r = 47.332			Rev 5
		Assumed Rated Flow = 148021 lb/hr	388.8 GPM		
		Rated = 524.83 btu/lb			

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	
1.0000	1.0000	245.3520	245.3520	1.0087	1.0087	530.7	Rev 5
0.00%	0	0.00%	0				

P Rtd	P+err	T Sat	r+perr	Numac rerr	r+perr+Numac	h Rtdout	h Rtd return	Flow
1114.7	840 psi	523.8	47.5905	0	47.5905	524.83	412.64	148,424
	75%	75						

Uncertainty
RWCUPMA2 = -403 lb/hr

This a bias and the actual contributed Heat is Higher than indicated — Rev 5

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.2.3 RWCU Inlet/Outlet Flow Heat Error due to Fluid Specific Weight Pressure Loop Uncertainty (**RWCUP_SW**)

Pressure is utilized as an input to the Numac to determine the specific weight of the fluid. The pressure loop uncertainty combined with the Numac computer uncertainty introduces an error in the calculated specific weight.

The loop error is comprised of 1) pressure loop, PT, 2) NUMAC computer uncertainties. The combined uncertainties are:

RWCUpress error=	21 psi

Ref.: 3.4.10

Flow+err = C x K x (DP x r+err / r)^0.5

The flow error is the difference between the rated flow at rated specific weight minus the flow at specific weight plus error:

RWCUp_SW = [Flowrated (h_in - h_out) - Flowrated+error (h_in - h_out)] x 2.93E-07 / 3889 x 100% Rev 5

r = Fluid Specific Weight

K = 9449.90 Rev 5

Calib Flow = 189823.1 lb/hr 500 GPM (Note)

Calib inWC = 403.5

Fa Error	
Rated 533F	1.0087
Calibrated	1.0045

Assumed Calib Temp = 530.7 Rev 5

Assumed Calib Press = 1114.7

r = 47.332 Rev 5

Assumed Rated Flow = 148021 lb/hr 388.8 GPM

Rated h = 524.83 btu/lb

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd in	T Rtd out
1.0000	1.0000	245.3520	245.3520	1.0087	1.0087	530.7	433.8
0.00%	0	0.00%	0				

P Rtd	P+err	r+perr	Numac rerr	r+perr+Numac	h Rtd in	h Rtd out	Flow	
1020	1041 psi	47.2821	0	47.2821	524.96	412.64	147,942	Rev 5

TTL MFW Heat	
16,616,340	BTU/hr

Rev 5

16,625,169 BTU/hr at rated conditions Rev 5

Error

8,829 Rev 5

Uncertainty in Rated MWt
RWCUp_sw = 0.0001%

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.3 Reactor Water Cleanup Flow Error due to Flow Element Uncertainty (**RWCUc**)

The RWCU flow is affected by the FE error that is assigned to the flow element expansion coefficient.

C

The FE uncertainty is determined based in calculation:

Ref.: 3.4.10

Flow+err = C+err x K x (DP)^0.5

The flow error is the difference between the rated flow minus the flow with the C coefficient error:

RWCUc = Flowrated - Flowrated+error

Fa Error		**K =** 9449.90			Rev 5
Rated 533F	1.0087	Calib Flow = 189823.1 LB/HR	500 GPM	(Note)	
Calibrated	1.0045	Calib inWC = 403.50			
		Assumed Calib Temp = 530.70			Rev 5
		Assumed Calib Press = 1114.70			
		r = 47.332			Rev 5
		Assumed Rated Flow = 148021 lb/hr	389 GPM		
		Rated h = 524.83 btu/lb			

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0150	245.3520	245.3520	1.0087	1.0087	530.7	530.7
1.50%	150	0.00%	0				0

P Rtd	r	h	Flow	
1114.7	47.3324	524.8	150,241	Rev 5

Uncertainty
RWCUc = 2220.3 lb/hr Rev 5

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.4 Reactor Water Cleanup Flow Error due to Differential Pressure (DP) Loop Uncertainty (**RWCUdp**)

This error is introduced by the differential pressure instrument loop. The uncertainties in the loop are found in: Ref.: 3.4.10

The loop is comprised of 1) flow transmitter, FT, 2) NUMAC computer. The uncertainties are in % DP span:

The flow error is the difference between the rated flow minus the flow with the C coefficient error:

RWCUdp = Flowrated - Flowrated+error

Accuracy: **Loop Drift:**

RWCU_AFT	RWCU_ANU_IE	RWCU_ANU_A/D	RWCU_VDFT	RWCU_VDNU_IE	RWCU_VDNU_A/D
0.503%	0.100%	0.233%	0.900%	0.127%	0.127%

Loop Calibration:

RWCU_CEFT	RWCU_CENU_A/D
0.139%	0.02%

The uncertainties are random and independent and combined by the SRSS method:

1.09%	span DP

Flow+err = C x K x (DP+err)^0.5

Fa Error
Rated 533F 1.0087
Calibrated 1.0045

K = 9449.90
Calib Flow = 189823.1 LB/HR 500 GPM (Note) Rev 5
Calib inWC = 403.50
Assumed Calib Temp = 530.70 Rev 5
Assumed Calib Press = 1114.70
r = 47.332 Rev 5
Assumed Rated Flow = 148021 LB/HR 389 GPM
Rated h = 524.83 btu/lb

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	245.3520	249.7338	1.0087	1.0087	530.7	530.7
0.00%	0						0

P Rtd	r	h	Flow
1114.7	47.3324	524.83	149,336

Rev 5

Uncertainty
RWCUdp = 1315.9 lb/hr Rev 5

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.5 Reactor Water Cleanup Flow Error due to Signal Conditioning/NSSS Computer Loop Uncertainty **(RWCUNSSS_cptr)**

The differential pressure is converted to flow by the Numac computer and retransmitted as flow signal to the plant computer for heat balance calculations.

This portion of the loop is comprised of 1) NUMAC computer output, 2) NSSS computer uncertainty. The uncertainties are in % flow span:

Accuracy:

RWCU_ANU_D/A	RWCU_AA/D
0.233%	0.188%

Loop Drift:

RWCU_VDNU_D/A	RWCU_VNA/D
0.13%	0.000%

Loop Calibration:

RWCU_CENU_D/A	RWCU_CEA/D
0.02%	0.188%

The uncertainties are random and independent and combined by the SRSS method:

0.38%	span FLOW

The flow error is the difference between the rated flow at without loop error minus the flow plus loop error:

RWCUNSSS_cptr = Flowrated - Flowrated+error

Fa Error		**K =** 9449.90			Rev 5
Rated 533F	1.0087	Calib Flow = 189823.1 lb/hr	500 GPM	(Note)	
Calibrated	1.0045	Calib inWC = 403.50			
		Assumed Calib Temp = 530.70			Rev 5
		Assumed Calib Press = 1114.70			
		r = 47.332			Rev 5
		Assumed Rated Flow = 148021 lb/hr	389 GPM		
		Rated h = 524.83 btu/lb			

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	245.3520	245.3520	1.0087	1.0087	530.7	530.7
0.00%	0						0

P Rtd	r	h	Flowrated+err
1114.7	47.3324	524.83	148,733.9

Rev 5

Uncertainty
RWCUNSSS_cptr= 713.3 lb/hr

Rev 5

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.6 Reactor Water Cleanup Total Flow due to Flow Loop Uncertainties (**RWCUf**)

RWCU Inlet h - Outlet h.

The total RWCU Flow Uncertainty is calculated below:

RWCUfu =+/-SQRT(RWCUPMA1^2+RWCUc^2+RWCUdp^2+RWCUNSSS_cptr^2)-RWCUFa-RWCUPMA2

Notice that the bias PMAs are factored with both signs, since the negative uncertainty is the one that has impact in the heat balance calculations, that is, that (-) less indication means that power is higher; however, it will be factored in both directions for simplicity.

RWCUfu = 3710 lb/hr

Then, the heat error contribution is the calculated inlet flow heat error minus the outlet flow heat error:

RWCUh_in = 524.96 btu/lb
RWCUh_out = 412.64 btu/lb

Rev 5

And the RWCU heat error contribution is calculated by the following expression:

RWCU = [RWCUfu (RWCUh_in - RWCUh_out) x MWt_BTU_hr (conversion factor)] / Rated MWt 100%

RWCUf = 0.0031% This total error will be treated as bias in the total heat balance error

Rev 5

7.2.4.7 Reactor Water Cleanup Flow Enthalpy Heat Error due to Temperature Uncertainty (RWCUht)

This error is the error resultant of temperature measurement errors by the inlet/outlet RWCU thermocouple loops factored into the fluid enthalpy determination. The thermocouples are instruments with good repeatability and stability. However, fabrication errors can amount to several farenheit degrees. The fabrication errors can be calibrated out, since essentially it is a bias, systematic error. The temperature loops for RWCU are not calibrated out. Finally, since most of the thermocouples loop error is a bias, the conservative and safe way to apply the error, is for the two temperature error to be set in the same direction; therefore, the effect is additive, bias. The temperature loops error is found in:

Ref. 3.4.6

The heat error is the difference between the inlet flow heat error minus the outlet flow heat error:

RWCUht = [Flow [(hin - hin+error) + (hout - hout+error)]] x 2.93E-07 / 3889 x 100% | Rev 5

In flow heat

TRtd	T+err	P Rtd	h rated	h+err	Flow
530.7	541.6	1020	524.96	538.69	148,021
Error (F)	**10.9**				

Rev 5

Out flow heat

TRtd	T+err	P Rtd	h rated	h+err	Flow
433.8	444.7	1020	412.64	424.67	148,021
Error (F)	10.9				

Rev 5

Error	
3,813,151	**BTU/hr error at rated reactor water cleanup flow**

Rev 5

Uncertainty in Rated MWt	
RWCUht = 0.0287%	This error is a bias

Rev 5

7.2.4.8 Reactor Water Cleanup Flow Enthalpy Heat Error due to Pressure Loop Uncertainty (**RWCUhp**)

The reactor water cleanup enthalpy determination is affected by the loop pressure error. The pressure has a very small effect in the water enthalpy, however, it is determined in this calculation. The loop uncertainty is documented in:

Ref.: 3.4.4

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

RWCUhp = [Flow [(hin - hin+error) - (hout - hout+error)]] x 2.93E-07 / 3889 x 100% Rev 5

In flow heat

P Rtd	P+err	TRtd	h rated	h+err	Flow
1020	1040.2	530.7	524.96	524.93	148,000
Error (psi)	20.2				

Rev 5

Out flow heat

P Rtd	P+err	TRtd	h rated	h+err	Flow
1020	1040.2	433.8	412.64	412.66	148,000
Error (psi)	20.2				

Rev 5

Error

6,672 BTU/hr at rated reactor water cleanup flow Rev 5

Uncertainty in Rated MWt
RWCUhp = 0.00005%

7.2.5 Recirculation Pumps Heat Error due to Watts Loop Uncertainty (**RRPw**)

This section calculates the uncertainty due to RRP watts loop error, calculated in:

Ref.: 3.4.11

The rated power for the pump-motor and the motor efficiency (0.93) is from reference:

(Ref. 3.4.3)

There are two recirculation pumps, the calculated error below is per pump. The actual total MW for the 2 pumps is taken from above reference.

W 2 pump = 7.33

The Watt error contribution is calculated as follows:

RRPw = [(W Rtd/pump + MW Loop Span x Span err) x Motor eff] - W Rtd/pump x Motor eff] / 3889 x 100% Rev 5

W Rtd/pmp+err	Motor Eff	W+err
3.823	0.93	3.55
	Error =	1.50 % span
	Span =	10.5 Mwatt

TTL Mwatt	
3.41	Mwatt

Error

0.1465 Mwatt

Uncertainty in Rated MWT

RRPw = 0.0038%

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	2/14/2017	John Wilkens	3/13/2017	N/A	N/A

7.2.6 Thermal Loses (TL)

This section calculates the uncertainty due to TL error. This error will be treated as a bias error since the estimated value is larger or smaller than assumed, i.e. it is a fixed error not a random error.

An assumed error equal to 20% of the specified loses is used.

The rated Heat Loss is from reference:

(Ref. 3.4.2)

W Rtd	W+err
1.1	1.32
Error =	20.00%

TTL Mwatt Heat
1.32

MW

1.10 MW at rated conditions

Error

0.2200 MW error at rated radiated loses

Uncertainty in Rated MWT
TL = 0.0057%

This error is treated as bias.

Rev 5

Note: The computer utilizes this value combined with Other System Loses (Section 7.2.7) as Radiative power loses, QRAD = 1.94

7.2.7 Other System Loses (**OSL**)

The rated value includes Rod Dr ve seal purge flow to recirculation pumps. An assumed error equal to 20% of the specified loses is used.
This error will be treated as a bias error since if the estimated value is larger or smaller than assumed, i.e. it is a fixed error not a random error.

The rated Losses figure is from reference:

(Ref. 3.4.2)

W Rtd	W+err
1.18	1.416
Error =	**20%**

Rev 5

TTL Mwatt Heat		
1.42	MW	Rev 5
1.18	MW at rated conditions	Rev 5
Error		
0.2360	**MW error at rated radiated loses**	Rev 5

Uncertainty in Rated MWT	
OSL = 0.0061%	This error is treated as bias.

Rev 5

Note: The computer utilizes this value combined with Thermal Loses (Section 7.2.6) as Radiative power loses, QRAD = 1.94

7.2.8 Heat Balance Calculation Power Uncertainty (**Power U**)

The calculated heat balance uncertainty is the algebraic combination of the bias errors with the independent/random errors statistically combined, that contribute into the heat balance calculation, in accordance with the heat balance formula:

Power = MFW(MSh-FWh)-CRDF(hin-hout)+RWCU(hout-hin)-RRP+HL+Miscellaneous

Summary of Heat Balance Calculation Contributing Errors:

Random Errors:	MSmoist = 0.0000%	Rev 5
	CRDc = 0.0053%	
	CRDdp = 0.0061%	
	RRPw = 0.0038%	
	RWCUp_sw = 0.0001%	
Dependent Errors:	Errors	Variable
	FWhp = **	Rated MS pressure = 1020 psia
	FWm = **	
	FWht = **	
	MSm = **	
	MShp = 0.0296%	
	CRDhp = -0.00006%	
	RWCUhp = 0.00005%	
Bias Errors:	CRDt = -0.0012%	
	CRDht = -0.0096%	
	RWCUf = 0.0031%	
	RWCUht = 0.0287%	
	TL = 0.0057%	
	OSL = 0.0061%	

** Note that these terms are combined in reference 3.4.20 for an over all uncertainty of 0.66% for FWm, FWht and FWhp

Heat Balance Calculation Power Error (U):

Power Error = SQRT[((0.0066)^2+(MShp+CRDhp+RWCUhp)^2+MSmoist^2+CRDc^2+CRDdp^2+ +RWCUp_sw^2+RRPw^2x2]+CRDt+CRDht+RWCUf+RWCUht+TL+OSL — Rev 5

Power Error = **0.694%** — Rev 5

To ensure operation margin exist, due to possible instrumentation loops miss-calibration, actual drift (to be determined by history), etc., a margin is added:

Power U = Power Error + Margin

where margin is defined as 3840 * 102% – Rated Thermal Power – Power Error

Margin = 3916.8 - 3889 - Power Error
Margin = 0.021% and **Power U = 0.715%** — Rev 5

8.0 SUMMARY

The calculated Heat Balance Error performed in this calculation is applicable to fully operational LEFM. The Power Uncertainty is the difference between the 2% design basis and the rated termal power for the current LEFM mode of operation. Positive margin is maintained between the Power Uncertainty and the Power Error. The Heat Balance calculation error (Section 7.0) is: Rev 5

Power U = 0.715% Rev 5

(NC.DE-AP.ZZ-0002(Q), Rev. 12, Form 2)		CALCULATION CONTINUATION SHEET			SHEET: 1
CALC NO.: SC-BB-0525 Attachment 3	REV: 5	REF:			CONT'D ON SHEET: 2
ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	2/14/2017	John Wilkens	3/13/2017	N/A	N/A

Sections 1 through 4 have been replaced with the main body of the calculation

5.0 DESIGN INPUTS

5.1 Rated Power Conditions

100% rated Power Conditions are listed below. Actual 100% operation values might be used in lieu of rated nominal values, for other than Rated MWt, Feedwater Flow and Main Steam parameters as deemed appropriate. This is found acceptable, since for the purpose of error determination to rated MWt "heat differential errors", actual heat contribution deviation from measured/calculated heat to rated MWt due to instrumentation uncertainties, is required not the actual deviation value.

Rated MWt =	**3840MW**	(Ref. 3.4.17, 3.2.4)	Rev 5
Rated FW flow =	**1.6741E+07lbm/hr**	(Ref. 3.4.17)	
Rated FW temperature =	**431.6 F**	(Ref. 3.4.17)	
Rated MS flow =	**16773000**	(Ref. 3.4.17)	
Rated MS pressure =	**1020 psia**	(Ref. 3.4.17)	
Rated MS quality =	**100.000**	(Ref. 3.4.1)	
Rated RWCU flow =	**148000.0 lb/hr**	(Ref. 3.4.17)	Rev 5
Rated RWCU temperature =	**530.8 F**	(Ref. 3.4.17)	
Rated RWCU return temperature =	**433.9 F**	(Ref. 3.4.17)	
Rated CRD flow =	**32000.0 lb/hr**	(Ref. 3.4.3, 3.4.17)	
CRD Calibration pressure =	**1474.0 psia**	(Ref. 3.4.5)	
Rated CRD temperature =	**77 F**	(Ref. 3.4.5)	
Radiation Loses =	**1.10MW**	(Ref. 3.4.2, 3.4.17)	Rev 5
Other System Loses =	**1.18MW**	(Ref. 3.4.2, 3.4.17) Note: These loses are not included in UFSAR Heat Balance, Ref. 3.1.1	
MWt/BTU/hr =	**2.9300E-07**	(Ref. 3.4.1)	

Power = MFW(MSh-FWh)-CRDF(hin-hout)+RWCU(hout-hin)-RRP+HL+Miscellaneous

Notes:

1) This calculation uses rated MS quality of 100.00%, which will produce a more conservative number with respect to the actual plant MS quality. This parameter may be revised when the actual MS quality is measured after the implementation of EPU.
2) This calculation specifies radiation loses as 1.10 MW and other loses as 0.84 MW for the total lose of 1.94 MW. Reference 3.4.17 stated "other system loses" as 1.9 MW without specifically accounting for Radiation loses. Since the two total numbers are almost identical and the difference would have negligible affect on the Power Error, radiation loses of 1.10 MW and the other loses of 0.84 MW will be maintained.

6.0 ASSUMPTIONS

See sections 7.2.3, 7.2.4, 7.2.6 and 7.2.7 for specific assumptions. Rev 5

7.0 CALCULATIONS

7.1 Methodology

The methodology used to combine the uncertainties for the different contributors to the heat balance calculation is the square root of the sum of the squares of those uncertainties which are statistically independent. Then algebraically combined with the those errors that are systematic, or bias. The uncertainties are considered to be random, two sided distributions. This methodology has been utilized before, and has been endorsed by the NRC and various industry standards (Ref. 3.4.12-3.4.14).

The uncertainty calculation combines the different errors from the different parameters contributing to the heat balance in accordance to the heat balance equation. The contributing parameters errors are taken from the specific system uncertainty calculation.

These errors are generally classified in two groups:

a) Instrument loop(s) uncertainty
b) Process effects

The individual uncertainties affecting the heat balance calculation are determined by the application of the corresponding process algorithm, as described below:

a) the appropriate algorithm for the specific process parameter is set in the form to its specific contribution to the heat balance at specified rated conditions,
b) subsequently, the instrumentation loop error is factored in the process algorithm to calculate the corresponding process parameter with the error built-in,
c) the difference of the calculated contributed process parameter heat, with error, to the rated process rated heat is then calculated,
d) the resultant heat error contribution is then divided by the rated 100% power thermal megawatts. The result is the error contribution by the specific process to the total heat balance uncertainty,
e) finally, all the calculated heat errors are combined in accordance to their parameter function in the heat balance equation. The resultant combination of all contributing errors is the Heat Balance Uncertainty.

7.2 Uncertainties Calculation

7.2.1 Main Feedwater Uncertainty(ies)

Referring to the schematic drawing in section 4.0, it can be seen that the Main Feedwater heat contribution is affected by the following parameters:

a) Mass Flow Measurement affected by: 1) flow, 2) temperature, and 3) pressure instrumentation loops error.

The error provided by the vendor for the ultrasonic flow meter already factors the corresponding temperature and pressure loops effect.

b) Feedwater Enthalpy determination affected by: 1) temperature, and 2) pressure, instrumentation loops error.

The main feedwater enthalpy is calculated using the following signals:

- Main Steam Pressure and Main Feedwater Temperature

The main feedwater mass error is provided as percentage of span at 100% rated power at span of 20,000,000 lbm/hr as documented in Ref.: 3.4.7 Section 7.12.3. The number to be used for 100% flow is positive error of +0.72% flow span at 20,000,000 lbm/hr span or 144,000 lbm/hr.
(Note: Ref.: 3.4.7 Section 7.12.1 NSSS Computer-Feedwater Flow took credit for constant correction of feedwater flow by crossflow. For this calculation where crossflow correction is not credited, the number in Section 7.12.1 cannot be used. Instead the error calculated in Section 7.12.3: GETARS Total Flow 3840 MWt should be used. The propagation of feedwater flow error is identical between NSSS computer and GETARS computer, i.e. both their loops consist of feedwater nozzles, flow transmitters, DFCS Foxboro interface modules, and computers.)

The heat error is the difference in the MFW heat content at rated flow conditions minus the heat error content at rated conditions plus flow error:

FWm = [hrated (Flowrated - Flowrated+err)] x 2.93E-07/3840 x100%

F Rtd	F+err	P Rtd	TRtd	h rated
16,741,000	16,885,000	1020	431.6	410.23

Error % reading **0.7200%**

TTL MFW Heat
6,926,704,606 BTU/hr

6,867,631,732 BTU/hr at rated conditions

Error
59,072,873 BTU/hr at rated main feedwater flow

Uncertainty in Rated MWT
FWm = 0.4507%

7.2.1.2 Main Feedwater Heat Enthalpy Error due to Pressure Loop Uncertainty (**FWhp**)

The main feedwater enthalpy is determined from reactor loop pressure, that is affected by the loop uncertainty.
The pressure loop uncertainty is documented in:

Ref.: 3.4.4

The heat error is the difference in the MFW heat content at rated flow and enthalpy conditions minus the heat content at rated flow with enthalpy at rated pressure plus pressure induced error:

FWhp = [Flow (hrated - hrated+err)] x 2.93E-07 / 3840 x 100%

P Rtd	P+err	TRtd	h rated	h+err	Flow	
1020	1026.1	431.6	410.23	410.23	16,741,000	Rev 5
Error (psi) =	6.1					

TTL MFW Heat
6,867,717,889 BTU/hr — Rev 5

6,867,631,732 BTU/hr at rated conditions — Rev 5

Error
86,156 BTU/hr at rated main feedwater flow — Rev 5

Uncertainty in Rated MWt
FWhp = 0.0007% — Rev 5

7.2.1.3 Main Feedwater Heat Enthalpy Error due to Temperature Loop Uncertainty (**FWht**)

The main feedwater enthalpy determination is affected by the loop temperature error, documented in:

Ref.: 3.4.8

The heat error is the difference in the MFW heat content at rated flow and enthalpy conditions minus the heat content at rated flow conditions with enthalpy at rated temperature plus temperature induced error:

FWht = [Flow (hrated - hrated+err)] x 2.93E-07 / 3840 x 100%

TRtd	T+err	P Rtd	h rated	h+err	Flow
431.6	433	1020	410.23	411.91	16,741,000

Error (F) = 1.53 This error is subject to change depending in performance history

TTL MFW Heat
6,895,730,240 BTU/hr

6,867,631,732 BTU/hr at rated conditions

Error
28,098,508 BTU/hr error at rated main feedwater flow

Uncertainty in Rated MWt
FWht = 0.2144%

7.2.2 Main Steam Flow Uncertainty(ies)

Referring to the schematic drawing in section 4.0, It can be seen that the Main Steam heat contribution is affected by the following parameters:

a) The calculated Main Steam Heat is affected by the mass flow measurement error (see section 7.2.1.1 Main Feedwater Mass Error).

b) Main Steam Enthalpy determination is affected by the pressure instrumentation loop error, documented in calculation:

Ref. 3.4.4

7.2.2.1 Main Steam Mass Flow Heat Error due to Main Feedwater Flow Uncertainty (**MSm**)

The main feedwater mass error is provided from Section 7.2.1.1:

The heat error is the difference in the Main Steam flow heat content at rated flow conditions minus the heat content at rated conditions plus flow error:

MSm = [hs rated (Flowrated - Flowrated+err)] x 2.93E-07 / 3840 x 100%

FWFEerr = 0.7200% Span Mass Flow

F Rtd	F+err	P Rtd	Moist Rtd	hs rated
16,773,000	16,917,000	1020	100	1192.19

TTL MFW Heat
20,168,331,463 BTU/hr

19,996,655,650 BTU/hr at rated conditions

Error
171,675,813 BTU/hr at rated main feedwater flow

Uncertainty in Rated MWT
MSm = 1.3099%

7.2.2.2 Main Steam Heat Enthalpy Error due to Pressure Loop Uncertainty (**MShp**)

This Section calculates the Main Heat Steam enthalpy error due to the loop pressure uncertainty, documented in:

Ref.: 3.4.4

The heat error is the difference in the Main Steam flow heat content at rated flow and enthalpy conditions minus the heat content at rated flow with enthalpy at rated pressure plus pressure induced error:

MShp = [Flow (hrated - hrated+err)] x 2.93E-07 / 3840 x 100%

P Rtd	P+err	Moist Rtd	Moist+err	h rated	h+err	Flow	
1020	1026.1	100	100.000	1192.19	1191.96	16,773,000	Rev 5
Error (psi) =	6.1		0				

TTL MS Heat
19,992,800,352 BTU/hr — Rev 5

19,996,655,650 BTU/hr at rated conditions — Rev 5

Error
3,855,299 BTU/hr error at rated main feedwater flow — Rev 5

Error in Rated MWt
MShp = 0.0294% — Rev 5

7.2.2.3. Main Steam Moisture Heat Enthalpy Error due to Steam Moisture Uncertainty (**MSmoist**)

This section calculates the Main Steam enthalpy error due to MS moisture uncertainty. The uncertainty is conservatively set to 50% of rated moisture content of 0.0%.

The heat error is the difference in the Main Steam flow heat content at rated flow and moisture conditions minus the heat content at rated moisture conditions plus moisture error:

MSmoist = [Flowrated hrated (hmoist-rated - hmoist-rated+err)] x 2.93E-07 / 3840 x 100%

P Rtd	P+err	Moist Rtd	Moist+err	h rated	h+err	Flow
1020	1020	100	100.0000	1192.19	1192.19	16,773,000
	0.00000	0.00%	0			

TTL MS Heat	
19,996,655,650	BTU/hr

19,996,655,650 BTU/hr at rated conditions

Error

\- **BTU/hr error at rated main feedwater flow**

Error in Rated MWt
MSmoist = 0.0000%

7.2.3 Control Rod Drive Flow

Referring to the schematic drawing in section 4.0, it can be seen that CRD flow is not monitored for pressure or temperature.

The CRD calculated heat is affected by the following effects:

a) Mass Flow Measurement affected by: 1) flow, instrumentation loop effect and 2) temperature, and 3) pressure deviation from calibration values

b) The CRD Enthalpy determination is affected by: 1) temperature, from applied constants, and 2) pressure, from reactor pressure loop error

The CRD flow loop errors are documented in calculation:

Ref. 3.4.5

The flow formula is derived from the ASME (Ref. 3.4.9) as follows:

Flow = C*Fa*K*(DP*r)^0.5

where K is calculated below:

K = Calib Flow/(Calib inWC * Calib r)^0.5

7.2.3.1 Control Rod Drive Flow Heat Error due to Flow Element and Fluid Specific Weight Uncertainty due to Temperature Error (**CRDt**)

The uncertainty is dependent for the following variables:

Fa = FE Thermal Expansion **r =** Fluid Specific Weight

The plant computer calculates the CRD flow with a constant flow K factor. However, the actual temperature could vary as much as 43F from the expected 77F, and this impacts the Fa and r impacting the calculated flow; therefore, the effect due to this temperature deviation is:

CRDt = [(hs rated - CRDh rated) (Flowrated - Flowrated+err)] x 2.93E-07 / 3840 x 100%

Ref.: 3.4.5

Fa Error	
Rated 77F	1.0003
@140 F	1.0013
@40 F	0.9995
Fa/F	1.8E-05

K = 448.48
Calib Flow = 50154 lb/hr 100 GPM
Calib inWC = **200**
Calib Temp = **77**
Calib Press = **1474.7**
r = 62.529
Assumed Rated Flow = **32000.0 lb/hr**
Rated Press = 1020 psia
Rated Temp = **77 F**
Rated h = 47.83 btu/lb

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	81.3694	81.3694	1.0003	1.0011	77	120
0.00%	0	0.00%	0				43

Temp error = Calib Temp - Min Temp

P Rtd	r	h Rtd	Flow	hs Rtd
1020	61.9029	47.83	31,863.902	1192.19

TTL CRD Heat
36,463,826 BTU/hr

36,619,571 BTU/hr at rated conditions

Error
(155,745) BTU/hr error at rated CRD flow

Error in Rated MWt
CRDt = -0.0012% This error is a bias, not a random instrument induced uncertainty.

7.2.3.2 Control Rod Drive Flow Heat Error due to Flow Element Uncertainty (**CRDc**)

The CRD contributed heat is affected by the FE error that is assigned to the flow element expansion coefficient.

C

The FE uncertainty is determined based in calculation:

Ref.: 3.4.5

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

CRDc = [(hs rated - CRDh rated) (Flowrated - Flowrated+err)] x 2.93E-07 / 3840 x 100%

Fa Error				
Rated 77F	1.0003	**K =** 448.48		
@140 F	1.0013	Calib Flow = 50154	100.00	
@60 F	0.9995	Calib inWC = 200.00		
Fa/F	1.8E-05	Assumed Calib Temp = 77.00		
		Assumed Calib Press = 1474.00		
		r = 62.529		0.0159925
		Assumed Rated Flow = 32000.0 lb/hr		
		Rated Press = 1020 psia		
		Rated Temp = 77 F		
		Rated h = 47.83 btu/lb		

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0200	81.3694	81.3694	1.0003	1.0003	77	77
2.00%	200	0.00%	0				0

P Rtd	r	h Rtd	Flow	hs Rtd
1020.00	62.4433	47.83	32,617.500	1192.19

TTL MFW Heat	
37,326,215	BTU/hr

36,619,571 BTU/hr at rated conditions

Error

706,644 BTU/hr error at rated CRD flow

Error in Rated MWt
CRDc = 0.0054%

7.2.3.3 Control Rod Drive Heat Error due to Differential Pressure (DP) Loop Uncertainty (**CRDdp**)

This error is calculated in calculation:

Ref.: 3.4.5

The loop is comprised of 1) flow transmitter, FT, 2) resistor, REST, 3) computer analog to digital card, A/D.
The uncertainties are in % DP span:

Accuracy: **Loop Drift:**

CRD_AFT	CRD_AREST	CRD_AA/D	CRD_VDFT	CRD_VDA/D
1.154%	0.100%	0.188%	1.450%	0.000%

Loop Calibration:

CRD_CEFT	CRD_CEA/D
0.140%	0.188%

The uncertainties are random and independent and combined by the SRSS method:

1.88%	span DP

(NC.DE-AP.ZZ-0002(Q), Rev. 12, Form 2)		CALCULATION CONTINUATION SHEET			SHEET: 13
CALC NO.: SC-BB-0525 Attachment 3	REV: 5	REF:			CONT'D ON SHEET: 14
ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	2/14/2017	John Wilkens	3/13/2017	N/A	N/A

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

CRDdp = [(hs rated - CRDh rated) (Flowrated - Flowrated+err)] x 2.93E-07 / 3840 x 100%

Fa Error

Rated 77F	1.0003
@140 F	1.0013
@60 F	0.9995
Fa/F	1.8E-05

K = 448.51
Calib Flow = 50157.2 lb/hr 100 GPM
Calib inWC = 200
Assumed Calib Temp = 77
Assumed Calib Press = 1474
r = 62.529
Assumed Rated Flow = 32000.0 lb/hr
Rated Press = 1020.0 lb/hr
Rated Temp = 77 F
CRDh rated = 47.83 btu/lb

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	81.3584	85.1183	1.0003	1.0003	77	77
0.00%	0	1.88%					0

P Rtd	r	CRDh rated	Flowrated+err	hs Rtd
1020	62.4433	47.83	32,708.537	1192.19

TTL MFW Heat
37,430,393 BTU/hr

36,619,571 BTU/hr at rated conditions

Error
810,822 BTU/hr at rated CRD flow

Error in Rated MWt
CRDdp = 0.0062%

7.2.3.4 Control Rod Drive Flow Enthalpy Heat Error due to Temperature Calibration Deviation (**CRDht**)

The plant computer calculates the CRD fluid enthalpy at a constant 77F and reactor pressure. However, the actual temperature varies and it is assumed to vary as much as 43F from the expected 77F; therefore, the effect due to this temperature deviation in the calculated enthalpy is:

Ref. 3.4.5

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

CRDht = [Flow (hs rated - CRDh rated) - Flow (hs rated - CRDh rated+err)] x 2.93E-07 / 3840 x 100%

TRtd	T Max/Min	T+err	P Rtd	h rated	h+err	hs rated	Flow
77	40	37	1020	47.83	8.05	1192.19	32,000

TTL RWCU Heat
37,892,585 BTU/hr

36,619,571 BTU/hr at rated conditions

Error
(1,273,014) BTU/hr at rated CRD flow

Uncertainty in Rated MWt
CRDht = -0.0097%

This error is a bias, not a random instrument induced uncertainty.

7.2.3.5 Control Rod Drive Flow Enthalpy Heat Error due to Pressure Loop Uncertainty (**CRDhp**)

The plant computer calculates the CRD fluid enthalpy at a constant 77Fand reactor loop pressure, that is affected by the loop uncertainty.
The pressure loop uncertainty is documented in:

Ref.: 3.4.4

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

CRDhp = [Flow (hs rated - CRDh rated) - Flow (hs rated+err - CRDh rated)] x 2.93E-07 / 3840 x 100%

P Rtd	P+err	TRtd	CRDh rated	hs rated	hs rated+err	Flow	
1020	1026.1	77	47.83	1192.19	1191.96	32,000	Rev 5

Error (psi) = 6.1

TTL MFW Heat		
36,612,216	BTU/hr	Rev 5

36,619,571 BTU/hr at rated conditions — Rev 5

Error

(7,355) BTU/hr at rated CRD flow — Rev 5

Uncertainty in Rated MWt	
CRDhp = -0.00006%	Rev 5

7.2.4 Reactor Water Cleanup Uncertainty(ies)

Referring to the schematic drawing in section 4.0, it can be seen that RWCU flow is measured and mass calculated by a "NUMAC" process unit. Differential pressure, temperature, by dedicated thermocouples, and reactor pressure are an input to the instrument. Therefore, the RWCU contributed heat is affected by the following parameters:

a) Mass Flow Measurement affected by: 1) flow, 2) temperature, and 3) pressure induced factors/instrumentation loops errors

b) The RWCU Enthalpy determination is affected by: 1) temperature instrumentation loop error (see discussion for pressure)

The flow formula is derived from the ASME (Ref. 3.4.9) as follows:

Flow = C*K*(DP)^0.5

where K is:

K = Calib Flow / [C*(Calib inWC)^0.5]

7.2.4.1 RWCU Inlet/Outlet Flow Heat Error due to Flow Element Expansion deviation from Calibration (**RWCUFa**)

The Numac computer calculating the mass flow has a built-in Fa constant different than the flow element Fa provided at the calculated venturi rated temperature of 533F. This induces a bias error. Furthermore, the plant NUMAC normalizes the flow mass signal to a specific weight of 47.0 lbm/cuft for pressure and temperature conditions, back calculated below; therefore, the rated conditions are set at 530.8F.

Pressure Density Compensated to :	47.18 lb/cuft	530.8 F	**908 psia**
The Fa used in the calculation is fixed to:		1.0045	
The correct Fa at rated 533 F is:		1.0087	

Based on the Fa differences the induced flow error is calculated below:

Fa = FE Thermal Expansion

Ref.: 3.4.10

Flow+err = C x Fa+err / Fa x K x (DP)^0.5

K = 9448.61
Calib Flow = 189797.2 lb/hr **500 GPM** (Note)
Calib inWC = **403.5**
Assumed Calib Temp = **530.8**
Assumed Calib Press = **1114.7**
r = 47.326
Assumed Rated Flow = 148000 lb/hr **389 GPM**
Rated h = 524.95 btu/lb

Fa Error
Rated 533F **1.0087**
Calibrated **1.0045**

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	245.3519	245.3519	1.0087	1.0045	530.8	530.8
0.00%	0	0.00%	0				0

P Rtd	P+err	r	h Rtd	Flow+err
1114.7	1114.7	47.3259	524.95	147,384
	0			

Uncertainty
RWCUFa -616.2 lb/hr

This a bias and the actual contributed Heat is Higher than indicated

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.2 RWCU Inlet/Outlet Flow Heat Error due to Fluid Specific Weight deviation (**RWCUPMA**)

This error is the combination of several uncertainties calculated below:

7.2.4.2.1 RWCU Inlet/Outlet Flow Error due to Fluid Specific Weight Numac Lookup Tables Error (**RWCUPMA1**)

The Numac performs the fluid specific weight determination with an error of 0.1 specific weight, this effect in the flow is calculated below.

r = Fluid Specific Weight

Ref.: 3.4.10

Flow+err = C x K x (DP x r+err / r)^0.5

The flow error is the difference between the rated flow at rated specific weight minus the flow at specific weight plus error:

RWCUPMA1 = Flowrated - Flowrated+error

K = 9448.61
Calib Flow = 189797.2 lb/hr 500 GPM (Note)
Calib inWC = 403.5
Assumed Calib Temp = 530.8
Assumed Calib Press = 1114.7
r = 47.326
Assumed Rated Flow = 148000 lb/hr 388.8 GPM
Rated hout = 524.95 btu/lb

Fa Error
Rated 533F 1.0087
Calibrated 1.0045

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd
1.0000	1.0000	245.3519	245.3519	1.0087	1.0087	530.8
0.00%	0	0.00%	0			

P Rtd	P+err	r	Numac err	r+perr+Numac	h Rtd	Flow
1114.7	1114.7 psi	47.326	0.1	47.426	524.95	148,157
	0 psi					

Uncertainty
RWCUPMA1 = 156.3 lb/hr

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.2.2 RWCU Inlet/Outlet Flow Error due to Fluid Specific Weight Numac 0.75 Factor Pressure Correction Factor Error (**RWCUPMA2**)

The Numac computer introduces a 0.75 factor to the input pressure raw value and calculates the specific weight for saturated conditions, which bias the actual flow.

Ref.: 3.4.10

Flow+err = C x K x (DP x r+err / r)^0.5

The flow error is the difference between the rated flow at rated specific weight minus the flow at specific weight plus error:

RWCUPMA2 = Flowrated - Flowrated+error

r = Fluid Specific Weight

		K = 9448.61		
		Calib Flow = 189797.2 lb/hr	500 GPM	(Note)
Fa Error		Calib inWC = 403.5		
Rated 533F	1.0087	Assumed Calib Temp = 530.8		
Calibrated	1.0045	Assumed Calib Press = 1114.7		
		r = 47.326		
		Assumed Rated Flow = 148000 lb/hr	388.8 GPM	
		Rated = 524.95 btu/lb		

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd
1.0000	1.0000	245.3519	245.3519	1.0087	1.0087	530.8
0.00%	0	0.00%	0			

P Rtd	P+err	T Sat	r+perr	Numac rerr	r+perr+Numac	h Rtdout	h Rtd return	Flow
1114.7	840 psi	523.8	47.5895	0	47.5895	524.95	412.75	148,412
	75%	75						

Uncertainty
RWCUPMA2 = -412 lb/hr

This a bias and the actual contributed Heat is Higher than indicated

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.2.3 RWCU Inlet/Outlet Flow Heat Error due to Fluid Specific Weight Pressure Loop Uncertainty (**RWCUP_SW**)

Pressure is utilized as an input to the Numac to determine the specific weight of the fluid. The pressure loop uncertainty combined with the Numac computer uncertainty introduces an error in the calculated specific weight.

The loop error is comprised of 1) pressure loop, PT, 2) NUMAC computer uncertainties. The combined uncertainties are:

RWCUpress error=	21 psi

Ref.: 3.4.10

Flow+err = C x K x (DP x r+err / r)^0.5

The flow error is the difference between the rated flow at rated specific weight minus the flow at specific weight plus error:

RWCUp_SW = [Flowrated (h_in - h_out) - Flowrated+error (h_in - h_out)] x 2.93E-07 / 3840 x 100%

r = Fluid Specific Weight

K = 9448.61

Calib Flow = 189797.2 lb/hr 500 GPM (Note)

Calib inWC = 403.5

Assumed Calib Temp = 530.8

Assumed Calib Press = 1114.7

r = 47.326

Assumed Rated Flow = 148000 lb/hr 388.8 GPM

Rated h = 524.95 btu/lb

Fa Error	
Rated 533F	1.0087
Calibrated	1.0045

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd in	T Rtd out
1.0000	1.0000	245.3519	245.3519	1.0087	1.0087	530.8	433.9
0.00%	0	0.00%	0				

P Rtd	P+err	r+perr	Numac rerr	r+perr+Numac	h Rtd in	h Rtd out	Flow
1020	1041 psi	47.2756	0	47.2756	525.08	412.75	147,922

TTL MFW Heat	
16,616,239	BTU/hr

16,625,077 BTU/hr at rated conditions

Error

8,837

Uncertainty in Rated MWt
RWCUp_sw = 0.0001%

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.3 Reactor Water Cleanup Flow Error due to Flow Element Uncertainty (**RWCUc**)

The RWCU flow is affected by the FE error that is assigned to the flow element expansion coefficient.

C

The FE uncertainty is determined based in calculation:

Ref.: 3.4.10

Flow+err = C+err x K x (DP)^0.5

The flow error is the difference between the rated flow minus the flow with the C coefficient error:

RWCUc = Flowrated - Flowrated+error

Fa Error

Rated 533F	1.0087	**K =** 9448.61			
Calibrated	1.0045	Calib Flow = 189797.2 LB/HR	500 GPM	(Note)	
		Calib inWC = 403.50			
		Assumed Calib Temp = 530.80			
		Assumed Calib Press = 1114.70			
		r = 47.33			
		Assumed Rated Flow = 148000 lb/hr	389 GPM		
		Rated h = 524.95 btu/lb			

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0150	245.3519	245.3519	1.0087	1.0087	530.8	530.8
1.50%	150	0.00%	0				0

P Rtd	r	h	Flow
1114.7	47.3259	525.0	150,220

Uncertainty
RWCUc = 2220.0 lb/hr

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.4 Reactor Water Cleanup Flow Error due to Differential Pressure (DP) Loop Uncertainty (**RWCUdp**)

This error is introduced by the differential pressure instrument loop. The uncertainties in the loop are found in: Ref.: 3.4.10

The loop is comprised of 1) flow transmitter, FT, 2) NUMAC computer. The uncertainties are in % DP span:

The flow error is the difference between the rated flow minus the flow with the C coefficient error:

RWCUdp = Flowrated - Flowrated+error

Accuracy: **Loop Drift:**

RWCU_AFT	RWCU_ANU_IE	RWCU_ANU_A/D	RWCU_VDFT	RWCU_VDNU_IE	RWCU_VDNU_A/D
0.503%	0.100%	0.233%	0.900%	0.127%	0.127%

Loop Calibration:

RWCU_CEFT	RWCU_CENU_A/D
0.139%	0.02%

The uncertainties are random and independent and combined by the SRSS method:

1.09%	span DP

Flow+err = C x K x (DP+err)^0.5

Fa Error

Rated 533F	1.0087
Calibrated	1.0045

K = 9448.61
Calib Flow = 189797.2 LB/HR 500 GPM (Note)
Calib inWC = 403.50
Assumed Calib Temp = 530.80
Assumed Calib Press = 1114.70
r = 47.326
Assumed Rated Flow = 148000 LB/HR 389 GPM
Rated h = 524.95 btu/lb

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	245.3519	249.7337	1.0087	1.0087	530.8	530.8
0.00%	0						0

P Rtd	r	h	Flowrated+err
1114.7	47.3259	524.95	149,316

Uncertainty
RWCUdp = 1315.7 lb/hr

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.5 Reactor Water Cleanup Flow Error due to Signal Conditioning/NSSS Computer Loop Uncertainty **(RWCUNSSS_cptr)**

The differential pressure is converted to flow by the Numac computer and retransmitted as flow signal to the plant computer for heat balance calculations.

This portion of the loop is comprised of 1) NUMAC computer output, 2) NSSS computer uncertainty. The uncertainties are in % flow span:

Accuracy:

RWCU_ANU_D/A	RWCU_AA/D
0.233%	0.188%

Loop Drift:

RWCU_VDNU_D/A	RWCU_VNA/D
0.13%	0.000%

Loop Calibration:

RWCU_CENU_D/A	RWCU_CEA/D
0.02%	0.188%

The uncertainties are random and independent and combined by the SRSS method:

0.38%	span FLOW

The flow error is the difference between the rated flow at without loop error minus the flow plus loop error:

RWCUNSSS_cptr = Flowrated - Flowrated+error

Fa Error
Rated 533F 1.0087
Calibrated 1.0045

K = 9448.61
Calib Flow = 189797.2 lb/hr 500 GPM (Note)
Calib inWC = 403.50
Assumed Calib Temp = 530.80
Assumed Calib Press = 1114.70
r = 47.33
Assumed Rated Flow = 148000 lb/hr 389 GPM
Rated h = 524.95 btu/lb

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	245.3519	245.3519	1.0087	1.0087	530.8	530.8
0.00%	0						0

P Rtd	r	h	Flow
1114.7	47.3259	524.95	148,714.0

Uncertainty
RWCUNSSS_cptr= 713.7 lb/hr

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.6 Reactor Water Cleanup Total Flow due to Flow Loop Uncertainties (**RWCUf**)

RWCU Inlet h - Outlet h.

The total RWCU Flow Uncertainty is calculated below:

$RWCU_{fu}$ =+/-SQRT(RWCUPMA1^2+RWCUc^2+RWCUdp^2+RWCUNSSS_cptr^2)-RWCUFa-RWCUPMA2

Notice that the bias PMAs are factored with both signs, since the negative uncertainty is the one that has impact in the heat balance calculations, that is, that (-) less indication means that power is higher; however, it will be factored in both directions for simplicity.

$RWCU_{fu}$ = 3710 lb/hr

Then, the heat error contribution is the calculated inlet flow heat error minus the outlet flow heat error:

$RWCUh_{in}$ = 525.08 btu/lb
$RWCUh_{out}$ = 412.75 btu/lb

And the RWCU heat error contribution is calculated by the following expression:

RWCU = [$RWCU_{fu}$ ($RWCUh_{in}$ - $RWCUh_{out}$) x MWt_BTU_hr (conversion factor)] / Rated MWt 100%

RWCUf = 0.0032% This total error will be treated as bias in the total heat balance error

7.2.4.7 Reactor Water Cleanup Flow Enthalpy Heat Error due to Temperature Uncertainty (RWCUht)

This error is the error resultant of temperature measurement errors by the inlet/outlet RWCU thermocouple loops factored into the fluid enthalpy determination. The thermocouples are instruments with good repeatability and stability. However, fabrication errors can amount to several farenheit degrees. The fabrication errors can be calibrated out, since essentially it is a bias, systematic error. The temperature loops for RWCU are not calibrated out. Finally, since most of the thermocouples loop error is a bias, the conservative and safe way to apply the error, is for the two temperature error to be set in the same direction; therefore, the effect is additive, bias. The temperature loops error is found in:

Ref. 3.4.6

The heat error is the difference between the inlet flow heat error minus the outlet flow heat error:

RWCUht = [Flow [(hin - hin+error) + (hout - hout+error)]] x 2.93E-07 / 3840 x 100%

In flow heat

TRtd	T+err	P Rtd	h rated	h+err	Flow
530.8	541.7	1020	525.08	538.82	148,000
Error (F)	10.9				

Out flow heat

TRtd	T+err	P Rtd	h rated	h+err	Flow
433.9	444.8	1020	412.75	424.78	148,000
Error (F)	10.9				

Error	
3,813,231	**BTU/hr error at rated reactor water cleanup flow**

Uncertainty in Rated MWt	
RWCUht = 0.0291%	This error is a bias

7.2.4.8 Reactor Water Cleanup Flow Enthalpy Heat Error due to Pressure Loop Uncertainty (**RWCUhp**)

The reactor water cleanup enthalpy determination is affected by the loop pressure error. The pressure has a very small effect in the water enthalpy, however, it is determined in this calculation. The loop uncertainty is documented in:

Ref.: 3.4.4

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

RWCUhp = [Flow [(hin - hin+error) - (hout - hout+error)]] x 2.93E-07 / 3840 x 100%

In flow heat

P Rtd	P+err	TRtd	h rated	h+err	Flow
1020	1040.2	530.8	525.08	525.05	148,000
Error (psi)	20.2				

Out flow heat

P Rtd	P+err	TRtd	h rated	h+err	Flow
1020	1040.2	433.9	412.75	412.77	148,000
Error (psi)	20.2				

Error

6,681 BTU/hr at rated reactor water cleanup flow

Uncertainty in Rated MWt
RWCUhp = 0.00005%

7.2.5 Recirculation Pumps Heat Error due to Watts Loop Uncertainty (**RRPw**)

This section calculates the uncertainty due to RRP watts loop error, calculated in:

Ref.: 3.4.11

The rated power for the pump-motor and the motor efficiency (0.93) is from reference:

(Ref. 3.4.3)

There are two recirculation pumps, the calculated error below is per pump. The actual total MW for the 2 pumps is taken from above reference.

W 2 pump = 7.33

The Watt error contribution is calculated as follows:

RRPw = [(W Rtd/pump + MW Loop Span x Span err) x Mottor eff] - W Rtd/pump x Motor eff] / 3840 x 100%

W Rtd/pmp+err	Motor Eff	W+err
3.823	0.93	3.55
	Error =	1.50 % span
	Span =	10.5 Mwatt

TTL Mwatt	
3.41	Mwatt

Error
0.1465 Mwatt

Uncertainty in Rated MWT
RRPw = 0.0038%

7.2.6 Thermal Loses (TL)

This section calculates the uncertainty due to TL error. This error will be treated as a bias error since the estimated value is larger or smaller than assumed, i.e. it is a fixed error not a random error.

An assumed error equal to 20% of the specified loses is used.

The rated Heat Loss is from reference:

(Ref. 3.4.2)

W Rtd	W+err
1.1	1.32
Error =	20.00%

TTL Mwatt Heat
1.32

MW

1.10 MW at rated conditions

Error

0.2200 MW error at rated radiated loses

Uncertainty in Rated MWT
TL = 0.006%

This error is treated as bias.

Note: The computer utilizes this value combined with Other System Loses (Section 7.2.7) as Radiative power loses, QRAD = 1.94

7.2.7 Other System Loses (**OSL**)

The rated value includes Rod Drive seal purge flow to recirculation pumps. An assumed error equal to 20% of the specified loses is used.
This error will be treated as a bias error since if the estimated value is larger or smaller than assumed, i.e. it is a fixed error not a random error.

The rated Losses figure is from reference:

(Ref. 3.4.2)

W Rtd	W+err
1.18	1.416
Error =	20%

Rev 5

TTL Mwatt Heat	
1.42	MW

Rev 5

1.18 MW at rated conditions

Rev 5

Error

0.2360 MW error at rated radiated loses

Rev 5

Uncertainty in Rated MWT
OSL = 0.006%

This error is treated as bias.

Rev 5

Note: The computer utilizes this value combined with Thermal Loses (Section 7.2.6) as Radiative power loses, QRAD = 1.94

7.2.8 Heat Balance Calculation Power Uncertainty (**Power U**)

The calculated heat balance uncertainty is the algebraic combination of the bias errors with the independent/random errors statistically combined, that contribute into the heat balance calculation, in accordance with the heat balance formula:

Power = MFW(MSh-FWh)-CRDF(hin-hout)+RWCU(hout-hin)-RRP+HL+Miscellaneous

Summary of Heat Balance Calculation Contributing Errors:

Random Errors:	FWm = 0.4507%	
	FWht = 0.2144%	
	MSm = 1.3099%	
	MSmoist = 0.0000%	
	CRDc = 0.0054%	
	CRDdp = 0.0062%	
	RRPw = 0.0038%	
	RWCUp_sw = 0.0001%	
Dependent Errors:	Errors	Variable
	FWhp = 0.0007%	Rated MS pressure = 1020 psia Rev 5
	MShp = 0.0294%	
	CRDhp = -0.00006%	
	RWCUhp = 0.00005%	
Bias Errors:	CRDt = -0.0012%	
	CRDht = -0.0097%	
	RWCUf = 0.0032%	
	RWCUht = 0.0291%	
	TL = 0.006%	
	OSL = 0.006%	Rev 5

Heat Balance Calculation Power Error (U):

Power Error = SQRT[(MSm-FWm)^2+(MShp-FWhp+CRDhp+RWCUhp)^2+FWht^2+MSmoist^2+CRDc^2+CRDdp^2+
+RWCUp_sw^2+RRPw^2x2]+CRDt+CRDht+RWCUf+RWCUht+TL+OSL

Power Error = **0.919%** Rev 5

To ensure operation margin exist, due to possible instrumentation loops miss-calibration, actual drift (to be determined by history), etc., a margin is added:

Power U = Power Error + Margin

where margin is defined as 2.0% (SET POWER U) - Power Error

Margin = 1.081% and **Power U = 2.000%** Rev 5

8.0 SUMMARY

The calculated Heat Balance Error performed in this calculation is applicable to the hand calculation error when determined process values and steam tables heat values are used with an accuracy of 3 decimal places. This results are applicable to hand calculated heat balance since less hardware errors are involved in the hand calculation, data collection. The Heat Balance calculation error (Section 7.0) is:

Power U = 2.000%

(NC.DE-AP.ZZ-0002(Q), Rev. 12, Form 2)		CALCULATION CONTINUATION SHEET			SHEET: 1
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ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	2/14/2017	John Wilkens	3/13/2017	N/A	N/A

Sections 1 through 4 have been replaced with the main body of the calculatior

5.0 DESIGN INPUTS Rev 5

5.1 Rated Power Conditions

100% rated Power Conditions are listed below. Actual 100% operation values might be used in lieu of rated nominal values, for other than Rated MWt, Feedwater Flow and Main Steam parameters as deemed appropriate. This is found acceptable, since for the purpose of error determination to rated MWt "heat differential errors", actual heat contribution deviation from measured/calculated heat to rated MWt due to instrumentation uncertainties, is required not the actual deviation value.

Rated MWt =	**3902MW**	(Ref. 3.4.19, 3.2.5, Att. 8)
Rated FW flow =	**1.4962E+07lbm/hr**	(Ref. 3.4.19, Att. 8)
Rated FW temperature =	**331.5 F**	(Ref. 3.4.19, Att. 8)
Rated MS flow =	**14994000**	(Ref. 3.4.19, Att. 8)
Rated MS pressure =	**1001 psia**	(Ref. 3.4.19, Att. 8)
Rated MS quality =	**100.000**	(Ref. 3.4.1)
Rated RWCU flow =	**148000.0 lb/hr**	(Ref. 3.4.19, Att. 8)
Rated RWCU temperature =	**517.8 F**	(Ref. 3.4.19, Att. 8)
Rated RWCU return temperature =	**419.2 F**	(Ref. 3.4.19, Att. 8)
Rated CRD flow =	**32000.0 lb/hr**	(Ref. 3.4.3, 3.4.18)
CRD Calibration pressure =	**1474.0 psia**	(Ref. 3.4.5)
Rated CRD temperature =	**77 F**	(Ref. 3.4.19, Att. 8)
Radiation Loses =	**1.10MW**	(Ref. 3.4.2, 3.4.19)
Other System Loses =	**1.18MW**	(Ref. 3.4.2, 3.4.19) Note: These loses are not included in UFSAR Heat Balance, Ref. 3.1.1
MWt/BTU/hr =	**2.9300E-07**	(Ref. 3.4.1)

Power = MFW(MSh-FWh)-CRDF(hin-hout)+RWCU(hout-hin)-RRP+HL+Miscellaneous

Notes:

1) This calculation uses rated MS quality of 100.00%, which will produce a more conservative number with respect to the actual plant MS quality. This parameter may be revised when the actual MS quality is measured after the implementation of EPU.
2) This calculation specifies radiation loses as 1.10 MW and other loses as 0.84 MW for the total lose of 1.94 MW. Reference 3.4.17 stated "other system loses" as 1.9 MW without specifically accounting for Radiation loses. Since the two total numbers are almost identical and the difference would have negligible affect on the Power Error, radiation loses of 1.10 MW and the other loses of 0.84 MW will be maintained.

6.0 ASSUMPTIONS

See sections 7.2.3, 7.2.4, 7.2.6 and 7.2.7 for specific assumptions.

7.0 CALCULATIONS

Rev 5

7.1 Methodology

The methodology used to combine the uncertainties for the different contributors to the heat balance calculation is the square root of the sum of the squares of those uncertainties which are statistically independent. Then algebraically combined with the those errors that are systematic, or bias. The uncertainties are considered to be random, two sided distributions. This methodology has been utilized before, and has been endorsed by the NRC and various industry standards (Ref. 3.4.12-3.4.14).

The uncertainty calculation combines the different errors from the different parameters contributing to the heat balance in accordance to the heat balance equation. The contributing parameters errors are taken from the specific system uncertainty calculation.

These errors are generally classified in two groups:

a) Instrument loop(s) uncertainty
b) Process effects

The individual uncertainties affecting the heat balance calculation are determined by the application of the corresponding process algorithm, as described below:

a) the appropriate algorithm for the specific process parameter is set in the form to its specific contribution to the heat balance at specified rated conditions,
b) subsequently, the instrumentation loop error is factored in the process algorithm to calculate the corresponding process parameter with the error built-in,
c) the difference of the calculated contributed process parameter heat, with error, to the rated process rated heat is then calculated,
d) the resultant heat error contribution is then divided by the rated 100% power thermal megawatts. The result is the error contribution by the specific process to the total heat balance uncertainty,
e) finally, all the calculated heat errors are combined in accordance to their parameter function in the heat balance equation. The resultant combination of all contributing errors is the Heat Balance Uncertainty.

7.2 Uncertainties Calculation

Rev 5

7.2.1 Main Feedwater Uncertainty(ies)

The Main Feedwater uncertainties are included in the total thermal power uncertainty provided by the LEFM is 0.34% per Reference 3.4.20. This includes the Main Feedwater mass flow error, main feedwater heat enthalpy error, and the Main Steam mass flow error

Referring to the schematic drawing in section 4.0, it can be seen that the Main Feedwater heat contribution is affected by the following parameters:

a) Mass Flow Measurement affected by: 1) flow, 2) temperature, and 3) pressure instrumentation loops error.

The error provided by the vendor for the ultrasonic flow meter already factors the corresponding temperature and pressure loops effect.

b) Feedwater Enthalpy determination affected by: 1) temperature, and 2) pressure, instrumentation loops error.

The main feedwater enthalpy is calculated using the following signals:

- Feedwater Pressure and Main Feedwater Temperature

7.2.1.1 Main Feedwater Mass Flow Heat Error due to Flow Element Uncertainty (**FWm**)

Deleted

7.2.1.2 Main Feedwater Heat Enthalpy Error due to Pressure Loop Uncertainty (**FWhp**)

Deleted

7.2.1.3 Main Feedwater Heat Enthalpy Error due to Temperature Loop Uncertainty (**FWht**)

Deleted

7.2.2 Main Steam Flow Uncertainty(ies) Rev 5

Referring to the schematic drawing in section 4.0, It can be seen that the Main Steam heat contribution is affected by the following parameters:

a) The calculated Main Steam Heat is affected by the mass flow measurement error (see section 7.2.1.1 Main Feedwater Mass Error).

b) Main Steam Enthalpy determination is affected by the pressure instrumentation loop error, documented in calculation:

Ref. 3.4.4

7.2.2.1 Main Steam Mass Flow Heat Error due to Main Feedwater Flow Uncertainty (**MSm**)

Deleted

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.2.2 Main Steam Heat Enthalpy Error due to Pressure Loop Uncertainty **(MShp)** Rev 5

This Section calculates the Main Heat Steam enthalpy error due to the loop pressure uncertainty, documented in:

Ref.: 3.4.4

The heat error is the difference in the Main Steam flow heat content at rated flow and enthalpy conditions minus the heat content at rated flow with enthalpy at rated pressure plus pressure induced error:

MShp = [Flow (hrated - hrated+err)] x 2.93E-07 / 3902 x 100%

P Rtd	P+err	Moist Rtd	Moist+err	h rated	h+err	Flow
1000.69	1006.79	100	100.000	1192.91	1192.69	14,994,000
Error (psi) =	6.1		0			

TTL MS Heat
17,883,129,657 BTU/hr

17,886,503,873 BTU/hr at rated conditions

Error
3,374,216 BTU/hr error at rated main feedwater flow

Error in Rated MWt
MShp = 0.0253%

7.2.2.3. Main Steam Moisture Heat Enthalpy Error due to Steam Moisture Uncertainty (**MSmoist**) Rev 5

This section calculates the Main Steam enthalpy error due to MS moisture uncertainty. The uncertainty is conservatively set to 50% of rated moisture content of 0.0%.

The heat error is the difference in the Main Steam flow heat content at rated flow and moisture conditions minus the heat content at rated moisture conditions plus moisture error:

MSmoist = [Flowrated hrated (hmoist-rated - hmoist-rated+err)] x 2.93E-07 / 3902 x 100%

P Rtd	P+err	Moist Rtd	Moist+err	h rated	h+err	Flow
1000.69	1000.69	100	100.0000	1192.91	1192.91	14,994,000
	0.00000	0.00%	0			

TTL MS Heat
17,886,503,873 BTU/hr

17,886,503,873 BTU/hr at rated conditions

Error
- BTU/hr error at rated main feedwater flow

Error in Rated MWt
MSmoist = 0.0000%

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	2/14/2017	John Wilkens	3/13/2017	N/A	N/A

7.2.3 Control Rod Drive Flow

Rev 5

Referring to the schematic drawing in section 4.0, it can be seen that CRD flow is not monitored for pressure or temperature.

The CRD calculated heat is affected by the following effects:

a) Mass Flow Measurement affected by: 1) flow, instrumentation loop effect and 2) temperature, and 3) pressure deviation from calibration values

b) The CRD Enthalpy determination is affected by: 1) temperature, from applied constants, and 2) pressure, from reactor pressure loop error

The CRD flow loop errors are documented in calculation:

Ref. 3.4.5

The flow formula is derived from the ASME (Ref. 3.4.9) as follows:

Flow = C*Fa*K*(DP*r)^0.5

where K is calculated below:

K = Calib Flow/(Calib inWC * Calib r)^0.5

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Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.3.1 Control Rod Drive Flow Heat Error due to Flow Element and Fluid Specific Weight Uncertainty due to Temperature Error (**CRDt**) Rev 5

The uncertainty is dependent for the following variables:

Fa = FE Thermal Expansion **r =** Fluid Specific Weight

The plant computer calculates the CRD flow with a constant flow K factor. However, the actual temperature could vary as much as 43F from the expected 77F, and this impacts the Fa and r impacting the calculated flow; therefore, the effect due to this temperature deviation is:

CRDt = [(hs rated - CRDh rated) (Flowrated - Flowrated+err)] x 2.93E-07 / 3902 x 100%

Ref.: 3.4.5

K = 448.48
Calib Flow = 50154 lb/hr 100 GPM
Calib inWC = **200**
Calib Temp = **77**
Calib Press = **1474.7**
r = 62.529
Assumed Rated Flow = **32000.0 lb/hr**
Rated Press = 1001 psia
Rated Temp = **77 F**
Rated h = 47.78 btu/lb

Fa Error	
Rated 77F	1.0003
@140 F	1.0013
@40 F	0.9995
Fa/F	1.8E-05

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	81.3694	81.3694	1.0003	1.0011	77	120
0.00%	0	0.00%	0				**43**

Temp error = Calib Temp - Min Temp

P Rtd	r	h Rtd	Flow	hs Rtd
1000.69	61.8993	47.78	31,862.980	1192.91

TTL CRD Heat
36,487,315 BTU/hr

36,644,221 BTU/hr at rated conditions

Error
(156,906) BTU/hr error at rated CRD flow

Error in Rated MWt
CRDt = -0.0012%

This error is a bias, not a random instrument induced uncertainty.

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Michael Miller	2/14/2017	John Wilkens	3/13/2017	N/A	N/A

7.2.3.2 Control Rod Drive Flow Heat Error due to Flow Element Uncertainty (CRDc) Rev 5

The CRD contributed heat is affected by the FE error that is assigned to the flow element expansion coefficient.

C

The FE uncertainty is determined based in calculation:

Ref.: 3.4.5

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

CRDc = [(hs rated - CRDh rated) (Flowrated - Flowrated+err)] x 2.93E-07 / 3902 x 100%

Fa Error		**K =** 448.48		
Rated 77F	1.0003	Calib Flow = 50154	100.00	
@140 F	1.0013	Calib inWC = 200.00		
@60 F	0.9995	Assumed Calib Temp = 77.00		
Fa/F	1.8E-05	Assumed Calib Press = 1474.00		
		r = 62.529	0.0159925	
		Assumed Rated Flow = 32000.0 lb/hr		
		Rated Press = 1001 psia		
		Rated Temp = 77 F		
		Rated h = 47.78 btu/lb		

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0200	81.3694	81.3694	1.0003	1.0003	77	77
2.00%	200	0.00%	0				0

P Rtd	r	h Rtd	Flow	hs Rtd
1000.69	62.4396	47.78	32,616.541	1192.91

TTL MFW Heat

37,350,242 BTU/hr

36,644,221 BTU/hr at rated conditions

Error

706,021 BTU/hr error at rated CRD flow

Error in Rated MWt

CRDc = 0.0053%

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.3.3 Control Rod Drive Heat Error due to Differential Pressure (DP) Loop Uncertainty (**CRDdp**) Rev 5

This error is calculated in calculation:

Ref.: 3.4.5

The loop is comprised of 1) flow transmitter, FT, 2) resistor, REST, 3) computer analog to digital card, A/D.
The uncertainties are in % DP span:

Accuracy: **Loop Drift:**

CRD_AFT	CRD_AREST	CRD_AA/D	CRD_VDFT	CRD_VDA/D
1.154%	0.100%	0.188%	1.450%	0.000%

Loop Calibration:

CRD_CEFT	CRD_CEA/D
0.140%	0.188%

The uncertainties are random and independent and combined by the SRSS method:

1.88%	span DP

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ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:		DATE:
Michael Miller	2/14/2017	John Wilkens	3/13/2017	N/A		N/A

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

Rev 5

CRDdp = [(hs rated - CRDh rated) (Flowrated - Flowrated+err)] x 2.93E-07 / 3902 x 100%

Fa Error

Rated 77F	1.0003
@140 F	1.0013
@60 F	0.9995
Fa/F	1.8E-05

K = 448.51
Calib Flow = 50157.2 lb/hr 100 GPM
Calib inWC = 200
Assumed Calib Temp = 77
Assumed Calib Press = 1474
r = 62.529
Assumed Rated Flow = 32000.0 lb/hr
Rated Press = 1000.7 lb/hr
Rated Temp = 77 F
CRDh rated = 47.78 btu/lb

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	81.3584	85.1183	1.0003	1.0003	77	77
0.00%	0	1.88%					0

P Rtd	r	CRDh rated	Flowrated+err	hs Rtd
1000.69	62.4396	47.78	32,707.575	1192.91

TTL MFW Heat
37,454,488 BTU/hr

36,644,221 BTU/hr at rated conditions

Error
810,267 BTU/hr at rated CRD flow

Error in Rated MWt
CRDdp = 0.0061%

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.3.4 Control Rod Drive Flow Enthalpy Heat Error due to Temperature Calibration Deviation (**CRDht**) Rev 5

The plant computer calculates the CRD fluid enthalpy at a constant 77F and reactor pressure. However, the actual temperature varies and it is assumed to vary as much as 43F from the expected 77F; therefore, the effect due to this temperature deviation in the calculated enthalpy is:

Ref. 3.4.5

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

CRDht = [Flow (hs rated - CRDh rated) - Flow (hs rated - CRDh rated+err)] x 2.93E-07 / 3902 x 100%

TRtd	T Max/Min	T+err	P Rtd	h rated	h+err	hs rated	Flow
77	40	37	1000.69	47.78	7.99	1192.91	32,000

TTL RWCU Heat
37,917,380 BTU/hr

36,644,221 BTU/hr at rated conditions

Error
(1,273,159) BTU/hr at rated CRD flow

Uncertainty in Rated MWt
CRDht = -0.0096%

This error is a bias, not a random instrument induced uncertainty.

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.3.5 Control Rod Drive Flow Enthalpy Heat Error due to Pressure Loop Uncertainty (**CRDhp**) Rev 5

The plant computer calculates the CRD fluid enthalpy at a constant 77Fand reactor loop pressure, that is affected by the loop uncertainty.
The pressure loop uncertainty is documented in:

Ref.: 3.4.4

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

CRDhp = [Flow (hs rated - CRDh rated) - Flow (hs rated+err - CRDh rated)] x 2.93E-07 / 3902 x 100%

P Rtd	P+err	TRtd	CRDh rated	hs rated	hs rated+err	Flow
1000.69	1006.79	77	47.78	1192.91	1192.69	32,000

Error (psi) = 6.1

TTL MFW Heat	
36,637,020	BTU/hr

36,644,221 BTU/hr at rated conditions

Error

(7,201) BTU/hr at rated CRD flow

Uncertainty in Rated MWt
CRDhp = -0.00005%

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	2/14/2017	John Wilkens	3/13/2017	N/A	N/A

Rev 5

7.2.4 Reactor Water Cleanup Uncertainty(ies)

Referring to the schematic drawing in section 4.0, it can be seen that RWCU flow is measured and mass calculated by a "NUMAC" process unit. Differential pressure, temperature, by dedicated thermocouples, and reactor pressure are an input to the instrument. Therefore, the RWCU contributed heat is affected by the following parameters:

a) Mass Flow Measurement affected by: 1) flow, 2) temperature, and 3) pressure induced factors/instrumentation loops errors

b) The RWCU Enthalpy determination is affected by: 1) temperature instrumentation loop error (see discussion for pressure)

The flow formula is derived from the ASME (Ref. 3.4.9) as follows:

Flow = C*K*(DP)^0.5

where K is:

K = Calib Flow / [C*(Calib inWC)^0.5]

7.2.4.1 RWCU Inlet/Outlet Flow Heat Error due to Flow Element Expansion deviation from Calibration (**RWCUFa**) Rev 5

The Numac computer calculating the mass flow has a built-in Fa constant different than the flow element Fa provided at the calculated venturi rated temperature of 533F. This induces a bias error. Furthermore, the plant NUMAC normalizes the flow mass signal to a specific weight of 47.0 lbm/cuft for pressure and temperature conditions, back calculated below; therefore, the rated conditions are set at 530.7F.

Pressure Density Compensated to :	48.01 lb/cuft	517.8 F	**908 psia**
The Fa used in the calculation is fixed to:		1.0045	
The correct Fa at rated 533 F is:		1.0087	

Based on the Fa differences the induced flow error is calculated below:

Fa = FE Thermal Expansion

Ref.: 3.4.10

Flow+err = C x Fa+err / Fa x K x (DP)^0.5

K = 9449.90
Calib Flow = 189823.1 lb/hr **500 GPM** (Note)
Calib inWC = **403.5**
Assumed Calib Temp = **530.7**
Assumed Calib Press = **1114.7**
r = 47.332
Assumed Rated Flow = 148021 lb/hr **389 GPM**
Rated h = 524.83 btu/lb

Fa Error
Rated 533F **1.0087**
Calibrated **1.0045**

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	245.3520	245.3520	1.0087	1.0045	530.7	530.7
0.00%	0	0.00%	0				0

P Rtd	P+err	r	h Rtd	Flow+err
1114.7	1114.7	47.3324	524.83	147,404
	0			

Uncertainty
RWCUFa -616.3 lb/hr

This a bias and the actual contributed Heat is Higher than indicated

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.2 RWCU Inlet/Outlet Flow Heat Error due to Fluid Specific Weight deviation (**RWCUPMA**) Rev 5

This error is the combination of several uncertainties calculated below:

7.2.4.2.1 RWCU Inlet/Outlet Flow Error due to Fluid Specific Weight Numac Lookup Tables Error (**RWCUPMA1**)

The Numac performs the fluid specific weight determination with an error of 0.1 specific weight, this effect in the flow is calculated below.

r = Fluid Specific Weight

Ref.: 3.4.10

Flow+err = C x K x (DP x r+err / r)^0.5

The flow error is the difference between the rated flow at rated specific weight minus the flow at specific weight plus error:

RWCUPMA1 = Flowrated - Flowrated+error

K = 9449.90
Calib Flow = 189823.1 lb/hr 500 GPM (Note)
Calib inWC = 403.5
Assumed Calib Temp = 530.7
Assumed Calib Press = 1114.7
r = 47.332
Assumed Rated Flow = 148021 lb/hr 388.8 GPM
Rated hout = 524.83 btu/lb

Fa Error	
Rated 533F	1.0087
Calibrated	1.0045

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd
1.0000	1.0000	245.3520	245.3520	1.0087	1.0087	530.7
0.00%	0	0.00%	0			

P Rtd	P+err	r	Numac err	r+perr+Numac	h Rtd	Flow
1114.7	1114.7 psi	47.332	**0.1**	47.432	524.83	148,177
	0 psi					

Uncertainty
RWCUPMA1 = 156.3 lb/hr

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

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Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.4.2.2 RWCU Inlet/Outlet Flow Error due to Fluid Specific Weight Numac 0.75 Factor Pressure Correction Factor Error (**RWCUPMA2**) Rev 5

The Numac computer introduces a 0.75 factor to the input pressure raw value and calculates the specific weight for saturated conditions, which bias the actual flow.

Ref.: 3.4.10

Flow+err = C x K x (DP x r+err / r)^0.5

The flow error is the difference between the rated flow at rated specific weight minus the flow at specific weight plus error:

RWCUPMA2 = Flowrated - Flowrated+error

r = Fluid Specific Weight

K = 9449.90
Calib Flow = 189823.1 lb/hr 500 GPM (Note)
Calib inWC = 403.5
Assumed Calib Temp = 530.7
Assumed Calib Press = 1114.7
r = 47.332
Assumed Rated Flow = 148021 lb/hr 388.8 GPM
Rated = 524.83 btu/lb

Fa Error	
Rated 533F	1.0087
Calibrated	1.0045

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	h Rtd return	Flow
1.0000	1.0000	245.3520	245.3520	1.0087	1.0087	530.7	396.68	148,422
0.00%	0	0.00%	0					

P Rtd	P+err	T Sat	r+perr	Numac rerr	r+perr+Numac	h Rtdout
1114.7	840 psi	523.8	47.5895	0	47.5895	524.83
	75%	75				

Uncertainty
RWCUPMA2 = -402 lb/hr

This a bias and the actual contributed Heat is Higher than indicated

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

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Michael Miller	2/14/2017	John Wilkens	3/13/2017	N/A	N/A

7.2.4.2.3 RWCU Inlet/Outlet Flow Heat Error due to Fluid Specific Weight Pressure Loop Uncertainty (**RWCUP_SW**) Rev 5

Pressure is utilized as an input to the Numac to determine the specific weight of the fluid. The pressure loop uncertainty combined with the Numac computer uncertainty introduces an error in the calculated specific weight.

The loop error is comprised of 1) pressure loop, PT, 2) NUMAC computer uncertainties. The combined uncertainties are:

RWCUpress error= 21 psi

Ref.: 3.4.10

Flow+err = C x K x (DP x r+err / r)^0.5

The flow error is the difference between the rated flow at rated specific weight minus the flow at specific weight plus error:

RWCUp_SW = [Flowrated (h_in - h_out) - Flowrated+error (h_in - h_out)] x 2.93E-07 / 3902 x 100%

r = Fluid Specific Weight

K = 9449.90
Calib Flow = 189823.1 lb/hr 500 GPM (Note)
Calib inWC = 403.5
Assumed Calib Temp = 530.7
Assumed Calib Press = 1114.7
r = 47.332
Assumed Rated Flow = 148021 lb/hr 388.8 GPM
Rated h = 524.83 btu/lb

Fa Error	
Rated 533F	1.0087
Calibrated	1.0045

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd in	T Rtd out
1.0000	1.0000	245.3520	245.3520	1.0087	1.0087	530.7	419.2
0.00%	0	0.00%	0				

P Rtd	P+err	r+perr	Numac rerr	r+perr+Numac	h Rtd in	h Rtd out	Flow
1000.69	1022 psi	47.2689	0	47.2689	509.11	396.68	147,921

TTL MFW Heat
16,631,277 BTU/hr

16,642,445 BTU/hr at rated conditions

Error
11,168

Uncertainty in Rated MWt
RWCUp_sw = 0.0001%

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

Rev 5

7.2.4.3 Reactor Water Cleanup Flow Error due to Flow Element Uncertainty (**RWCUc**)

The RWCU flow is affected by the FE error that is assigned to the flow element expansion coefficient.

C

The FE uncertainty is determined based in calculation:

Ref.: 3.4.10

Flow+err = C+err x K x (DP)^0.5

The flow error is the difference between the rated flow minus the flow with the C coefficient error:

RWCUc = Flowrated - Flowrated+error

Fa Error

Rated 533F	1.0087	**K =** 9449.90		
Calibrated	1.0045	Calib Flow = 189823.1 LB/HR	500 GPM	(Note)
		Calib inWC = 403.50		
		Assumed Calib Temp = 530.70		
		Assumed Calib Press = 1114.70		
		r = 47.332		
		Assumed Rated Flow = 148021 lb/hr	389 GPM	
		Rated h = 524.83 btu/lb		

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0150	245.3520	245.3520	1.0087	1.0087	530.7	530.7
1.50%	150	0.00%	0				0

P Rtd	r	h	Flow
1114.7	47.3324	524.8	150,241

Uncertainty
RWCUc = 2220.3 lb/hr

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

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Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.4.4 Reactor Water Cleanup Flow Error due to Differential Pressure (DP) Loop Uncertainty (**RWCUdp**) Rev 5

This error is introduced by the differential pressure instrument loop. The uncertainties in the loop are found in: Ref.: 3.4.10

The loop is comprised of 1) flow transmitter, FT, 2) NUMAC computer. The uncertainties are in % DP span:

The flow error is the difference between the rated flow minus the flow with the C coefficient error:

RWCUdp = Flowrated - Flowrated+error

Accuracy: **Loop Drift:**

RWCU_AFT	RWCU_ANU_IE	RWCU_ANU_A/D	RWCU_VDFT	RWCU_VDNU_IE	RWCU_VDNU_A/D
0.503%	0.100%	0.233%	0.900%	0.127%	0.127%

Loop Calibration:

RWCU_CEFT	RWCU_CENU_A/D
0.139%	0.02%

The uncertainties are random and independent and combined by the SRSS method:

1.09%	span DP

Flow+err = C x K x (DP+err)^0.5

Fa Error

Rated 533F 1.0087

Calibrated 1.0045

K = 9449.90

Calib Flow = 189823.1 LB/HR 500 GPM (Note)

Calib inWC = 403.50

Assumed Calib Temp = 530.70

Assumed Calib Press = 1114.70

r = 47.332

Assumed Rated Flow = 148021 LB/HR 389 GPM

Rated h = 524.83 btu/lb

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	245.3520	249.7338	1.0087	1.0087	530.7	530.7
0.00%	0						0

P Rtd	r	h	Flowrated+err
1114.7	47.3324	524.83	149,336

Uncertainty
RWCUdp = 1315.9 lb/hr

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

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Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.4.5 Reactor Water Cleanup Flow Error due to Signal Conditioning/NSSS Computer Loop Uncertainty **(RWCUNSSS_cptr)** Rev 5

The differential pressure is converted to flow by the Numac computer and retransmitted as flow signal to the plant computer for heat balance calculations.

This portion of the loop is comprised of 1) NUMAC computer output, 2) NSSS computer uncertainty. The uncertainties are in % flow span:

Accuracy:

RWCU_ANU_D/A	RWCU_AA/D
0.233%	0.188%

Loop Drift:

RWCU_VDNU_D/A	RWCU_VNA/D
0.13%	0.000%

Loop Calibration:

RWCU_CENU_D/A	RWCU_CEA/D
0.02%	0.188%

The uncertainties are random and independent and combined by the SRSS method:

0.38%	span FLOW

The flow error is the difference between the rated flow at without loop error minus the flow plus loop error:

RWCUNSSS_cptr = Flowrated - Flowrated+error

Fa Error
Rated 533F 1.0087
Calibrated 1.0045

K = 9449.90
Calib Flow = 189823.1 lb/hr 500 GPM (Note)
Calib inWC = 403.50
Assumed Calib Temp = 530.70
Assumed Calib Press = 1114.70
r = 47.332
Assumed Rated Flow = 148021 lb/hr 389 GPM
Rated h = 524.83 btu/lb

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	245.3520	245.3520	1.0087	1.0087	530.7	530.7
0.00%	0						0

P Rtd	r	h	Flow
1114.7	47.3324	524.83	148,734.3

Uncertainty
RWCUNSSS_cptr= 713.8 lb/hr

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

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Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.4.6 Reactor Water Cleanup Total Flow due to Flow Loop Uncertainties (**RWCUf**) Rev 5

RWCU Inlet h - Outlet h.

The total RWCU Flow Uncertainty is calculated below:

RWCUfu =+/-SQRT(RWCUPMA1^2+RWCUc^2+RWCUdp^2+RWCUNSSS_cptr^2)-RWCUFa-RWCUPMA2

Notice that the bias PMAs are factored with both signs, since the negative uncertainty is the one that has impact in the heat balance calculations, that is, that (-) less indication means that power is higher; however, it will be factored in both directions for simplicity.

RWCUfu = 3700 lb/hr

Then, the heat error contribution is the calculated inlet flow heat error minus the outlet flow heat error:

RWCUh_in = 509.11 btu/lb
RWCUh_out = 396.68 btu/lb

And the RWCU heat error contribution is calculated by the following expression:

RWCU = [RWCUfu (RWCUh_in - RWCUh_out) x MWt_BTU_hr (conversion factor)] / Rated MWt 100%

RWCUf = 0.0031% This total error will be treated as bias in the total heat balance error

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Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.4.7 Reactor Water Cleanup Flow Enthalpy Heat Error due to Temperature Uncertainty (RWCUht) Rev 5

This error is the error resultant of temperature measurement errors by the inlet/outlet RWCU thermocouple loops factored into the fluid enthalpy determination. The thermocouples are instruments with good repeatability and stability. However, fabrication errors can amount to several farenheit degrees. The fabrication errors can be calibrated out, since essentially it is a bias, systematic error. The temperature loops for RWCU are not calibrated out. Finally, since most of the thermocouples loop error is a bias, the conservative and safe way to apply the error, is for the two temperature error to be set in the same direction; therefore, the effect is additive, bias. The temperature loops error is found in:

Ref. 3.4.6

The heat error is the difference between the inlet flow heat error minus the outlet flow heat error:

RWCUht = [Flow [(hin - hin+error) + (hout - hout+error)]] x 2.93E-07 / 3902 x 100%

In flow heat

TRtd	T+err	P Rtd	h rated	h+err	Flow
517.8	528.7	1000.69	509.11	522.50	148,021
Error (F)	10.9				

Out flow heat

TRtd	T+err	P Rtd	h rated	h+err	Flow
419.2	430.1	1000.69	396.68	408.57	148,021
Error (F)	10.9				

Error	
3,741,117	**BTU/hr error at rated reactor water cleanup flow**

Uncertainty in Rated MWt	
RWCUht = 0.0281%	This error is a bias

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Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

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7.2.4.8 Reactor Water Cleanup Flow Enthalpy Heat Error due to Pressure Loop Uncertainty (**RWCUhp**)

The reactor water cleanup enthalpy determination is affected by the loop pressure error. The pressure has a very small effect in the water enthalpy, however, it is determined in this calculation. The loop uncertainty is documented in:

Ref.: 3.4.4

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

RWCUhp = [Flow [(hin - hin+error) - (hout - hout+error)]] x 2.93E-07 / 3902 x 100%

In flow heat

P Rtd	P+err	TRtd	h rated	h+err	Flow
1000.69	1020.89	517.8	509.11	509.09	148,000
Error (psi)	20.2				

Out flow heat

P Rtd	P+err	TRtd	h rated	h+err	Flow
1000.69	1020.89	419.2	396.68	396.70	148,000
Error (psi)	20.2				

Error

5,764 BTU/hr at rated reactor water cleanup flow

Uncertainty in Rated MWt
RWCUhp = 0.00004%

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Michael Miller	2/14/2017	John Wilkens	3/13/2017	N/A	N/A

7.2.5 Recirculation Pumps Heat Error due to Watts Loop Uncertainty (**RRPw**) Rev 5

This section calculates the uncertainty due to RRP watts loop error, calculated in:

Ref.: 3.4.11

The rated power for the pump-motor and the motor efficiency (0.93) is from reference:

(Ref. 3.4.3)

There are two recirculation pumps, the calculated error below is per pump. The actual total MW for the 2 pumps is taken from above reference.

W 2 pump = 7.33

The Watt error contribution is calculated as follows:

RRPw = [(W Rtd/pump + MW Loop Span x Span err) x Mottor eff] - W Rtd/pump x Motor eff] / 3902 x 100%

W Rtd/pmp+err	Motor Eff	W+err
3.823	0.93	3.55
	Error =	1.50 % span
	Span =	10.5 Mwatt

TTL Mwatt	
3.41	Mwatt

Error
0.1465 Mwatt

Uncertainty in Rated MWT
RRPw = 0.0038%

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7.2.6 Thermal Loses (TL) Rev 5

This section calculates the uncertainty due to TL error. This error will be treated as a bias error since the estimated value is larger or smaller than assumed, i.e. it is a fixed error not a random error.

An assumed error equal to 20% of the specified loses is used.

The rated Heat Loss is from reference:

(Ref. 3.4.2)

W Rtd	W+err
1.1	1.32
Error =	**20.00%**

TTL Mwatt Heat
1.32 MW

1.10 MW at rated conditions

Error
0.2200 MW error at rated radiated loses

Uncertainty in Rated MWT
TL = 0.006%
This error is treated as bias.

Note: The computer utilizes this value combined with Other System Loses (Section 7.2.7) as Radiative power loses, QRAD = 1.94

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Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.7 Other System Loses (**OSL**) Rev 5

The rated value includes Rod Drive seal purge flow to recirculation pumps. An assumed error equal to 20% of the specified loses is used. This error will be treated as a bias error since if the estimated value is larger or smaller than assumed, i.e. it is a fixed error not a random error.

The rated Losses figure is from reference:

(Ref. 3.4.2)

W Rtd	W+err
1.18	1.416
Error =	20%

TTL Mwatt Heat
1.42 MW

1.18 MW at rated conditions

Error
0.2360 MW error at rated radiated loses

Uncertainty in Rated MWT
OSL = 0.006%

This error is treated as bias.

Note: The computer utilizes this value combined with Thermal Loses (Section 7.2.6) as Radiative power loses, QRAD = 1.94

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Michael Miller	2/14/2017	John Wilkens	3/13/2017	N/A	N/A

7.2.8 Heat Balance Calculation Power Uncertainty (**Power U**) Rev 5

The calculated heat balance uncertainty is the algebraic combination of the bias errors with the independent/random errors statistically combined, that contribute into the heat balance calculation, in accordance with the heat balance formula:

Power = MFW(MSh-FWh)-CRDF(hin-hout)+RWCU(hout-hin)-RRP+HL+Miscellaneous

Summary of Heat Balance Calculation Contributing Errors:

Random Errors:	MSmoist = 0.0000%	
	CRDc = 0.0053%	
	CRDdp = 0.0061%	
	RRPw = 0.0038%	
	RWCUp_sw = 0.0001%	
Dependent Errors:	Errors	Variable
	FWm = **	
	FWht = **	
	MSm = **	
	FWhp = **	Rated MS pressure = 1001 psia
	MShp = 0.0253%	
	CRDhp = -0.00005%	
	RWCUhp = 0.00004%	
Bias Errors:	CRDt = -0.0012%	
	CRDht = -0.0096%	
	RWCUf = 0.0031%	
	RWCUht = 0.0281%	
	TL = 0.006%	
	OSL = 0.006%	

** Note that these terms are combined in reference 3.4.20 for an over all uncertainty of 0.34% for FWm, FWht and FWhp

Heat Balance Calculation Power Error (U):

Power Error = SQRT[((0.0034)^2+(MShp+CRDhp+RWCUhp)^2+MSmoist^2+CRDc^2+CRDdp^2+
+RWCUp_sw^2+RRPw^2x2]+CRDt+CRDht+RWCUf+RWCUht+TL+OSL

Power Error = **0.373%**

To ensure operation margin exist, due to possible instrumentation loops miss-calibration, actual drift (to be determined by history), etc., a margin is added:

Power U = Power Error + Margin

where margin is defined as 3840 * 102% –Rated Thermal Power – Power Error

Margin = 3916.8 - 3902 - Power Error
Margin = 0.006% and **Power U =** 0.379%

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8.0 SUMMARY

Rev 5

The calculated Heat Balance Error performed in this calculation is applicable to fully operational LEFM. The Power Uncertainty is the difference between the 2% design basis and the rated termal power for the current LEFM mode of operation. Positive margin is maintained between the Power Uncertainty and the Power Error. The Heat Balance calculation error (Section 7.0) is:

Power U = 0.379%

Sections 1 through 4 have been replaced with the main body of the calculatior

5.0 DESIGN INPUTS Rev 5

5.1 Rated Power Conditions

100% rated Power Conditions are listed below. Actual 100% operation values might be used in lieu of rated nominal values, for other than Rated MWt, Feedwater Flow and Main Steam parameters as deemed appropriate. This is found acceptable, since for the purpose of error determination to rated MWt "heat differential errors", actual heat contribution deviation from measured/calculated heat to rated MWt due to instrumentation uncertainties, is required not the actual deviation value.

Rated MWt =	**3889MW**	This power level is set at the highest whole MWt power level which produces positive margin
Rated FW flow =	**1.4962E+07lbm/hr**	(Ref. 3.4.19, Att. 8)
Rated FW temperature =	**331.5 F**	(Ref. 3.4.19, Att. 8)
Rated MS flow =	**14994000**	(Ref. 3.4.19, Att. 8)
Rated MS pressure =	**1001 psia**	(Ref. 3.4.19, Att. 8)
Rated MS quality =	**100.000**	(Ref. 3.4.1)
Rated RWCU flow =	**148000.0 lb/hr**	(Ref. 3.4.19, Att. 8)
Rated RWCU temperature =	**517.8 F**	(Ref. 3.4.19, Att. 8)
Rated RWCU return temperature =	**419.2 F**	(Ref. 3.4.19, Att. 8)
Rated CRD flow =	**32000.0 lb/hr**	(Ref. 3.4.3, 3.4.18)
CRD Calibration pressure =	**1474.0 psia**	(Ref. 3.4.5)
Rated CRD temperature =	**77 F**	(Ref. 3.4.19, Att. 8)
Radiation Loses =	**1.10MW**	(Ref. 3.4.2, 3.4.19)
Other System Loses =	**1.18MW**	(Ref. 3.4.2, 3.4.19) Note: These loses are not included in UFSAR Heat Balance, Ref. 3.1.1
MWt/BTU/hr =	**2.9300E-07**	(Ref. 3.4.1)

Power = MFW(MSh-FWh)-CRDF(hin-hout)+RWCU(hout-hin)-RRP+HL+Miscellaneous

Notes:

1) This calculation uses rated MS quality of 100.00%, which will produce a more conservative number with respect to the actual plant MS quality. This parameter may be revised when the actual MS quality is measured after the implementation of EPU.
2) This calculation specifies radiation loses as 1.10 MW and other loses as 0.84 MW for the total lose of 1.94 MW. Reference 3.4.17 stated "other system loses" as 1.9 MW without specifically accounting for Radiation loses. Since the two total numbers are almost identical and the difference would have negligible affect on the Power Error, radiation loses of 1.10 MW and the other loses of 0.84 MW will be maintained.

6.0 ASSUMPTIONS

The Main Feedwater uncertainties is included in the total termal power uncertainty provided by the LEFM while in mantenance mode is 0.66% per Reference 3.4.20 is provided based on a power level of 3902MWt. This is not interpolated based on a 3889MWt since the uncertainty provided by Reference 4.1.20 is only provided in two significant digits and the impact is neglible.

The design inputs from reference 3.4.17 are used as bounding design inputs and a 3889MWt heat balance is not included in reference 3.4.17. The difference between the operating region of the steam tables between the inputs of 3902MWt and 3889MWt are considered to be minimal and the impact is neglible.

See sections 7.2.3, 7.2.4, 7.2.6 and 7.2.7 for specific assumptions.

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Michael Miller	2/14/2017	John Wilkens	3/13/2017	N/A	N/A

7.0 CALCULATIONS

Rev 5

7.1 Methodology

The methodology used to combine the uncertainties for the different contributors to the heat balance calculation is the square root of the sum of the squares of those uncertainties which are statistically independent. Then algebraically combined with the those errors that are systematic, or bias. The uncertainties are considered to be random, two sided distributions. This methodology has been utilized before, and has been endorsed by the NRC and various industry standards (Ref. 3.4.12-3.4.14).

The uncertainty calculation combines the different errors from the different parameters contributing to the heat balance in accordance to the heat balance equation. The contributing parameters errors are taken from the specific system uncertainty calculation.

These errors are generally classified in two groups:

a) Instrument loop(s) uncertainty
b) Process effects

The individual uncertainties affecting the heat balance calculation are determined by the application of the corresponding process algorithm, as described below:

a) the appropriate algorithm for the specific process parameter is set in the form to its specific contribution to the heat balance at specified rated conditions,
b) subsequently, the instrumentation loop error is factored in the process algorithm to calculate the corresponding process parameter with the error built-in,
c) the difference of the calculated contributed process parameter heat, with error, to the rated process rated heat is then calculated,
d) the resultant heat error contribution is then divided by the rated 100% power thermal megawatts. The result is the error contribution by the specific process to the total heat balance uncertainty,
e) finally, all the calculated heat errors are combined in accordance to their parameter function in the heat balance equation. The resultant combination of all contributing errors is the Heat Balance Uncertainty.

7.2 Uncertainties Calculation

Rev 5

7.2.1 Main Feedwater Uncertainty(ies)

The Main Feedwater uncertainties are included in the total thermal power uncertainy provided by the LEFM while in mantenance mode is 0.66% per Reference 3.4.20. This includes the Main Feedwater mass flow error, main feedwater heat enthalpy error, and the Main Steam mass flow error

Referring to the schematic drawing in section 4.0, it can be seen that the Main Feedwater heat contribution is affected by the following parameters:

a) Mass Flow Measurement affected by: 1) flow, 2) temperature, and 3) pressure instrumentation loops error.

The error provided by the vendor for the ultrasonic flow meter already factors the corresponding temperature and pressure loops effect.

b) Feedwater Enthalpy determination affected by: 1) temperature, and 2) pressure, instrumentation loops error.

The main feedwater enthalpy is calculated using the following signals:

- Feedwater Pressure and Main Feedwater Temperature

7.2.1.1 Main Feedwater Mass Flow Heat Error due to Flow Element Uncertainty (**FWm**)

Deleted

7.2.1.2 Main Feedwater Heat Enthalpy Error due to Pressure Loop Uncertainty (**FWhp**)

Deleted

7.2.1.3 Main Feedwater Heat Enthalpy Error due to Temperature Loop Uncertainty (**FWht**)

Deleted

Rev 5

7.2.2 Main Steam Flow Uncertainty(ies)

Referring to the schematic drawing in section 4.0, It can be seen that the Main Steam heat contribution is affected by the following parameters:

a) The calculated Main Steam Heat is affected by the mass flow measurement error (see section 7.2.1.1 Main Feedwater Mass Error).

b) Main Steam Enthalpy determination is affected by the pressure instrumentation loop error, documented in calculation:

Ref. 3.4.4

7.2.2.1 Main Steam Mass Flow Heat Error due to Main Feedwater Flow Uncertainty (**MSm**)

Deleted

(NC.DE-AP.ZZ-0002(Q), Rev. 12, Form 2)			CALCULATION CONTINUATION SHEET		SHEET:	5
CALC NO.:	SC-BB-0525 Attachment 5	REV:	5	REF:	CONT'D ON SHEET:	6

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Michael Miller	2/14/2017	John Wilkens	3/13/2017	N/A	N/A

7.2.2.2 Main Steam Heat Enthalpy Error due to Pressure Loop Uncertainty (**MShp**) Rev 5

This Section calculates the Main Heat Steam enthalpy error due to the loop pressure uncertainty, documented in:

Ref.: 3.4.4

The heat error is the difference in the Main Steam flow heat content at rated flow and enthalpy conditions minus the heat content at rated flow with enthalpy at rated pressure plus pressure induced error:

MShp = [Flow (hrated - hrated+err)] x 2.93E-07 / 3889 x 100%

P Rtd	P+err	Moist Rtd	Moist+err	h rated	h+err	Flow
1000.69	1006.79	100	100.000	1192.91	1192.69	14,994,000
Error (psi) =	6.1		0			

TTL MS Heat
17,883,129,657 BTU/hr

17,886,503,873 BTU/hr at rated conditions

Error
3,374,216 BTU/hr error at rated main feedwater flow

Error in Rated MWt
MShp = 0.0254%

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Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.2.3. Main Steam Moisture Heat Enthalpy Error due to Steam Moisture Uncertainty (**MSmoist**) Rev 5

This section calculates the Main Steam enthalpy error due to MS moisture uncertainty. The uncertainty is conservatively set to 50% of rated moisture content of 0.0%.

The heat error is the difference in the Main Steam flow heat content at rated flow and moisture conditions minus the heat content at rated moisture conditions plus moisture error:

MSmoist = [Flowrated hrated (hmoist-rated - hmoist-rated+err)] x 2.93E-07 / 3889 x 100%

P Rtd	P+err	Moist Rtd	Moist+err	h rated	h+err	Flow
1000.69	1000.69	100	100.0000	1192.91	1192.91	14,994,000
	0.00000	0.00%	0			

TTL MS Heat
17,886,503,873 BTU/hr

17,886,503,873 BTU/hr at rated conditions

Error
- BTU/hr error at rated main feedwater flow

Error in Rated MWt
MSmoist = 0.0000%

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Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.3 Control Rod Drive Flow

Rev 5

Referring to the schematic drawing in section 4.0, it can be seen that CRD flow is not monitored for pressure or temperature.

The CRD calculated heat is affected by the following effects:

a) Mass Flow Measurement affected by: 1) flow, instrumentation loop effect and 2) temperature, and 3) pressure deviation from calibration values

b) The CRD Enthalpy determination is affected by: 1) temperature, from applied constants, and 2) pressure, from reactor pressure loop error

The CRD flow loop errors are documented in calculation:

Ref. 3.4.5

The flow formula is derived from the ASME (Ref. 3.4.9) as follows:

Flow = C*Fa*K*(DP*r)^0.5

where K is calculated below:

K = Calib Flow/(Calib inWC * Calib r)^0.5

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Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.3.1 Control Rod Drive Flow Heat Error due to Flow Element and Fluid Specific Weight Uncertainty due to Temperature Error (**CRDt**) Rev 5

The uncertainty is dependent for the following variables:

Fa = FE Thermal Expansion **r =** Fluid Specific Weight

The plant computer calculates the CRD flow with a constant flow K factor. However, the actual temperature could vary as much as 43F from the expected 77F, and this impacts the Fa and r impacting the calculated flow; therefore, the effect due to this temperature deviation is:

CRDt = [(hs rated - CRDh rated) (Flowrated - Flowrated+err)] x 2.93E-07 / 3889 x 100%

Ref.: 3.4.5

K = 448.48
Calib Flow = 50154 lb/hr 100 GPM
Calib inWC = **200**
Calib Temp = **77**
Calib Press = **1474.7**
r = 62.529
Assumed Rated Flow = **32000.0 lb/hr**
Rated Press = 1001 psia
Rated Temp = **77 F**
Rated h = 47.78 btu/lb

Fa Error	
Rated 77F	1.0003
@140 F	1.0013
@40 F	0.9995
Fa/F	1.8E-05

T+err 120

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd
1.0000	1.0000	81.3694	81.3694	1.0003	1.0011	77 ÷ 43
0.00% ÷	0	0.00% ÷	0			

Temp error = Calib Temp - Min Temp

P Rtd	r	h Rtd	Flow	hs Rtd
1000.69	61.8993	47.78	31,862.980	1192.91

TTL CRD Heat
36,487,315 BTU/hr

36,644,221 BTU/hr at rated conditions

Error
(156,906) BTU/hr error at rated CRD flow

Error in Rated MWt
CRDt = -0.0012% This error is a bias, not a random instrument induced uncertainty.

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.3.2 Control Rod Drive Flow Heat Error due to Flow Element Uncertainty (**CRDc**) Rev 5

The CRD contributed heat is affected by the FE error that is assigned to the flow element expansion coefficient.

C

The FE uncertainty is determined based in calculation:

Ref.: 3.4.5

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

CRDc = [(hs rated - CRDh rated) (Flowrated - Flowrated+err)] x 2.93E-07 / 3889 x 100%

Fa Error				
Rated 77F	1.0003	**K =** 448.48		
@140 F	1.0013	Calib Flow = 50154	100.00	
@60 F	0.9995	Calib inWC = 200.00		
Fa/F	1.8E-05	Assumed Calib Temp = 77.00		
		Assumed Calib Press = 1474.00		
		r = 62.529	0.0159925	
		Assumed Rated Flow = 32000.0 lb/hr		
		Rated Press = 1001 psia		
		Rated Temp = 77 F		
		Rated h = 47.78 btu/lb		

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0200	81.3694	81.3694	1.0003	1.0003	77	77
2.00%	200	0.00%	0				0

P Rtd	r	h Rtd	Flow	hs Rtd
1000.69	62.4396	47.78	32,616.541	1192.91

TTL MFW Heat	
37,350,242	BTU/hr

36,644,221 BTU/hr at rated conditions

Error

706,021 BTU/hr error at rated CRD flow

Error in Rated MWt
CRDc = 0.0053%

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	2/14/2017	John Wilkens	3/13/2017	N/A	N/A

7.2.3.3 Control Rod Drive Heat Error due to Differential Pressure (DP) Loop Uncertainty (**CRDdp**) Rev 5

This error is calculated in calculation:

Ref.: 3.4.5

The loop is comprised of 1) flow transmitter, FT, 2) resistor, REST, 3) computer analog to digital card, A/D.
The uncertainties are in % DP span:

Accuracy: **Loop Drift:**

CRD_AFT	CRD_AREST	CRD_AA/D	CRD_VDFT	CRD_VDA/D
1.154%	0.100%	0.188%	1.450%	0.000%

Loop Calibration:

CRD_CEFT	CRD_CEA/D
0.140%	0.188%

The uncertainties are random and independent and combined by the SRSS method:

1.88%	span DP

(NC.DE-AP.ZZ-0002(Q), Rev. 12, Form 2)			CALCULATION CONTINUATION SHEET			SHEET: 11
CALC NO.: SC-BB-0525 Attachment 5		REV: 5		REF:		CONT'D ON SHEET: 12
ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:		DATE:
Michael Miller	2/14/2017	John Wilkens	3/13/2017	N/A		N/A

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

Rev 5

CRDdp = [(hs rated - CRDh rated) (Flowrated - Flowrated+err)] x 2.93E-07 / 3889 x 100%

Fa Error

Rated 77F	1.0003
@140 F	1.0013
@60 F	0.9995
Fa/F	1.8E-05

K = 448.51
Calib Flow = 50157.2 lb/hr 100 GPM
Calib inWC = 200
Assumed Calib Temp = 77
Assumed Calib Press = 1474
r = 62.529
Assumed Rated Flow = 32000.0 lb/hr
Rated Press = 1000.7 lb/hr
Rated Temp = 77 F
CRDh rated = 47.78 btu/lb

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	81.3584	85.1183	1.0003	1.0003	77	77
0.00%	0	1.88%					0

P Rtd	r	CRDh rated	Flowrated+err	hs Rtd
1000.69	62.4396	47.78	32,707.575	1192.91

TTL MFW Heat
37,454,488 BTU/hr

36,644,221 BTU/hr at rated conditions

Error
810,267 BTU/hr at rated CRD flow

Error in Rated MWt
CRDdp = 0.0061%

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.3.4 Control Rod Drive Flow Enthalpy Heat Error due to Temperature Calibration Deviation (**CRDht**) Rev 5

The plant computer calculates the CRD fluid enthalpy at a constant 77F and reactor pressure. However, the actual temperature varies and it is assumed to vary as much as 43F from the expected 77F; therefore, the effect due to this temperature deviation in the calculated enthalpy is:

Ref. 3.4.5

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

CRDht = [Flow (hs rated - CRDh rated) - Flow (hs rated - CRDh rated+err)] x 2.93E-07 / 3889 x 100%

TRtd	T Max/Min	T+err	P Rtd	h rated	h+err	hs rated	Flow
77	40	37	1000.69	47.78	7.99	1192.91	32,000

TTL RWCU Heat
37,917,380 BTU/hr

36,644,221 BTU/hr at rated conditions

Error
(1,273,159) BTU/hr at rated CRD flow

Uncertainty in Rated MWt
CRDht = -0.0096%

This error is a bias, not a random instrument induced uncertainty.

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.3.5 Control Rod Drive Flow Enthalpy Heat Error due to Pressure Loop Uncertainty (**CRDhp**) Rev 5

The plant computer calculates the CRD fluid enthalpy at a constant 77Fand reactor loop pressure, that is affected by the loop uncertainty.
The pressure loop uncertainty is documented in:

Ref.: 3.4.4

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

CRDhp = [Flow (hs rated - CRDh rated) - Flow (hs rated+err - CRDh rated)] x 2.93E-07 / 3889 x 100%

P Rtd	P+err	TRtd	CRDh rated	hs rated	hs rated+err	Flow
1000.69	1006.79	77	47.78	1192.91	1192.69	32,000

Error (psi) = 6.1

TTL MFW Heat	
36,637,020	BTU/hr

36,644,221 BTU/hr at rated conditions

Error
(7,201) BTU/hr at rated CRD flow

Uncertainty in Rated MWt
CRDhp = -0.00005%

Rev 5

7.2.4 Reactor Water Cleanup Uncertainty(ies)

Referring to the schematic drawing in section 4.0, it can be seen that RWCU flow is measured and mass calculated by a "NUMAC" process unit. Differential pressure, temperature, by dedicated thermocouples, and reactor pressure are an input to the instrument. Therefore, the RWCU contributed heat is affected by the following parameters:

a) Mass Flow Measurement affected by: 1) flow, 2) temperature, and 3) pressure induced factors/instrumentation loops errors

b) The RWCU Enthalpy determination is affected by: 1) temperature instrumentation loop error (see discussion for pressure)

The flow formula is derived from the ASME (Ref. 3.4.9) as follows:

Flow = C*K*(DP)^0.5

where K is:

K = Calib Flow / [C*(Calib inWC)^0.5]

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.4.1 RWCU Inlet/Outlet Flow Heat Error due to Flow Element Expansion deviation from Calibration (**RWCU$_{Fa}$**) Rev 5

The Numac computer calculating the mass flow has a built-in Fa constant different than the flow element Fa provided at the calculated venturi rated temperature of 533F. This induces a bias error. Furthermore, the plant NUMAC normalizes the flow mass signal to a specific weight of 47.0 lbm/cuft for pressure and temperature conditions, back calculated below; therefore, the rated conditions are set at 530.7F.

Pressure Density Compensated to :	48.01 lb/cuft	517.8 F	**908 psia**
The Fa used in the calculation is fixed to:		1.0045	
The correct Fa at rated 533 F is:		1.0087	

Based on the Fa differences the induced flow error is calculated below:

Fa = FE Thermal Expansion

Ref.: 3.4.10

Flow+err = C x Fa+err / Fa x K x (DP)^0.5

K = 9449.90
Calib Flow = 189823.1 lb/hr **500 GPM** (Note)
Calib inWC = **403.5**
Assumed Calib Temp = **530.7**
Assumed Calib Press = **1114.7**
r = 47.332
Assumed Rated Flow = 148021 lb/hr **389 GPM**
Rated h = 524.83 btu/lb

Fa Error
Rated 533F **1.0087**
Calibrated **1.0045**

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	245.3520	245.3520	1.0087	1.0045	530.7	530.7
0.00%	0	0.00%	0				0

P Rtd	P+err	r	h Rtd	Flow+err
1114.7	1114.7	47.3324	524.83	147,404
	0			

Uncertainty
RWCUFa -616.3 lb/hr

This a bias and the actual contributed Heat is Higher than indicated

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

Rev 5

7.2.4.2 RWCU Inlet/Outlet Flow Heat Error due to Fluid Specific Weight deviation (**RWCUPMA**)

This error is the combination of several uncertainties calculated below:

7.2.4.2.1 RWCU Inlet/Outlet Flow Error due to Fluid Specific Weight Numac Lookup Tables Error (**RWCUPMA1**)

The Numac performs the fluid specific weight determination with an error of 0.1 specific weight, this effect in the flow is calculated below.

r = Fluid Specific Weight

Ref.: 3.4.10

Flow+err = C x K x (DP x r+err / r)^0.5

The flow error is the difference between the rated flow at rated specific weight minus the flow at specific weight plus error:

RWCUPMA1 = Flowrated - Flowrated+error

K = 9449.90
Calib Flow = 189823.1 lb/hr 500 GPM (Note)
Calib inWC = 403.5
Assumed Calib Temp = 530.7
Assumed Calib Press = 1114.7
r = 47.332
Assumed Rated Flow = 148021 lb/hr 388.8 GPM
Rated hout = 524.83 btu/lb

Fa Error
Rated 533F 1.0087
Calibrated 1.0045

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd
1.0000	1.0000	245.3520	245.3520	1.0087	1.0087	530.7
0.00%	0	0.00%	0			

P Rtd	P+err	r	Numac err	r+perr+Numac	h Rtd	Flow
1114.7	1114.7 psi	47.332	0.1	47.432	524.83	148,177
	0 psi					

Uncertainty
RWCUPMA1 = 156.3 lb/hr

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.4.2.2 RWCU Inlet/Outlet Flow Error due to Fluid Specific Weight Numac 0.75 Factor Pressure Correction Factor Error (**RWCUPMA2**) Rev 5

The Numac computer introduces a 0.75 factor to the input pressure raw value and calculates the specific weight for saturated conditions, which bias the actual flow.

Ref.: 3.4.10

Flow+err = C x K x (DP x r+err / r)^0.5

The flow error is the difference between the rated flow at rated specific weight minus the flow at specific weight plus error:

RWCUPMA2 = Flowrated - Flowrated+error

r = Fluid Specific Weight

K = 9449.90
Calib Flow = 189823.1 lb/hr 500 GPM (Note)
Calib inWC = 403.5
Assumed Calib Temp = 530.7
Assumed Calib Press = 1114.7
r = 47.332
Assumed Rated Flow = 148021 lb/hr 388.8 GPM
Rated = 524.83 btu/lb

Fa Error	
Rated 533F	1.0087
Calibrated	1.0045

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	h Rtd return	Flow
1.0000	1.0000	245.3520	245.3520	1.0087	1.0087	530.7	396.68	148,422
0.00%	0	0.00%	0					

P Rtd	P+err	T Sat	r+perr	Numac rerr	r+perr+Numac	h Rtdout
1114.7	840 psi	523.8	47.5895	0	47.5895	524.83
	75%	**75**				

Uncertainty
RWCUPMA2 = -402 lb/hr This a bias and the actual contributed Heat is Higher than indicated

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.4.2.3 RWCU Inlet/Outlet Flow Heat Error due to Fluid Specific Weight Pressure Loop Uncertainty (**RWCUP_SW**) Rev 5

Pressure is utilized as an input to the Numac to determine the specific weight of the fluid. The pressure loop uncertainty combined with the Numac computer uncertainty introduces an error in the calculated specific weight.

The loop error is comprised of 1) pressure loop, PT, 2) NUMAC computer uncertainties. The combined uncertainties are:

RWCUpress error= 21 psi

Ref.: 3.4.10

Flow+err = C x K x (DP x r+err / r)^0.5

The flow error is the difference between the rated flow at rated specific weight minus the flow at specific weight plus error:

RWCUp_SW = [Flowrated (h_in - h_out) - Flowrated+error (h_in - h_out)] x 2.93E-07 / 3889 x 100%

r = Fluid Specific Weight

K = 9449.90

Calib Flow = 189823.1 lb/hr 500 GPM (Note)

Calib inWC = 403.5

Assumed Calib Temp = 530.7

Assumed Calib Press = 1114.7

r = 47.332

Assumed Rated Flow = 148021 lb/hr 388.8 GPM

Rated h = 524.83 btu/lb

Fa Error	
Rated 533F	1.0087
Calibrated	1.0045

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd in	T Rtd out
1.0000	1.0000	245.3520	245.3520	1.0087	1.0087	530.7	419.2
0.00%	0	0.00%	0				

P Rtd	P+err	r+perr	Numac rerr	r+perr+Numac	h Rtd in	h Rtd out	Flow
1000.69	1022 psi	47.2689	0	47.2689	509.11	396.68	147,921

TTL MFW Heat
16,631,277 BTU/hr

16,642,445 BTU/hr at rated conditions

Error
11,168

Uncertainty in Rated MWt
RWCUp_sw = 0.0001%

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	2/14/2017	John Wilkens	3/13/2017	N/A	N/A

Rev 5

7.2.4.3 Reactor Water Cleanup Flow Error due to Flow Element Uncertainty (**RWCUc**)

The RWCU flow is affected by the FE error that is assigned to the flow element expansion coefficient,

C

The FE uncertainty is determined based in calculation:

Ref.: 3.4.10

Flow+err = C+err x K x (DP)^0.5

The flow error is the difference between the rated flow minus the flow with the C coefficient error:

RWCUc = Flowrated - Flowrated+error

Fa Error
Rated 533F 1.0087
Calibrated 1.0045

K = 9449.90
Calib Flow = 189823.1 LB/HR 500 GPM (Note)
Calib inWC = 403.50
Assumed Calib Temp = 530.70
Assumed Calib Press = 1114.70
r = 47.332
Assumed Rated Flow = 148021 lb/hr 389 GPM
Rated h = 524.83 btu/lb

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0150	245.3520	245.3520	1.0087	1.0087	530.7	530.7
1.50%	150	0.00%	0				0

P Rtd	r	h	Flow
1114.7	47.3324	524.8	150,241

Uncertainty
RWCUc = 2220.3 lb/hr

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.4.4 Reactor Water Cleanup Flow Error due to Differential Pressure (DP) Loop Uncertainty (**RWCUdp**) Rev 5

This error is introduced by the differential pressure instrument loop. The uncertainties in the loop are found in: Ref.: 3.4.10

The loop is comprised of 1) flow transmitter, FT, 2) NUMAC computer. The uncertainties are in % DP span:

The flow error is the difference between the rated flow minus the flow with the C coefficient error:

RWCUdp = Flowrated - Flowrated+error

Accuracy: **Loop Drift:**

RWCU_AFT	RWCU_ANU_IE	RWCU_ANU_A/D	RWCU_VDFT	RWCU_VDNU_IE	RWCU_VDNU_A/D
0.503%	0.100%	0.233%	0.900%	0.127%	0.127%

Loop Calibration:

RWCU_CEFT	RWCU_CENU_A/D
0.139%	0.02%

The uncertainties are random and independent and combined by the SRSS method:

1.09%	span DP

Flow+err = C x K x (DP+err)^0.5

Fa Error
Rated 533F 1.0087
Calibrated 1.0045

K = 9449.90
Calib Flow = 189823.1 LB/HR 500 GPM (Note)
Calib inWC = 403.50
Assumed Calib Temp = 530.70
Assumed Calib Press = 1114.70
r = 47.332
Assumed Rated Flow = 148021 LB/HR 389 GPM
Rated h = 524.83 btu/lb

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	245.3520	249.7338	1.0087	1.0087	530.7	530.7
0.00%	0						0

P Rtd	r	h	Flowrated+err
1114.7	47.3324	524.83	149,336

Uncertainty
RWCUdp = 1315.9 lb/hr

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.4.5 Reactor Water Cleanup Flow Error due to Signal Conditioning/NSSS Computer Loop Uncertainty **(RWCUNSSS_cptr)** Rev 5

The differential pressure is converted to flow by the Numac computer and retransmitted as flow signal to the plant computer for heat balance calculations.

This portion of the loop is comprised of 1) NUMAC computer output, 2) NSSS computer uncertainty. The uncertainties are in % flow span:

Accuracy:

RWCU_ANU_D/A	RWCU_AA/D
0.233%	0.188%

Loop Drift:

RWCU_VDNU_D/A	RWCU_VNA/D
0.13%	0.000%

Loop Calibration:

RWCU_CENU_D/A	RWCU_CEA/D
0.02%	0.188%

The uncertainties are random and independent and combined by the SRSS method:

0.38%	span FLOW

The flow error is the difference between the rated flow at without loop error minus the flow plus loop error:

RWCUNSSS_cptr = Flowrated - Flowrated+error

Fa Error
Rated 533F 1.0087
Calibrated 1.0045

K = 9449.90
Calib Flow = 189823.1 lb/hr 500 GPM (Note)
Calib inWC = 403.50
Assumed Calib Temp = 530.70
Assumed Calib Press = 1114.70
r = 47.332
Assumed Rated Flow = 148021 lb/hr 389 GPM
Rated h = 524.83 btu/lb

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	245.3520	245.3520	1.0087	1.0087	530.7	530.7
0.00%	0						0

P Rtd	r	h	Flow
1114.7	47.3324	524.83	148,734.3

Uncertainty
RWCUNSSS_cptr= 713.8 lb/hr

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	2/14/2017	John Wilkens	3/13/2017	N/A	N/A

7.2.4.6 Reactor Water Cleanup Total Flow due to Flow Loop Uncertainties **(RWCUf)** Rev 5

RWCU Inlet h - Outlet h.

The total RWCU Flow Uncertainty is calculated below:

RWCUfu =+/-SQRT(RWCUPMA1^2+RWCUc^2+RWCUdp^2+RWCUNSSS_cptr^2)-RWCUFa-RWCUPMA2

Notice that the bias PMAs are factored with both signs, since the negative uncertainty is the one that has impact in the heat balance calculations, that is, that (-) less indication means that power is higher; however, it will be factored in both directions for simplicity.

RWCUfu = 3700 lb/hr

Then, the heat error contribution is the calculated inlet flow heat error minus the outlet flow heat error:

RWCUh_in = 509.11 btu/lb
RWCUh_out = 396.68 btu/lb

And the RWCU heat error contribution is calculated by the following expression:

RWCU = [RWCUfu (RWCUh_in - RWCUh_out) x MWt_BTU_hr (conversion factor)] / Rated MWt 100%

RWCUf = 0.0031% This total error will be treated as bias in the total heat balance error

7.2.4.7 Reactor Water Cleanup Flow Enthalpy Heat Error due to Temperature Uncertainty (RWCUht) Rev 5

This error is the error resultant of temperature measurement errors by the inlet/outlet RWCU thermocouple loops factored into the fluid enthalpy determination. The thermocouples are instruments with good repeatability and stability. However, fabrication errors can amount to several farenheit degrees. The fabrication errors can be calibrated out, since essentially it is a bias, systematic error. The temperature loops for RWCU are not calibrated out. Finally, since most of the thermocouples loop error is a bias, the conservative and safe way to apply the error, is for the two temperature error to be set in the same direction; therefore, the effect is additive, bias. The temperature loops error is found in:

Ref. 3.4.6

The heat error is the difference between the inlet flow heat error minus the outlet flow heat error:

RWCUht = [Flow [(hin - hin+error) + (hout - hout+error)]] x 2.93E-07 / 3889 x 100%

In flow heat

TRtd	T+err	P Rtd	h rated	h+err	Flow
517.8	528.7	1000.69	509.11	522.50	148,021
Error (F)	10.9				

Out flow heat

TRtd	T+err	P Rtd	h rated	h+err	Flow
419.2	430.1	1000.69	396.68	408.57	148,021
Error (F)	10.9				

Error	
3,741,117	**BTU/hr error at rated reactor water cleanup flow**

Uncertainty in Rated MWt	
RWCUht = 0.0282%	This error is a bias

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.4.8 Reactor Water Cleanup Flow Enthalpy Heat Error due to Pressure Loop Uncertainty (**RWCUhp**) Rev 5

The reactor water cleanup enthalpy determination is affected by the loop pressure error. The pressure has a very small effect in the water enthalpy, however, it is determined in this calculation. The loop uncertainty is documented in:

Ref.: 3.4.4

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

RWCUhp = [Flow [(hin - hin+error) - (hout - hout+error)]] x 2.93E-07 / 3889 x 100%

In flow heat

P Rtd	P+err	TRtd	h rated	h+err	Flow
1000.69	1020.89	517.8	509.11	509.09	148,000
Error (psi)	20.2				

Out flow heat

P Rtd	P+err	TRtd	h rated	h+err	Flow
1000.69	1020.89	419.2	396.68	396.70	148,000
Error (psi)	20.2				

Error

5,764 BTU/hr at rated reactor water cleanup flow

Uncertainty in Rated MWt
RWCUhp = 0.00004%

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.5 Recirculation Pumps Heat Error due to Watts Loop Uncertainty (**RRPw**) Rev 5

This section calculates the uncertainty due to RRP watts loop error, calculated in:

Ref.: 3.4.11

The rated power for the pump-motor and the motor efficiency (0.93) is from reference:

(Ref. 3.4.3)

There are two recirculation pumps, the calculated error below is per pump. The actual total MW for the 2 pumps is taken from above reference.

W 2 pump = 7.33

The Watt error contribution is calculated as follows:

RRPw = [(W Rtd/pump + MW Loop Span x Span err) x Mottor eff] - W Rtd/pump x Motor eff] / 3889 x 100%

W Rtd/pmp+err	Motor Eff	W+err
3.823	0.93	3.55
	Error =	**1.50 % span**
	Span =	**10.5 Mwatt**

TTL Mwatt
3.41 Mwatt

Error
0.1465 Mwatt

Uncertainty in Rated MWT
RRPw = 0.0038%

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

Rev 5

7.2.6 Thermal Loses (TL)

This section calculates the uncertainty due to TL error. This error will be treated as a bias error since the estimated value is larger or smaller than assumed, i.e. it is a fixed error not a random error.

An assumed error equal to 20% of the specified loses is used.

The rated Heat Loss is from reference:

(Ref. 3.4.2)

W Rtd	W+err
1.1	1.32
Error =	20.00%

TTL Mwatt Heat
1.32 MW

1.10 MW at rated conditions

Error

0.2200 MW error at rated radiated loses

Uncertainty in Rated MWT
TL = 0.006%

This error is treated as bias.

Note: The computer utilizes this value combined with Other System Loses (Section 7.2.7) as Radiative power loses, QRAD = 1.94

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.7 Other System Loses (**OSL**) Rev 5

The rated value includes Rod Drive seal purge flow to recirculation pumps. An assumed error equal to 20% of the specified loses is used.
This error will be treated as a bias error since if the estimated value is larger or smaller than assumed, i.e. it is a fixed error not a random error.

The rated Losses figure is from reference:

(Ref. 3.4.2)

W Rtd	W+err
1.18	1.416
Error =	20%

TTL Mwatt Heat	
1.42	MW

1.18 MW at rated conditions

Error

0.2360 MW error at rated radiated loses

Uncertainty in Rated MWT	This error is treated as bias.
OSL = 0.006%	

Note: The computer utilizes this value combined with Thermal Loses (Section 7.2.6) as Radiative power loses, QRAD = 1.94

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	**2/14/2017**	**John Wilkens**	**3/13/2017**	**N/A**	**N/A**

7.2.8 Heat Balance Calculation Power Uncertainty (**Power U**) Rev 5

The calculated heat balance uncertainty is the algebraic combination of the bias errors with the independent/random errors statistically combined, that contribute into the heat balance calculation, in accordance with the heat balance formula:

Power = MFW(MSh-FWh)-CRDF(hin-hout)+RWCU(hout-hin)-RRP+HL+Miscellaneous

Summary of Heat Balance Calculation Contributing Errors:

Random Errors:	MSmoist = 0.0000%	
	CRDc = 0.0053%	
	CRDdp = 0.0061%	
	RRPw = 0.0038%	
	RWCUp_sw = 0.0001%	
Dependent Errors:	Errors	Variable
	FWm = **	
	FWht = **	
	MSm = **	
	FWhp = **	Rated MS pressure = 1001 psia
	MShp = 0.0254%	
	CRDhp = -0.00005%	
	RWCUhp = 0.00004%	
Bias Errors:	CRDt = -0.0012%	
	CRDht = -0.0096%	
	RWCUf = 0.0031%	
	RWCUht = 0.0282%	
	TL = 0.006%	
	OSL = 0.006%	

** Note that these terms are combined in reference 3.4.20 for an over all uncertainty of 0.66% for FWm, FWht and FWhp

Heat Balance Calculation Power Error (U):

Power Error = SQRT[((0.0066)^2+(MShp+CRDhp+RWCUhp)^2+MSmoist^2+CRDc^2+CRDdp^2+
+RWCUp_sw^2+RRPw^2x2]+CRDt+CRDht+RWCUf+RWCUht+TL+OSL

Power Error = **0.693%**

To ensure operation margin exist, due to possible instrumentation loops miss-calibration, actual drift (to be determined by history), etc., a margin is added:

Power U = Power Error + Margin

where margin is defined as 3840 * 102% – Rated Thermal Power – Power Error

Margin = 3916.8 - 3889 - Power Error
Margin = 0.022% and **Power U =** 0.715%

ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	2/14/2017	John Wilkens	3/13/2017	N/A	N/A

8.0 SUMMARY

Rev 5

The calculated Heat Balance Error performed in this calculation is applicable to fully operational LEFM. The Power Uncertainty is the difference between the 2% design basis and the rated termal power for the current LEFM mode of operation. Positive margin is maintained between the Power Uncertainty and the Power Error. The Heat Balance calculation error (Section 7.0) is:

Power U = 0.715%

(NC.DE-AP.ZZ-0002(Q), Rev. 12, Form 2)		CALCULATION CONTINUATION SHEET			SHEET: 1
CALC NO.: SC-BB-0525 Attachment 6	REV: 5	REF:			CONT'D ON SHEET: 2
ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	2/14/2017	John Wilkens	3/13/2017	N/A	N/A

Sections 1 through 4 have been replaced with the main body of the calculation

5.0 DESIGN INPUTS

5.1 Rated Power Conditions

100% rated Power Conditions are listed below. Actual 100% operation values might be used in lieu of rated nominal values, for other than Rated MWt, Feedwater Flow and Main Steam parameters as deemed appropriate. This is found acceptable, since for the purpose of error determination to rated MWt "heat differential errors", actual heat contribution deviation from measured/calculated heat to rated MWt due to instrumentation uncertainties, is required not the actual deviation value.

Rated MWt =	**3840MW**	(Ref. 3.4.19, 3.2.4, Att 8)	Rev 5
Rated FW flow =	**1.4690E+07lbm/hr**	(Ref. 3.4.19, Att 8)	
Rated FW temperature =	**329.6 F**	(Ref. 3.4.19, Att 8)	
Rated MS flow =	**1.4722E+07lbm/hr**	(Ref. 3.4.19, Att 8)	
Rated MS pressure =	**1001 psia**	(Ref. 3.4.19, Att 8)	
Rated MS quality =	**100.000**	(Ref. 3.4.1)	
Rated RWCU flow =	**148000.0 lb/hr**	(Ref. 3.4.19, Att 8)	Rev 5
Rated RWCU temperature =	**517.9 F**	(Ref. 3.4.19, Att 8)	
Rated RWCU return temperature =	**419.4 F**	(Ref. 3.4.19, Att 8)	
Rated CRD flow =	**32000.0 lb/hr**	(Ref. 3.4.3, 3.4.17)	
CRD Calibration pressure =	**1474.0 psia**	(Ref. 3.4.5)	
Rated CRD temperature =	**77 F**	(Ref. 3.4.19, Att 8)	Rev 5
Radiation Loses =	**1.10MW**	(Ref. 3.4.2, 3.4.17)	
Other System Loses =	**1.18MW**	(Ref. 3.4.2, 3.4.17) Note: These loses are not included in UFSAR Heat Balance, Ref. 3.1.1	
MWt/BTU/hr =	**2.9300E-07**	(Ref. 3.4.1)	

Power = MFW(MSh-FWh)-CRDF(hin-hout)+RWCU(hout-hin)-RRP+HL+Miscellaneous

Notes:

1) This calculation uses rated MS quality of 100.00%, which will produce a more conservative number with respect to the actual plant MS quality. This parameter may be revised when the actual MS quality is measured after the implementation of EPU.
2) This calculation specifies radiation loses as 1.10 MW and other loses as 0.84 MW for the total lose of 1.94 MW. Reference 3.4.17 stated "other system loses" as 1.9 MW without specifically accounting for Radiation loses. Since the two total numbers are almost identical and the difference would have negligible affect on the Power Error, radiation loses of 1.10 MW and the other loses of 0.84 MW will be maintained.

6.0 ASSUMPTIONS

See sections 7.2.3, 7.2.4, 7.2.6 and 7.2.7 for specific assumptions. Rev 5

7.0 CALCULATIONS

7.1 Methodology

The methodology used to combine the uncertainties for the different contributors to the heat balance calculation is the square root of the sum of the squares of those uncertainties which are statistically independent. Then algebraically combined with the those errors that are systematic, or bias. The uncertainties are considered to be random, two sided distributions. This methodology has been utilized before, and has been endorsed by the NRC and various industry standards (Ref. 3.4.12-3.4.14).

The uncertainty calculation combines the different errors from the different parameters contributing to the heat balance in accordance to the heat balance equation. The contributing parameters errors are taken from the specific system uncertainty calculation.

These errors are generally classified in two groups:

a) Instrument loop(s) uncertainty
b) Process effects

The individual uncertainties affecting the heat balance calculation are determined by the application of the corresponding process algorithm, as described below:

a) the appropriate algorithm for the specific process parameter is set in the form to its specific contribution to the heat balance at specified rated conditions,
b) subsequently, the instrumentation loop error is factored in the process algorithm to calculate the corresponding process parameter with the error built-in,
c) the difference of the calculated contributed process parameter heat, with error, to the rated process rated heat is then calculated,
d) the resultant heat error contribution is then divided by the rated 100% power thermal megawatts. The result is the error contribution by the specific process to the total heat balance uncertainty,
e) finally, all the calculated heat errors are combined in accordance to their parameter function in the heat balance equation. The resultant combination of all contributing errors is the Heat Balance Uncertainty.

7.2 Uncertainties Calculation

7.2.1 Main Feedwater Uncertainty(ies)

Referring to the schematic drawing in section 4.0, it can be seen that the Main Feedwater heat contribution is affected by the following parameters:

a) Mass Flow Measurement affected by: 1) flow, 2) temperature, and 3) pressure instrumentation loops error.

The error provided by the vendor for the ultrasonic flow meter already factors the corresponding temperature and pressure loops effect.

b) Feedwater Enthalpy determination affected by: 1) temperature, and 2) pressure, instrumentation loops error.

The main feedwater enthalpy is calculated using the following signals:

- Main Steam Pressure and Main Feedwater Temperature

The main feedwater mass error is provided as percentage of span at 100% rated power at span of 20,000,000 lbm/hr as documented in Ref.: 3.4.7 Section 7.12.3. The number to be used for 100% flow with reduced reactor feedwater flow is positive error of +0.77% flow span at 20,000,000 lbm/hr span or 155,000 lbm/hr. (Note: Ref.: 3.4.7 Section 7.12.1 NSSS Computer-Feedwater Flow took credit for constant correction of feedwater flow by LEFM. For this calculation where LEFM correction is not credited, the number in Section 7.12.1 cannot be used. Instead the error calculated in Section 7.12.3: GETARS Total Flow 3840 MWt should be used. The propagation of feedwater flow error is identical between NSSS computer and GETARS computer, i.e. both their loops consist of feedwater nozzles, flow transmitters, DFCS Foxboro interface modules, and computers.) Rev 5

The heat error is the difference in the MFW heat content at rated flow conditions minus the heat error content at rated conditions plus flow error:

FWm = [hrated (Flowrated - Flowrated+err)] x 2.93E-07/3840 x100%

F Rtd	F+err	P Rtd	TRtd	h rated
14,690,000	14,844,000	1000.69	329.6	301.91
Error % reading	0.7700%			

TTL MFW Heat
4,481,568,938 BTU/hr

4,435,074,622 BTU/hr at rated conditions

Error
46,494,315 BTU/hr at rated main feedwater flow

Uncertainty in Rated MWT
FWm = 0.3548%

7.2.1.2 Main Feedwater Heat Enthalpy Error due to Pressure Loop Uncertainty (**FWhp**)

The main feedwater enthalpy is determined from reactor loop pressure, that is affected by the loop uncertainty.
The pressure loop uncertainty is documented in:

Ref.: 3.4.4

The heat error is the difference in the MFW heat content at rated flow and enthalpy conditions minus the heat content at rated flow with enthalpy at rated pressure plus pressure induced error:

FWhp = [Flow (hrated - hrated+err)] x 2.93E-07 / 3840 x 100%

P Rtd	P+err	TRtd	h rated	h+err	Flow	
1000.69	1006.79	329.6	301.91	301.92	14,690,000	Rev 5
Error (psi) =	6.1					

TTL MFW Heat
4,435,227,702 BTU/hr — Rev 5

4,435,074,622 BTU/hr at rated conditions — Rev 5

Error
153,080 BTU/hr at rated main feedwater flow — Rev 5

Uncertainty in Rated MWt
FWhp = 0.0012% — Rev 5

7.2.1.3 Main Feedwater Heat Enthalpy Error due to Temperature Loop Uncertainty (**FWht**)

The main feedwater enthalpy determination is affected by the loop temperature error, documented in:

Ref.: 3.4.8

The heat error is the difference in the MFW heat content at rated flow and enthalpy conditions minus the heat content at rated flow conditions with enthalpy at rated temperature plus temperature induced error:

FWht = [Flow (hrated - hrated+err)] x 2.93E-07 / 3840 x 100%

TRtd	T+err	P Rtd	h rated	h+err	Flow
329.6	331	1000.69	301.91	303.49	14,690,000

Error (F) = 1.53 This error is subject to change depending in performance history

TTL MFW Heat
4,458,340,678 BTU/hr

4,435,074,622 BTU/hr at rated conditions

Error
23,266,056 BTU/hr error at rated main feedwater flow

Uncertainty in Rated MWt
FWht = 0.1775%

7.2.2 Main Steam Flow Uncertainty(ies)

Referring to the schematic drawing in section 4.0, It can be seen that the Main Steam heat contribution is affected by the following parameters:

a) The calculated Main Steam Heat is affected by the mass flow measurement error (see section 7.2.1.1 Main Feedwater Mass Error).

b) Main Steam Enthalpy determination is affected by the pressure instrumentation loop error, documented in calculation:

Ref. 3.4.4

7.2.2.1 Main Steam Mass Flow Heat Error due to Main Feedwater Flow Uncertainty (**MSm**)

The main feedwater mass error is provided from Section 7.2.1.1:

The heat error is the difference in the Main Steam flow heat content at rated flow conditions minus the heat content at rated conditions plus flow error:

MSm = [hs rated (Flowrated - Flowrated+err)] x 2.93E-07 / 3840 x 100%

FWFEerr = 0.7700% Span Mass Flow

F Rtd	F+err	P Rtd	Moist Rtd	hs rated
14,722,000	14,876,000	1000.69	100	1192.91

TTL MFW Heat
17,745,740,403 BTU/hr

17,562,032,147 BTU/hr at rated conditions

Error
183,708,256 BTU/hr at rated main feedwater flow

Uncertainty in Rated MWT
MSm = 1.4017%

7.2.2.2 Main Steam Heat Enthalpy Error due to Pressure Loop Uncertainty (**MShp**)

This Section calculates the Main Heat Steam enthalpy error due to the loop pressure uncertainty, documented in:

Ref.: 3.4.4

The heat error is the difference in the Main Steam flow heat content at rated flow and enthalpy conditions minus the heat content at rated flow with enthalpy at rated pressure plus pressure induced error:

MShp = [Flow (hrated - hrated+err)] x 2.93E-07 / 3840 x 100%

P Rtd	P+err	Moist Rtd	Moist+err	h rated	h+err	Flow	
1000.69	1006.79	100	100.000	1192.91	1192.69	14,722,000	Rev 5
Error (psi) =	6.1		0				

TTL MS Heat
17,558,719,142 BTU/hr — Rev 5

17,562,032,147 BTU/hr at rated conditions — Rev 5

Error
3,313,005 BTU/hr error at rated main feedwater flow — Rev 5

Error in Rated MWt
MShp = 0.0253% — Rev 5

7.2.2.3. Main Steam Moisture Heat Enthalpy Error due to Steam Moisture Uncertainty (**MSmoist**)

This section calculates the Main Steam enthalpy error due to MS moisture uncertainty. The uncertainty is conservatively set to 50% of rated moisture content of 0.0%.

The heat error is the difference in the Main Steam flow heat content at rated flow and moisture conditions minus the heat content at rated moisture conditions plus moisture error:

MSmoist = [Flowrated hrated (hmoist-rated - hmoist-rated+err)] x 2.93E-07 / 3840 x 100%

P Rtd	P+err	Moist Rtd	Moist+err	h rated	h+err	Flow
1000.69	1000.69	100	100.0000	1192.91	1192.91	14,722,000
	0.00000	0.00%	0			

TTL MS Heat
17,562,032,147 BTU/hr

17,562,032,147 BTU/hr at rated conditions

Error
- BTU/hr error at rated main feedwater flow

Error in Rated MWt
MSmoist = 0.0000%

7.2.3 Control Rod Drive Flow

Referring to the schematic drawing in section 4.0, it can be seen that CRD flow is not monitored for pressure or temperature.

The CRD calculated heat is affected by the following effects:

a) Mass Flow Measurement affected by: 1) flow, instrumentation loop effect and 2) temperature, and 3) pressure deviation from calibration values

b) The CRD Enthalpy determination is affected by: 1) temperature, from applied constants, and 2) pressure, from reactor pressure loop error

The CRD flow loop errors are documented in calculation:

Ref. 3.4.5

The flow formula is derived from the ASME (Ref. 3.4.9) as follows:

Flow = C*Fa*K*(DP*r)^0.5

where K is calculated below:

K = Calib Flow/(Calib inWC * Calib r)^0.5

7.2.3.1 Control Rod Drive Flow Heat Error due to Flow Element and Fluid Specific Weight Uncertainty due to Temperature Error (**CRDt**)

The uncertainty is dependent for the following variables:

Fa = FE Thermal Expansion **r =** Fluid Specific Weight

The plant computer calculates the CRD flow with a constant flow K factor. However, the actual temperature could vary as much as 43F from the expected 77F, and this impacts the Fa and r impacting the calculated flow; therefore, the effect due to this temperature deviation is:

CRDt = [(hs rated - CRDh rated) (Flowrated - Flowrated+err)] x 2.93E-07 / 3840 x 100%

Ref.: 3.4.5

K = 448.48
Calib Flow = 50154 lb/hr 100 GPM
Calib inWC = **200**
Calib Temp = **77**
Calib Press = **1474.7**
r = 62.529
Assumed Rated Flow = **32000.0 lb/hr**
Rated Press = 1001 psia
Rated Temp = **77 F**
Rated h = 47.78 btu/lb

Fa Error	
Rated 77F	1.0003
@140 F	1.0013
@40 F	0.9995
Fa/F	1.8E-05

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	81.3694	81.3694	1.0003	1.0011	77	120
0.00%	0	0.00%	0				**43**

Temp error = Calib Temp - Min Temp

P Rtd	r	h Rtd	Flow	hs Rtd
1000.69	61.8993	47.78	31,862.980	1192.91

TTL CRD Heat
36,487,315 BTU/hr

36,644,221 BTU/hr at rated conditions

Error
(156,906) BTU/hr error at rated CRD flow

Error in Rated MWt
CRDt = -0.0012% This error is a bias, not a random instrument induced uncertainty.

7.2.3.2 Control Rod Drive Flow Heat Error due to Flow Element Uncertainty (**CRDc**)

The CRD contributed heat is affected by the FE error that is assigned to the flow element expansion coefficient.

C

The FE uncertainty is determined based in calculation:

Ref.: 3.4.5

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

CRDc = [(hs rated - CRDh rated) (Flowrated - Flowrated+err)] x 2.93E-07 / 3840 x 100%

Fa Error				
Rated 77F	1.0003	**K =** 448.48		
@140 F	1.0013	Calib Flow = 50154	100.00	
@60 F	0.9995	Calib inWC = 200.00		
Fa/F	1.8E-05	Assumed Calib Temp = 77.00		
		Assumed Calib Press = 1474.00		
		r = 62.529		0.0159925
		Assumed Rated Flow = 32000.0 lb/hr		
		Rated Press = 1001 psia		
		Rated Temp = 77 F		
		Rated h = 47.78 btu/lb		

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0200	81.3694	81.3694	1.0003	1.0003	77	77
2.00%	- 200	0.00%	- 0				- 0

P Rtd	r	h Rtd	Flow	hs Rtd
1000.69	62.4396	47.78	32,616.541	1192.91

TTL MFW Heat	
37,350,242	BTU/hr

36,644,221 BTU/hr at rated conditions

Error

706,021 BTU/hr error at rated CRD flow

Error in Rated MWt
CRDc = 0.0054%

7.2.3.3 Control Rod Drive Heat Error due to Differential Pressure (DP) Loop Uncertainty (**CRDdp**)

This error is calculated in calculation:

Ref.: 3.4.5

The loop is comprised of 1) flow transmitter, FT, 2) resistor, REST, 3) computer analog to digital card, A/D.
The uncertainties are in % DP span:

Accuracy: **Loop Drift:**

CRD_AFT	CRD_AREST	CRD_AA/D	CRD_VDFT	CRD_VDA/D
1.154%	0.100%	0.188%	1.450%	0.000%

Loop Calibration:

CRD_CEFT	CRD_CEA/D
0.140%	0.188%

The uncertainties are random and independent and combined by the SRSS method:

1.88%	span DP

(NC.DE-AP.ZZ-0002(Q), Rev. 12, Form 2)		CALCULATION CONTINUATION SHEET			SHEET: 13
CALC NO.: SC-BB-0525 Attachment 6	REV: 5	REF:			CONT'D ON SHEET: 14
ORIGINATOR:	DATE:	REVIEWER:	DATE:	VERIFIER:	DATE:
Michael Miller	2/14/2017	John Wilkens	3/13/2017	N/A	N/A

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

CRDdp = [(hs rated - CRDh rated) (Flowrated - Flowrated+err)] x 2.93E-07 / 3840 x 100%

Fa Error

Rated 77F	1.0003
@140 F	1.0013
@60 F	0.9995
Fa/F	1.8E-05

K = 448.51
Calib Flow = 50157.2 lb/hr 100 GPM
Calib inWC = 200
Assumed Calib Temp = 77
Assumed Calib Press = 1474
r = 62.529
Assumed Rated Flow = 32000.0 lb/hr
Rated Press = 1000.7 lb/hr
Rated Temp = 77 F
CRDh rated = 47.78 btu/lb

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	81.3584	85.1183	1.0003	1.0003	77	77
0.00%	0	1.88%					0

P Rtd	r	CRDh rated	Flowrated+err	hs Rtd
1000.69	62.4396	47.78	32,707.575	1192.91

TTL MFW Heat
37,454,488 BTU/hr

36,644,221 BTU/hr at rated conditions

Error
810,267 BTU/hr at rated CRD flow

Error in Rated MWt
CRDdp = 0.0062%

7.2.3.4 Control Rod Drive Flow Enthalpy Heat Error due to Temperature Calibration Deviation (**CRDht**)

The plant computer calculates the CRD fluid enthalpy at a constant 77F and reactor pressure. However, the actual temperature varies and it is assumed to vary as much as 43F from the expected 77F; therefore, the effect due to this temperature deviation in the calculated enthalpy is:

Ref. 3.4.5

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

CRDht = [Flow (hs rated - CRDh rated) - Flow (hs rated - CRDh rated+err)] x 2.93E-07 / 3840 x 100%

TRtd	T Max/Min	T+err	P Rtd	h rated	h+err	hs rated	Flow
77	40	37	1000.69	47.78	7.99	1192.91	32,000

TTL RWCU Heat
37,917,380 BTU/hr

36,644,221 BTU/hr at rated conditions

Error
(1,273,159) BTU/hr at rated CRD flow

Uncertainty in Rated MWt
CRDht = -0.0097%

This error is a bias, not a random instrument induced uncertainty.

7.2.3.5 Control Rod Drive Flow Enthalpy Heat Error due to Pressure Loop Uncertainty (**CRDhp**)

The plant computer calculates the CRD fluid enthalpy at a constant 77Fand reactor loop pressure, that is affected by the loop uncertainty.
The pressure loop uncertainty is documented in:

Ref.: 3.4.4

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

CRDhp = [Flow (hs rated - CRDh rated) - Flow (hs rated+err - CRDh rated)] x 2.93E-07 / 3840 x 100%

P Rtd	P+err	TRtd	CRDh rated	hs rated	hs rated+err	Flow	
1000.69	1006.79	77	47.78	1192.91	1192.69	32,000	Rev 5

Error (psi) = 6.1

TTL MFW Heat	
36,637,020	BTU/hr

Rev 5

36,644,221 BTU/hr at rated conditions — Rev 5

Error

(7,201) BTU/hr at rated CRD flow — Rev 5

Uncertainty in Rated MWt
CRDhp = -0.00005% — Rev 5

7.2.4 Reactor Water Cleanup Uncertainty(ies)

Referring to the schematic drawing in section 4.0, it can be seen that RWCU flow is measured and mass calculated by a "NUMAC" process unit. Differential pressure, temperature, by dedicated thermocouples, and reactor pressure are an input to the instrument. Therefore, the RWCU contributed heat is affected by the following parameters:

a) Mass Flow Measurement affected by: 1) flow, 2) temperature, and 3) pressure induced factors/instrumentation loops errors

b) The RWCU Enthalpy determination is affected by: 1) temperature instrumentation loop error (see discussion for pressure)

The flow formula is derived from the ASME (Ref. 3.4.9) as follows:

Flow = C*K*(DP)^0.5

where K is:

K = Calib Flow / [C*(Calib inWC)^0.5]

7.2.4.1 RWCU Inlet/Outlet Flow Heat Error due to Flow Element Expansion deviation from Calibration (**RWCUFa**)

The Numac computer calculating the mass flow has a built-in Fa constant different than the flow element Fa provided at the calculated venturi rated temperature of 533F. This induces a bias error. Furthermore, the plant NUMAC normalizes the flow mass signal to a specific weight of 47.0 lbm/cuft for pressure and temperature conditions, back calculated below; therefore, the rated conditions are set at 530.8F.

Pressure Density Compensated to :	48.00 lb/cuft	517.9 F	**908 psia**
The Fa used in the calculation is fixed to:		1.0045	
The correct Fa at rated 533 F is:		1.0087	

Based on the Fa differences the induced flow error is calculated below:

Fa = FE Thermal Expansion

Ref.: 3.4.10

Flow+err = C x Fa+err / Fa x K x (DP)^0.5

K = 9448.61
Calib Flow = 189797.2 lb/hr **500 GPM** (Note)
Calib inWC = **403.5**
Assumed Calib Temp = **530.8**
Assumed Calib Press = **1114.7**
r = 47.326
Assumed Rated Flow = 148000 lb/hr **389 GPM**
Rated h = 524.95 btu/lb

Fa Error
Rated 533F **1.0087**
Calibrated **1.0045**

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	245.3519	245.3519	1.0087	1.0045	530.8	530.8
0.00%	0	0.00%	0				0

P Rtd	P+err	r	h Rtd	Flow+err
1114.7	1114.7	47.3259	524.95	147,384
	0			

Uncertainty
RWCUFa -616.2 lb/hr

This a bias and the actual contributed Heat is Higher than indicated

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.2 RWCU Inlet/Outlet Flow Heat Error due to Fluid Specific Weight deviation (**RWCUPMA**)

This error is the combination of several uncertainties calculated below:

7.2.4.2.1 RWCU Inlet/Outlet Flow Error due to Fluid Specific Weight Numac Lookup Tables Error (**RWCUPMA1**)

The Numac performs the fluid specific weight determination with an error of 0.1 specific weight, this effect in the flow is calculated below.

r = Fluid Specific Weight

Ref.: 3.4.10

$Flow_{+err} = C \times K \times (DP \times r_{+err} / r)^{0.5}$

The flow error is the difference between the rated flow at rated specific weight minus the flow at specific weight plus error:

$RWCUPMA1 = Flow_{rated} - Flow_{rated+error}$

		K = 9448.61		
		Calib Flow = 189797.2 lb/hr	500 GPM	(Note)
Fa Error		Calib inWC = 403.5		
Rated 533F	1.0087	Assumed Calib Temp = 530.8		
Calibrated	1.0045	Assumed Calib Press = 1114.7		
		r = 47.326		
		Assumed Rated Flow = 148000 lb/hr	388.8 GPM	
		Rated hout = 524.95 btu/lb		

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd
1.0000	1.0000	245.3519	245.3519	1.0087	1.0087	530.8
0.00%	0	0.00%	0			

P Rtd	P+err	r	Numac err	r+perr+Numac	h Rtd	Flow
1114.7	1114.7 psi	47.326	0.1	47.426	524.95	148,157
	0 psi					

Uncertainty
$RWCUPMA1$ = 156.3 lb/hr

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.2.2 RWCU Inlet/Outlet Flow Error due to Fluid Specific Weight Numac 0.75 Factor Pressure Correction Factor Error (**RWCUPMA2**)

The Numac computer introduces a 0.75 factor to the input pressure raw value and calculates the specific weight for saturated conditions, which bias the actual flow.

Ref.: 3.4.10

Flow+err = C x K x (DP x r+err / r)^0.5

The flow error is the difference between the rated flow at rated specific weight minus the flow at specific weight plus error:

RWCUPMA2 = Flowrated - Flowrated+error

r = Fluid Specific Weight

K = 9448.61
Calib Flow = 189797.2 lb/hr 500 GPM (Note)
Calib inWC = 403.5
Assumed Calib Temp = 530.8
Assumed Calib Press = 1114.7
r = 47.326
Assumed Rated Flow = 148000 lb/hr 388.8 GPM
Rated = 524.95 btu/lb

Fa Error	
Rated 533F	1.0087
Calibrated	1.0045

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd
1.0000	1.0000	245.3519	245.3519	1.0087	1.0087	530.8
0.00%	0	0.00%	0			

P Rtd	P+err	T Sat	r+perr	Numac rerr	r+perr+Numac	h Rtdout	h Rtd return	Flow
1114.7	840 psi	523.8	47.5895	0	47.5895	524.95	396.90	148,412
	75%	75						

Uncertainty
RWCUPMA2 = -412 lb/hr

This a bias and the actual contributed Heat is Higher than indicated

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.2.3 RWCU Inlet/Outlet Flow Heat Error due to Fluid Specific Weight Pressure Loop Uncertainty (**RWCUP_SW**)

Pressure is utilized as an input to the Numac to determine the specific weight of the fluid. The pressure loop uncertainty combined with the Numac computer uncertainty introduces an error in the calculated specific weight.

The loop error is comprised of 1) pressure loop, PT, 2) NUMAC computer uncertainties. The combined uncertainties are:

RWCUpress error=	21 psi

Ref.: 3.4.10

Flow+err = C x K x (DP x r+err / r)^0.5

The flow error is the difference between the rated flow at rated specific weight minus the flow at specific weight plus error:

RWCUp_SW = [Flowrated (h_in - h_out) - Flowrated+error (h_in - h_out)] x 2.93E-07 / 3840 x 100%

r = Fluid Specific Weight

K = 9448.61
Calib Flow = 189797.2 lb/hr 500 GPM (Note)
Calib inWC = 403.5
Assumed Calib Temp = 530.8
Assumed Calib Press = 1114.7
r = 47.326
Assumed Rated Flow = 148000 lb/hr 388.8 GPM
Rated h = 524.95 btu/lb

Fa Error	
Rated 533F	1.0087
Calibrated	1.0045

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd in	T Rtd out
1.0000	1.0000	245.3519	245.3519	1.0087	1.0087	530.8	419.4
0.00%	0	0.00%	0				

P Rtd	P+err	r+perr	Numac rerr	r+perr+Numac	h Rtd in	h Rtd out	Flow
1000.69	1022 psi	47.2624	0	47.2624	509.23	396.90	147,901

TTL MFW Heat
16,614,845 BTU/hr

16,626,013 BTU/hr at rated conditions

Error
11,168

Uncertainty in Rated MWt
RWCUp_sw = 0.0001%

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.3 Reactor Water Cleanup Flow Error due to Flow Element Uncertainty (**RWCUc**)

The RWCU flow is affected by the FE error that is assigned to the flow element expansion coefficient.

C

The FE uncertainty is determined based in calculation:

Ref.: 3.4.10

Flow+err = C+err x K x (DP)^0.5

The flow error is the difference between the rated flow minus the flow with the C coefficient error:

RWCUc = Flowrated - Flowrated+error

Fa Error				
Rated 533F	1.0087	**K =** 9448.61		
Calibrated	1.0045	Calib Flow = 189797.2 LB/HR	500 GPM	(Note)
		Calib inWC = 403.50		
		Assumed Calib Temp = 530.80		
		Assumed Calib Press = 1114.70		
		r = 47.33		
		Assumed Rated Flow = 148000 lb/hr	389 GPM	
		Rated h = 524.95 btu/lb		

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0150	245.3519	245.3519	1.0087	1.0087	530.8	530.8
1.50%	150	0.00%	0				0

P Rtd	r	h	Flow
1114.7	47.3259	525.0	150,220

Uncertainty
RWCUc = 2220.0 lb/hr

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.4 Reactor Water Cleanup Flow Error due to Differential Pressure (DP) Loop Uncertainty (**RWCUdp**)

This error is introduced by the differential pressure instrument loop. The uncertainties in the loop are found in: Ref.: 3.4.10

The loop is comprised of 1) flow transmitter, FT, 2) NUMAC computer. The uncertainties are in % DP span:

The flow error is the difference between the rated flow minus the flow with the C coefficient error:

RWCUdp = Flowrated - Flowrated+error

Accuracy: **Loop Drift:**

RWCU_AFT	RWCU_ANU_IE	RWCU_ANU_A/D	RWCU_VDFT	RWCU_VDNU_IE	RWCU_VDNU_A/D
0.503%	0.100%	0.233%	0.900%	0.127%	0.127%

Loop Calibration:

RWCU_CEFT	RWCU_CENU_A/D
0.139%	0.02%

The uncertainties are random and independent and combined by the SRSS method:

1.09%	span DP

Flow+err = C x K x (DP+err)^0.5

Fa Error

Rated 533F 1.0087

Calibrated 1.0045

K = 9448.61

Calib Flow = 189797.2 LB/HR 500 GPM (Note)

Calib inWC = 403.50

Assumed Calib Temp = 530.80

Assumed Calib Press = 1114.70

r = 47.326

Assumed Rated Flow = 148000 LB/HR 389 GPM

Rated h = 524.95 btu/lb

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	245.3519	249.7337	1.0087	1.0087	530.8	530.8
0.00%	0						0

P Rtd	r	h	Flowrated+err
1114.7	47.3259	524.95	149,316

Uncertainty
RWCUdp = 1315.7 lb/hr

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.5 Reactor Water Cleanup Flow Error due to Signal Conditioning/NSSS Computer Loop Uncertainty (**RWCUNSSS_cptr)**

The differential pressure is converted to flow by the Numac computer and retransmitted as flow signal to the plant computer for heat balance calculations.

This portion of the loop is comprised of 1) NUMAC computer output, 2) NSSS computer uncertainty. The uncertainties are in % flow span:

Accuracy:

RWCU_ANU_D/A	RWCU_AA/D
0.233%	0.188%

Loop Drift:

RWCU_VDNU_D/A	RWCU_VNA/D
0.13%	0.000%

Loop Calibration:

RWCU_CENU_D/A	RWCU_CEA/D
0.02%	0.188%

The uncertainties are random and independent and combined by the SRSS method:

0.38%	span FLOW

The flow error is the difference between the rated flow at without loop error minus the flow plus loop error:

RWCUNSSS_cptr = Flowrated - Flowrated+error

Fa Error		**K =** 9448.61		
Rated 533F	1.0087	Calib Flow = 189797.2 lb/hr	500 GPM	(Note)
Calibrated	1.0045	Calib inWC = 403.50		
		Assumed Calib Temp = 530.80		
		Assumed Calib Press = 1114.70		
		r = 47.33		
		Assumed Rated Flow = 148000 lb/hr	389 GPM	
		Rated h = 524.95 btu/lb		

C Rtd	C+err	DP Rtd	DP+err	Fa Rtd	Fa+err	T Rtd	T+err
1.0000	1.0000	245.3519	245.3519	1.0087	1.0087	530.8	530.8
0.00%	0						0

P Rtd	r	h	Flow
1114.7	47.3259	524.95	148,714.0

Uncertainty
RWCUNSSS_cptr= 713.7 lb/hr

Note: This value is slightly different to the 189,197 lb/hr calculated in the reference due to rounding

7.2.4.6 Reactor Water Cleanup Total Flow due to Flow Loop Uncertainties (**RWCUf)**

RWCU Inlet h - Outlet h.

The total RWCU Flow Uncertainty is calculated below:

RWCUfu =+/-SQRT(RWCUPMA1^2+RWCUc^2+RWCUdp^2+RWCUNSSS_cptr^2)-RWCUFa-RWCUPMA2

Notice that the bias PMAs are factored with both signs, since the negative uncertainty is the one that has impact in the heat balance calculations, that is, that (-) less indication means that power is higher; however, it will be factored in both directions for simplicity.

RWCUfu = 3710 lb/hr

Then, the heat error contribution is the calculated inlet flow heat error minus the outlet flow heat error:

RWCUh_in = 509.23 btu/lb
RWCUh_out = 396.90 btu/lb

And the RWCU heat error contribution is calculated by the following expression:

RWCU = [RWCUfu (RWCUh_in - RWCUh_out) x MWt_BTU_hr (conversion factor)] / Rated MWt 100%

RWCUf = 0.0032% This total error will be treated as bias in the total heat balance error

7.2.4.7 Reactor Water Cleanup Flow Enthalpy Heat Error due to Temperature Uncertainty (RWCUht)

This error is the error resultant of temperature measurement errors by the inlet/outlet RWCU thermocouple loops factored into the fluid enthalpy determination.
The thermocouples are instruments with good repeatability and stability. However, fabrication errors can amount to several farenheit degrees.
The fabrication errors can be calibrated out, since essentially it is a bias, systematic error. The temperature loops for RWCU are not calibrated out.
Finally, since most of the thermocouples loop error is a bias, the conservative and safe way to apply the error, is for the two temperature error
to be set in the same direction; therefore, the effect is additive, bias. The temperature loops error is found in:

Ref. 3.4.6

The heat error is the difference between the inlet flow heat error minus the outlet flow heat error:

RWCUht = [Flow [(hin - hin+error) + (hout - hout+error)]] x 2.93E-07 / 3840 x 100%

In flow heat

TRtd	T+err	P Rtd	h rated	h+err	Flow
517.9	528.8	1000.69	509.23	522.62	148,000
Error (F)	10.9				

Out flow heat

TRtd	T+err	P Rtd	h rated	h+err	Flow
419.4	430.3	1000.69	396.90	408.79	148,000
Error (F)	10.9				

Error

3,741,250 **BTU/hr error at rated reactor water cleanup flow**

Uncertainty in Rated MWt
RWCUht = 0.0285% This error is a bias

7.2.4.8 Reactor Water Cleanup Flow Enthalpy Heat Error due to Pressure Loop Uncertainty (**RWCUhp**)

The reactor water cleanup enthalpy determination is affected by the loop pressure error. The pressure has a very small effect in the water enthalpy, however, it is determined in this calculation. The loop uncertainty is documented in:

Ref.: 3.4.4

The heat error is the difference in the CRD flow heat content at rated flow conditions minus the heat error content at rated conditions plus error:

RWCUhp = [Flow [(hin - hin+error) - (hout - hout+error)]] x 2.93E-07 / 3840 x 100%

In flow heat

P Rtd	P+err	TRtd	h rated	h+err	Flow
1000.69	1020.89	517.9	509.23	509.22	148,000
Error (psi)	20.2				

Out flow heat

P Rtd	P+err	TRtd	h rated	h+err	Flow
1000.69	1020.89	419.4	396.90	396.92	148,000
Error (psi)	20.2				

Error

5,768 BTU/hr at rated reactor water cleanup flow

Uncertainty in Rated MWt

RWCUhp = 0.00004%

7.2.5 Recirculation Pumps Heat Error due to Watts Loop Uncertainty (**RRPw**)

This section calculates the uncertainty due to RRP watts loop error, calculated in:

Ref.: 3.4.11

The rated power for the pump-motor and the motor efficiency (0.93) is from reference:

(Ref. 3.4.3)

There are two recirculation pumps, the calculated error below is per pump. The actual total MW for the 2 pumps is taken from above reference.

W 2 pump = 7.33

The Watt error contribution is calculated as follows:

RRPw = [(W Rtd/pump + MW Loop Span x Span err) x Mottor eff] - W Rtd/pump x Motor eff] / 3840 x 100%

W Rtd/pmp+err	Motor Eff	W+err
3.823	0.93	3.55
	Error =	1.50 % span
	Span =	10.5 Mwatt

TTL Mwatt	
3.41	Mwatt

Error

0.1465 Mwatt

Uncertainty in Rated MWT

RRPw = 0.0038%

7.2.6 Thermal Loses (**TL**)

This section calculates the uncertainty due to TL error. This error will be treated as a bias error since the estimated value is larger or smaller than assumed, i.e. it is a fixed error not a random error.

An assumed error equal to 20% of the specified loses is used.

The rated Heat Loss is from reference:

(Ref. 3.4.2)

W Rtd	W+err
1.1	1.32
Error =	**20.00%**

TTL Mwatt Heat
1.32

MW

1.10 MW at rated conditions

Error

0.2200 MW error at rated radiated loses

Uncertainty in Rated MWT
TL = 0.006%

This error is treated as bias.

Note: The computer utilizes this value combined with Other System Loses (Section 7.2.7) as Radiative power loses, QRAD = 1.94

7.2.7 Other System Loses (**OSL**)

The rated value includes Rod Drive seal purge flow to recirculation pumps. An assumed error equal to 20% of the specified loses is used.
This error will be treated as a bias error since if the estimated value is larger or smaller than assumed, i.e. it is a fixed error not a random error.

The rated Losses figure is from reference:

(Ref. 3.4.2)

W Rtd	W+err
1.18	1.416
Error =	20%

Rev 5

TTL Mwatt Heat
1.42

MW Rev 5

1.18 MW at rated conditions Rev 5

Error

0.2360 MW error at rated radiated loses Rev 5

Uncertainty in Rated MWT
OSL = 0.006%

This error is treated as bias. Rev 5

Note: The computer utilizes this value combined with Thermal Loses (Section 7.2.6) as Radiative power loses, QRAD = 1.94

7.2.8 Heat Balance Calculation Power Uncertainty (**Power U**)

The calculated heat balance uncertainty is the algebraic combination of the bias errors with the independent/random errors statistically combined, that contribute into the heat balance calculation, in accordance with the heat balance formula:

Power = MFW(MSh-FWh)-CRDF(hin-hout)+RWCU(hout-hin)-RRP+HL+Miscellaneous

Summary of Heat Balance Calculation Contributing Errors:

Random Errors:	FWm = 0.3548%	
	FWht = 0.1775%	
	MSm = 1.4017%	
	MSmoist = 0.0000%	
	CRDc = 0.0054%	
	CRDdp = 0.0062%	
	RRPw = 0.0038%	
	RWCUp_sw = 0.0001%	
Dependent Errors:	Errors	Variable
	FWhp = 0.0012%	Rated MS pressure = 1001 psia
	MShp = 0.0253%	
	CRDhp = -0.00005%	
	RWCUhp = 0.00004%	
Bias Errors:	CRDt = -0.0012%	
	CRDht = -0.0097%	
	RWCUf = 0.0032%	
	RWCUht = 0.0285%	
	TL = 0.006%	
	OSL = 0.006%	

Rev 5

Rev 5

Heat Balance Calculation Power Error (U):

Power Error = SQRT[(MSm-FWm)^2+(MShp-FWhp+CRDhp+RWCUhp)^2+FWht^2+MSmoist^2+CRDc^2+CRDdp^2+
+RWCUp_sw^2+RRPw^2x2]+CRDt+CRDht+RWCUf+RWCUht+TL+OSL

Power Error = **1.095%**

To ensure operation margin exist, due to possible instrumentation loops miss-calibration, actual drift (to be determined by history), etc., a margin is added:

Power U = Power Error + Margin

where margin is defined as 2.0% (SET POWER U) - Power Error

Margin = 0.905% and **Power U = 2.000%**

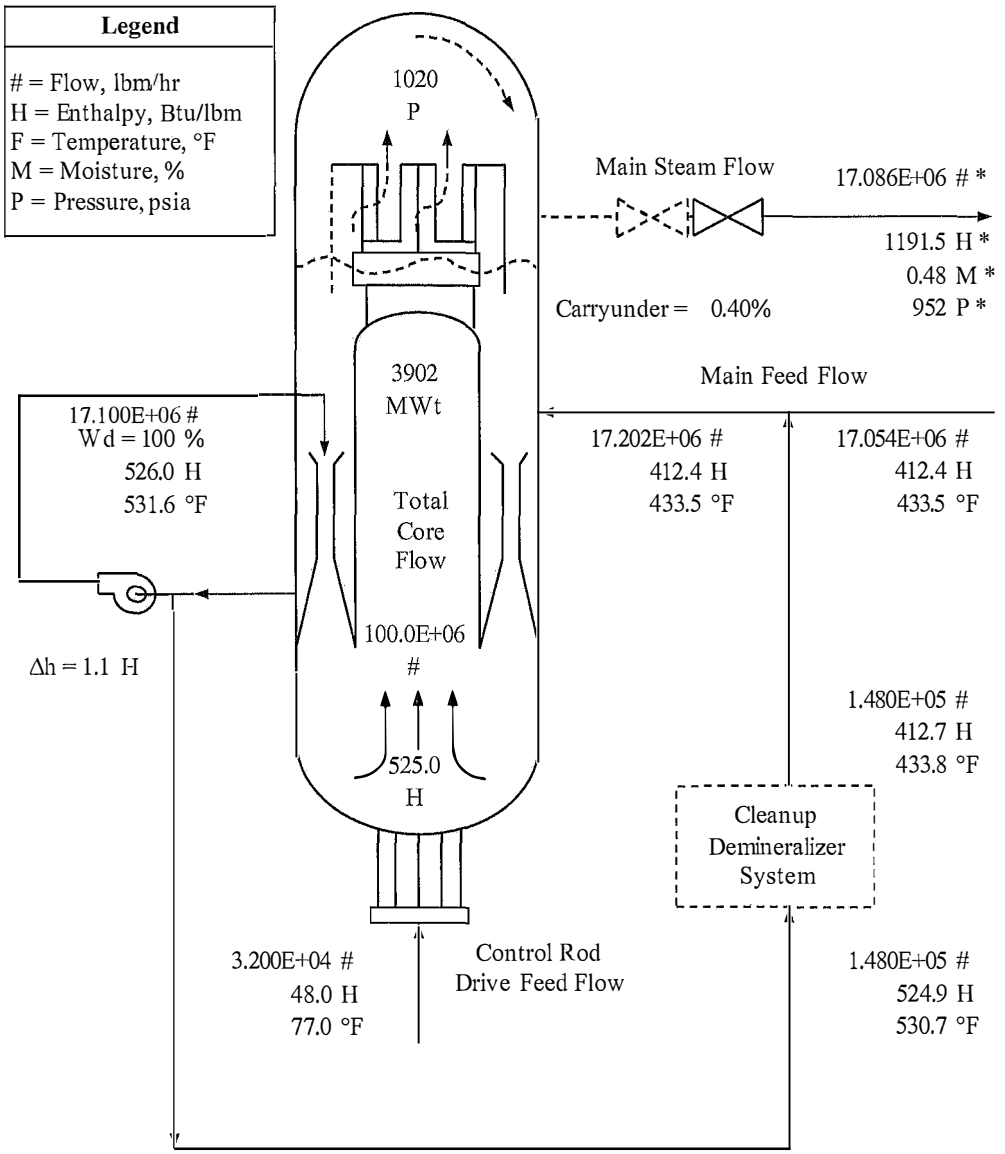
8.0 SUMMARY

The calculated Heat Balance Error performed in this calculation is applicable to the hand calculation error when determined process values and steam tables heat values are used with an accuracy of 3 decimal places. This results are applicable to hand calculated heat balance since less hardware errors are involved in the hand calculation, data collection. The Heat Balance calculation error (Section 7.0) is:

Power U = 2.000%

Figure 3-2: Reactor Heat Balance – TLTP (101.6% of CLTP)

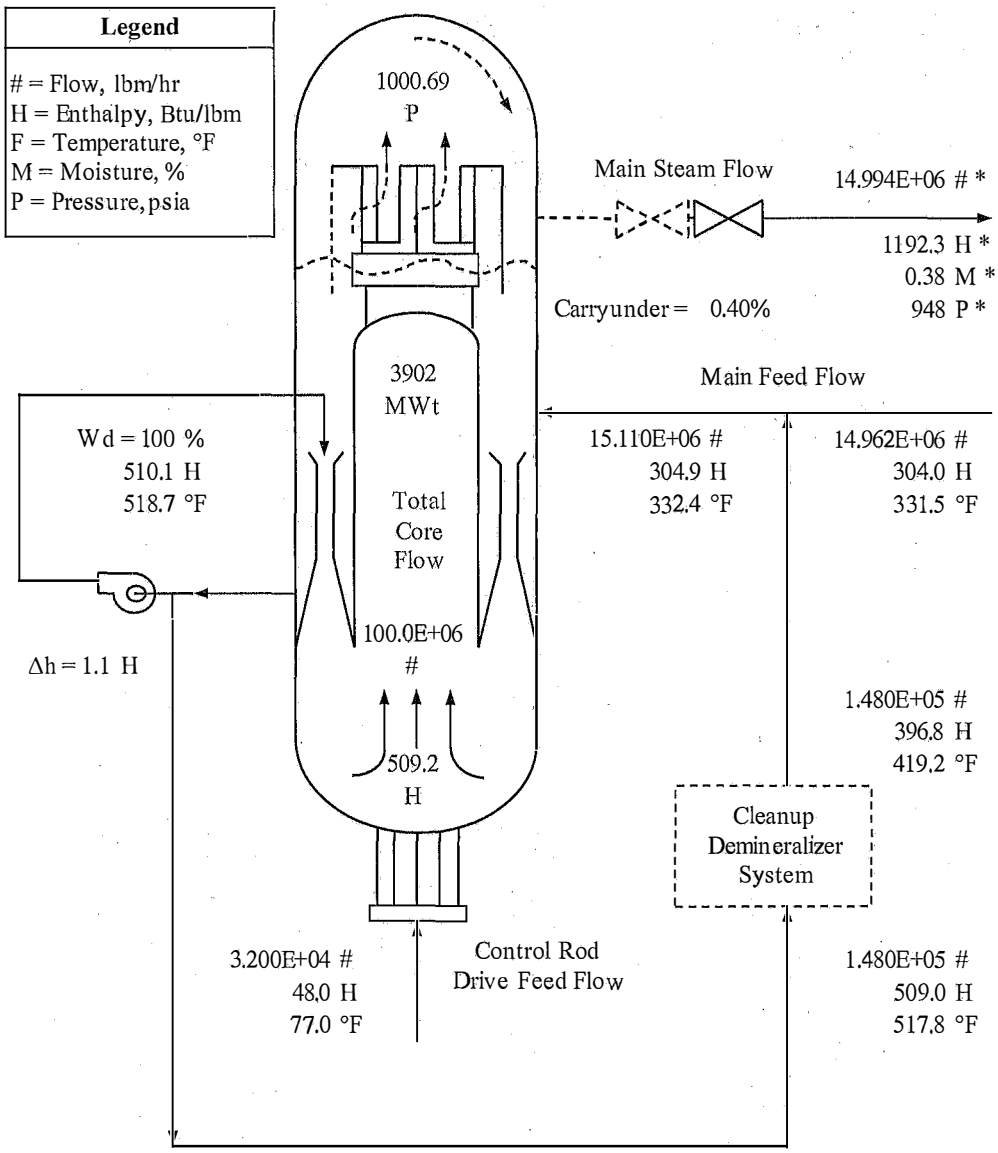
[T_{FW} = 433.5°F / P_{DOME} = 1020 psia]



*Conditions at upstream side of TSV

Core Thermal Power	3902.0
Pump Heating	10.7
Cleanup Losses	-4.9
Other System Losses	-2.6
Turbine Cycle Use	3905.2 MWt

Figure A-1
Reactor Heat Balance at 100%TLTP / 100%F Reduced FW Temperature



*Conditions at upstream side of TSV

Core Thermal Power	3902.0
Pump Heating	10.7
Cleanup Losses	-4.9
Other System Losses	-2.6
Turbine Cycle Use	3905.2 MWt