**ATTACHMENT 11**
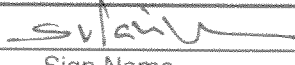**Exelon Generation Company, LLC Calculation LE-0113, Rev. 0, "Reactor Core Thermal Power Uncertainty Calculation Unit 1."**

**Exelon.**

**Design Analysis Major Revision Cover Sheet**

| Design Analysis (Major Revision) | | Last Page No. 93 | |
|---|---|---|---|
| **Analysis No.:** [1] | LE-0113 | **Revision:** [2] 0 | |
| **Title:** [3] | Reactor Core Thermal Power Uncertainty Calculation Unit 1 | | |
| **EC/ECR No.:** [4] | LG 09-00096 | **Revision:** [5] 001 | |

| **Station(s):** [7] | Limerick | **Component(s):** [14] | |
|---|---|---|---|
| **Unit No.:** [8] | 1 | N/A | |
| **Discipline:** [9] | LEDE | | |
| **Descrip. Code/Keyword:** [10] | N/A | | |
| **Safety/QA Class:** [11] | N | | |
| **System Code:** [12] | 006, 041, 042, 043, 044, 047 | | |
| **Structure:** [13] | N/A | | |

**CONTROLLED DOCUMENT REFERENCES** [15]

| Document No.: | From/To | Document No.: | From/To |
|---|---|---|---|
| LEAE-MUR-0001, Bounding Uncertainty Analysis for Thermal Power determination | From | L-S-11, Rev. 15, DBD Feedwater System | From |
| LM-0552, Rev. 7, Reactor Heat Balance Calculation Limerick Units 1 & 2 | From | L-S-15, Rev. 10, DBD Control Rod Drive System | From |
| LM-553, Rev. 0, Determination of the RPV Heat Loss | From | L-S-19, Rev. 10, DBD Recirculation System | From |
| LE-0116, Reactor Dome Narrow Range Pressure Measurement Uncertainty | From | L-S-36, Rev. 10, DBD Reactor Water Makeup System | From |
| LM-562, Rev. 2, CRD Flow Rates and System Pressures | From | Limerick PEPSE™ MUR PU and EPU Heat Balances - Eval 2009-03880 R0 | From |
| LEAM-MUR-0038 (Reactor Heat Balance) | To | LEAM-MUR-0046 (TS Instrument Setpoints) | To |
| LEAM-MUR-0039 (Power/Flow Map) | To | LEAM-MUR-0041 (Neutron Monitoring System w/ RBM) | To |
| LEAM-MUR-0048 (Generic Disposition Applicability Confirmation) | To | | |

| **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, ATI/AR#: |
| **This Design Analysis SUPERCEDES:** [18] | N/A | **In its entirety.** |

**Description of Revision** (list affected pages for partials): [19] Initial Issue.

This Calculation provides the uncertainty in the Core Thermal Power. This calculation is being performed in support of the Measurement Uncertainty Recapture (MUR) power up-rate.

| **Preparer:** [20] | Stephen Kimura | [signature] for Stephen Kimura via telecon | 12/2/09 |
|---|---|---|---|
| | Print Name | Sign Name | Date |

| **Method of Review:** [21] | Detailed Review ☒ | Alternate Calculations (attached) ☐ | Testing ☐ |
|---|---|---|---|
| **Reviewer:** [22] | Sharad Parikh | [signature] | 12/2/09 |
| | Print Name | Sign Name | Date |

**Exelon.**

| Review Notes: [23] | Independent review ☒ Peer review ☐ |
|---|---|
| | Performed a line by line review of the calculation. All comments were incorporated to the satisfaction of the reviewer. This calculation supports the margin uncertainty recapture (MUR) by reducing the measurement uncertainty of Core Thermal Power from 2 % to 0.35 %. |

| (For External Analyses Only) **External Approver:** [24] | Richard Brusato | *John Rehnal for R. Brusato per Telecon* | 12/02/09 |
|---|---|---|---|
| | Print Name | Sign Name | Date |
| **Exelon Reviewer:** [25] | Mitul Ajmera | *M PAjmera by phne* | 12/02/09 |
| | Print Name | Sign Name | Date |

| Independent 3rd Party Review Required? [26] | Yes ☒ No ☐ | | |
|---|---|---|---|
| **Exelon Approver:** [27] | Raymond George | *RTGe* | 12/2/09 |
| | Print Name | Sign Name | Date |

## TABLE OF CONTENTS

## TABLE OF TABLES

## 1.0 PURPOSE

The purpose of this calculation is to determine the uncertainty in the reactor core thermal power (heat balance) calculation performed by the Plant Process Computer (PPC). This calculation will evaluate the contribution of the different instrument channel loop uncertainties to the uncertainty of the Core Thermal Power (CTP) value using the reactor heat balance relationship when the plant is operating at 100% rated power under steady state conditions.

This calculation is being performed in support of the licensing amendment for Measurement Uncertainty Recapture (MUR) power uprate. This calculation applies to Limerick Generating Station Unit 1.

## 1.1 FUNCTIONAL DESCRIPTION AND CONFIGURATION

Limerick Generation Station (LGS) Unit 1 will be installing highly accurate ultrasonic feedwater flow meters per Engineering Change Request (ECR) LG 09-00096. This calculation will determine the uncertainty in Core Thermal Power calculation when the reactor heat balance is performed using the process computer with the feedwater flow and temperature measurement input supplied by the Caldon® Leading Edge Flow Meters Check Plus (LEFM✓+) System Ultrasonic Flow Meters (UFM).

## 2.0 DESIGN BASIS

Various plant parameters are monitored by the NSSS computer to develop the reactor core thermal power calculation. On June 1, 2000 Appendix K to Part 50 of Title 10 of the Code of Federal Regulations was changed to allow licensees to use a power uncertainty of less than 2 % in their LOCA analysis. The change allowed licenses to recapture power by using state-of-art devices to more precisely measure feedwater flow. Feedwater flow inaccuracy is a large contributor in the uncertainty determination of reactor power. This calculation is being performed in the support of a License Amendment Request (LAR) for a MUR power uprate.

## 2.1 INPUTS

Table 2-1 lists the parameters which specify input to the core thermal power calculation, their uncertainty values, and the source of these values.

The values for Feedwater Flow, Feedwater Temperature, and Reactor Narrow Range Dome Pressure are specified by separate calculations as follows (Ref. 4.8.6 thru 4.8.8):

- LEAE-MUR-0001, Bounding Uncertainty Analysis for Thermal Power determination

- LE-0116, Reactor Dome Narrow Range Pressure Measurement Uncertainty

The uncertainties for Reactor Water Clean-up (RWCU) Flow Rate, RWCU Inlet Temperature Thermocouple, Control Rod Drive (CRD) Flow Rate, and Recirculation Pump Power are calculated in individual sections of this calculation. Recirculation Pump Efficiency is given in calculation LM-0552 (Ref. 4.8.2). The thermal loss due to radiated heat loss to the drywell is specified by separate calculation LM-553 (Ref. 4.8.3) for calculating the reactor heat balance by hand.

Other inputs and the related source references are listed in the Table 2-1.

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Table 2-1.
Design Inputs

| Description | Inst. Tag No. | Computer Point | Nominal Value | Uncertainty | Uncertainty Basis |
|---|---|---|---|---|---|
| CRD Enthalpy | N/A | N/A | 71.93 Btu/lbm (100 °F and 1448 psig) (Ref. 4.9.3, Attachment 6) | ± 0.005 Btu/lbm | (Ref. 4.9.3) |
| CRD Water Flow Discharge Temperature | TE-046-103 | A1201 | 100°F(Ref. 4.4.1) | ± 0.7 °F | (Ref. Attachment 1) |
| CRD Water Flow Rate | FT-046-1N004 | A1711 | Nominal Flow 105 GPM (Ref. 4.8.5, Sec. 2.0) | 5.4 % | (Section 7.5.6) |
| Feedwater Enthalpy | N/A | N/A | 409.71 Btu/lbm (430.8 °F and 1155 psig) (Ref. 4.9.3, Attachment 6) | ± 0.005 Btu/lbm | (Ref. 4.9.3) |
| Feedwater Mass Flow Rate (LEFM ✓+ System) | 10-C986 | N/A | 15.09 Mlbm/hr (Ref. 4.8.9, Table 6-11a) | ± 0.32 % | (Ref. 4.8.6) |
| Feedwater Pressure | N/A | N/A | 1155 PSIG (Ref.4.4.1) | ± 10 psig | (Section 3.11) |
| Feedwater Temperature | TE-006-1N041A-F | A1744 thru A1750 | 430.8 °F (Ref. 4.8.9, Table 6-11a) | ± 0.57 °F | (Ref. 4.8.6) |
| Radiated Reactor Pressure Vessel (RPV) Heat Loss | N/A | N/A | 0.89 MW (U1) 1.04 MW (U2) (Ref. 4.8.3, Sec. 2.0) | ± 10 % | (Section 3.12) |
| Reactor Dome Pressure | PT-042-1N008 | E1234 | 1043 PSIG (1057.7 psia, Ref. 4.8.9, Table 6-11a) | ± 20 psig | (Ref. 4.8.8) |
| Saturated Steam Enthalpy | N/A | N/A | 1191.1 Btu/lbm (1043 psig, sat) (Ref. 4.9.3, Attachment 5) | ± 0.05 Btu/lbm | (Ref. 4.9.3) |
| Recirculation Pump Motor efficiency | 1A(B)-P201 | N/A | 94.8 % (Attachment 10 & Ref. 4.8.2) | N/A | N/A |
| Recirculation Pump Motor Power | 1A(B)-P201 | N/A | 7700 Hp (5.74 MW) (Ref. 4.3.3) | ± 1.4 % | (Section 7.6.8) |
| RWCU Discharge Enthalpy | N/A | N/A | 419.83 Btu/lbm (440 °F and 1168 psig) (Ref. 4.9.3, Attachment 6) | ± 0.005 Btu/lbm | (Ref. 4.9.3) |

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Table 2-1.
Design Inputs

| Description | Inst. Tag No. | Computer Point | Nominal Value | Uncertainty | Uncertainty Basis |
|---|---|---|---|---|---|
| RWCU Discharge Temperature | TE-044-1N015 | A1742 | 440 °F (Section 2.3.2) | ± 4.37 | (Section 7.4.6) |
| RWCU Inlet Flow Rate | FT-044-1N036A | A1718 | 360 GPM (Max) Ref. 4.5.11) | ± 2.3 % | (Section 7.3.6) |
| RWCU Regen Heat Exchanger Inlet Temperature | TE-044-1N004 | A1741 | 530 °F (Section 2.3.1) | 4.37 °F | (Section 7.4.6) |
| RWCU Suction Enthalpy | N/A | N/A | 524.39 Btu/lbm (530 °F and 1060 psig) | ± 0.005 Btu/lbm | (Ref. 4.9.3) |

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## 2.2 REACTOR WATER CLEANUP (RWCU) FLOW LOOP UNCERTAINTY

### 2.2.1 Reactor Water Cleanup System Equipment Design Data (Ref. 4.3.4)

System flow rate (lbm/hr)

| | |
|---|---|
| Normal operation "A" pump | 154,000 |
| Normal operation "B" plus "C" pump | 133,000 |
| Maximum operation | 180,000 |

| Main Cleanup Recirculation Pumps | "A" Pump | "B" & "C" Pumps |
|---|---|---|
| Number required | 1 | 2 |
| Capacity, % (each) | 100 | 50 |

"A" pump capacity is greater that the combined capacity of the "B" and "C" pumps

### 2.2.2 RWCU Flow Measurement Loop Diagram

RWCU flow is measured by an orifice plate (FE-044-1N035) located on the suction side of the RWCU Recirculation Pumps, which provides a ΔP signal to a Rosemount transmitter (FT-044-1N036A). The transmitter supplies a milliamp signal to the PPC for display in the Control Room. The instrument loop consists of the following: flow element, flow transmitter, a signal resistance unit and a PPC input/output (I/O) module. The loop configuration is shown below (Ref. 4.5.10):
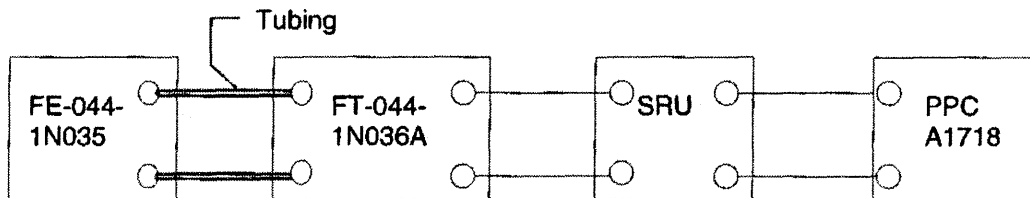


The loop components evaluated in this document (the applicable performance specifications and process parameter data):

### 2.2.3 RWCU System Inlet Flow (Ref. 4.4.1, 4.5.6, 4.5.10, 4.5.11, 4.5.16, 4.6.4, and 4.9.1)

Table 2-2.
RWCU System Inlet Flow Element – Unit 1

| | |
|---|---|
| Component I.D.: | FE-044-1N035 "RWCU SUCTION FLANGE UPSTREAM OF VALVE HV-44-1F001" |
| Device Type: | Orifice Plate |
| Manufacturer/Model No.: | Vickery Simms Inc./145C3227P037 |
| Reference Accuracy (A1): | ±1.50% of actual flow rate |
| Installation Accuracy: | ± 0.5% |
| Environmental Conditions (Temp.): | 40°F (min.) to 156°F (max.) |

Table 2-2.
RWCU System Inlet Flow Element – Unit 1

| Environmental Conditions (Press.): | (-) 1.0 (min.) to (+) 7.0 inches $H_2O$ (max.) |
|---|---|
| Environmental Conditions (RH %): | 20 (min.) to 90 (max.) |
| Pipe Size: | 6 inch schedule 80 |
| Flange Rating: | 600# |
| Pipe Class Service No.: | DCA-101 "RWCU from Recirc. Pump Suction Valve F004 |
| Normal Operating Temperature: | 539 °F |
| Design Temperature: | 582 °F |
| Maximum Operating Temperature: | 582 °F |
| Normal Operating Pressure: | 1060 psig |
| Design Pressure: | 1250 psig |
| Maximum Operating Pressure: | 1360 psig |
| Normal flow Rate: | 360 gpm |
| Maximum Flow Rate: | 477 gpm |
| ΔP @ Max. Flow Rate: | 200 inches $H_2O$, nameplate data: 1178 psig & 545 °F |

2.2.4    RWCU System Inlet Flow (Ref. 4.5.6, 4.5.10, 4.6.4, 4.7.2, 4.7.6, 4.7.7, 4.9.5, and 4.9.7)

Table 2-3.
RWCU System Inlet Flow Differential Pressure Transmitter

| Component I.D.: | FT-044-1N036A "REACTOR WATER CLEANUP INLET" |
|---|---|
| Location (AREA / EVEL / RM): | 016 / 283' / 506 |
| Device Type: | Differential Pressure Transmitter |
| Manufacturer/Model No.: | Rosemount/1153DB5RCN0039 |
| Quality Classification: | Q (Not Required) |
| Accident Service: | N/A |
| Seismic Category: | N/A |
| Tech Spec Requirement: | N/A |
| Upper Range Limit @ 68 °F: | 750 inches $H_2O$ |
| Lower Range Limit @ 68 °F: | 0–125 inches $H_2O$ |
| Calibrated Range: | 0 to 218.3 inches $H_2O$ - static pressure corrected |
| Operating Range: | 0 to 220 inches $H_2O$ at 1060psig |

Table 2-3.
RWCU System Inlet Flow Differential Pressure Transmitter

| | |
|---|---|
| Calibration Span: | 218.3 inches $H_2O$ |
| Output Signal: | 4 – 20 mA |
| Setpoint: | N/A |
| Calibration Period: | 24 months |
| Accuracy (A2): | ± 0.25 % calibrated span (see note) |
| Calibration Accuracy: | ± 0.5 % |
| Stability (Drift, D2): | ± 0.2 % URL for 30 months [2σ] |
| Temperature Effect (DTE1), per 100°F | ± (0.75 % of upper range limit + 0.5 % span) |
| Temperature Normal Operating Limits: | 40 to 200 °F |
| Overpressure Effect: | Maximum zero shift of ± 1.0 % URL above 2000 psig |
| Static Pressure Zero Effect: | ±0.2 % of upper range limit |
| Static Pressure Span Effect (SPNE2): | ± 0.5 % input reading per 1,000 psi. |
| Seismic (vibration) Effect (SEIS2): | Accuracy within ±0.5 % of upper range limit during and after a seismic disturbance defined by a required response spectrum with a ZPA of 4 g's. |
| Power Supply Effect (PSE2): | < 0.005 % of calibrated span per volt |
| Mounting Position Effect: | No span effect. Zero shift of up to 1.5 inH2O |
| EMI/RFI Effect: | Not Specified |
| Response time (damping): | Code N - Adjustable damping; max. 0.8 seconds |
| Harsh temperature effect (HTE2): | Accuracy within ± 5.0 % of URL during and after exposure to 265 °F (129.5 °C), 24 psig, for 35 hours. |
| Humidity limits: | 0 to 100 % Relative Humidity (RH) |
| Safety Classification: | Application - Non-safety-Related |
| Radiation Effect (e2R): | Accuracy within ± 4.0 % of URL during and after exposure to 2.2 x10$^7$ rads, TID of gamma |
| Note: Includes combined effects of linearity, hysteresis, and repeatability | |

2.2.5   RWCU System Signal Resistor Unit (Ref. 4.1.1, 4.5.10, 4.5.17, and 4.7.3):

Table 2-4.
RWCU System PPC Precision Signal Resistor Unit

| | |
|---|---|
| Dwg. Designation: | SRU-1 |
| Device Type: | Precision signal resistor unit |
| Manufacturer/Model No.: | Bailey Type 766 |

Table 2-4.
RWCU System PPC Precision Signal Resistor Unit

| Selected Range: | 250 Ohm |
|---|---|
| Accuracy: | ± 0.1 %, (± 0.25 ohm) |
| Safety Classification: | N/A |
| Temperature Effect: | ± 0.5 % for 40 – 120°F |
| Input Signal Range: | 4 to 20 mAdc |

2.2.6    RWCU System Computer Point – Plant Process Computer (PPC) (Ref. 4.5.10 and Attachment 4):

The PPC calculates Core Thermal Power based in part on the measurement of Reactor Water
Cleanup flow. The PPC uses an analog input card, which read the voltage drop across a precision
250 ohm resistor.

Table 2-5.
RWCU System PPC Analog Input Card Unit 1

| Component I.D.: | A1718 |
|---|---|
| Location: | 10-C603 (H12-P603) |
| Device Type: | PPC - Potentiometer (Analog) Input Card |
| Manufacturer/Model No.: | Analogic/ANDS5500 |
| Quality Classification: | N/A |
| Accident Service: | N/A |
| Seismic Category: | N |
| Tech Spec Requirement: | N/A |
| Selected Full Scale Span: | ± 5 VDC |
| Calibration Span: | (-) 5 VDC to (+) 5 VDC |
| Calibration Period: | 24 months |
| Accuracy (A3): | ± 0.5 % of full scale span |
| Input Impedance (resistance): | 10 Meg Ohms |
| Analog to Digital Converter: | Not Specified |
| Power Supply Effect (PSE3): | N/A |
| EMI/RFI Effect: | N/A |
| Response time (damping): | N/A |
| Operating Temperature Limits: | 32 to 122 °F (0 to 50 °C) |
| Humidity limits: | Not Specified |
| Safety Classification: | Non Safety-Related |

2.2.7 RWCU System Local Service Environments (Ref. 4.4.2):

Table 2-6.
RWCU System Local Service Environments

|  | Flow Transmitter | Plant Process Computer |
|---|---|---|
| Area / Room. | Area 016 | Area 008 – Control Room |
| Location | 506C – Cont. H2 Recombiner | Control Room (Comp. Rm. 553 ) |
| Normal Temp. Range (°F) | 65 min / 106 max / 85 norm | 65 min / 78 max / norm N/A |
| Normal Pressure | (-) 0.25 inches WG | + 0.25 inches WG |
| Normal Humidity (RH %) | 50 average / 90 maximum | 50 average / 90 maximum |
| Radiation | 2.50E-03 Rads/hr, 8.78E+02 TID | N/A |

## 2.3 REACTOR CLEANUP SYSTEM TEMPERATURE

2.3.1 RWCU System Regenerative Heat Exchanger Inlet Temperature (Ref. 4.4.1, 4.5.6, 4.5.11, 4.5.16, 4.6.4, 4.9.5, and 4.9.7)



Table 2-7.
RWCU System Inlet Thermocouple

| Component Numbers: | TE-044-1N004 "REACTOR WATER CLEANUP SYSTEM REGEN HEAT EXCH INLET TEMP" |
|---|---|
| Device Type: | Type T Copper – Constantan (CU/CN) |
| Manufacturer/Model No.: | California Alloy Co/Model 117C3485P073 |
| Element Range: | (-)200° to (+)700 °F |
| Calibrated Range | 0° - 600°F |
| Rated Accuracy: | ± 0.75°F |
| Output Signal: | (-) 0.674 mV to (+)15.769 mV |
| Safety Classification: | N/A |
| Pipe Class Service No.: | DCC-101 "RWCU pump discharge thru Regen HXs |
| Normal Operating Temperature | 530 °F (See Note 1) |
| Normal Operating Temperature Spec: | 535 °F |
| Design Temperature: | 582 °F |
| Maximum Operating Temperature: | 582 °F |

Table 2-7.
RWCU System Inlet Thermocouple

| Normal Operating Pressure: | 1235 psig |
|---|---|
| Design Pressure: | 1290 psig |
| Maximum Operating Pressure: | 1542 psig |
| Normal flow Rate: | 360 gpm |

Note 1: Reactor Engineering provided normal operating temperature based on 100% power operation for both Units. Data was retrieved once per hour for one week. The Unit 2 value of 530 °F in lieu of Unit 1 528 °F was used based on it being the most conservative.

2.3.2   RWCU System Regenerative Heat Exchanger Outlet Temperature (Ref. 4.1.1, 4.5.6, 4.5.16, 4.6.4, 4.5.11, 4.9.5, and 4.9.7)

```
┌─────────────────┐         ┌─────────────┐
│ TE-044-1N015    │         │ PPC A1742   │
│ Thermocouple    │ ──────▶ │             │
│                 │         │             │
└─────────────────┘         └─────────────┘
```
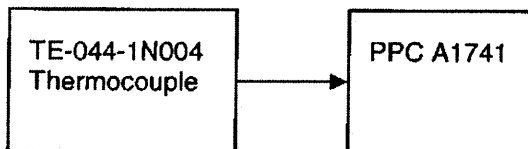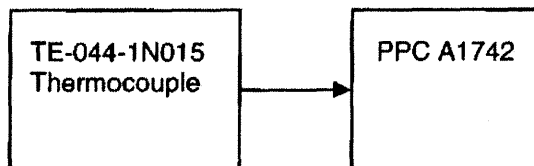
Table 2-8.
RWCU System Outlet Thermocouple

| Component Numbers: | TE-044-1N015 "REACTOR WATER CLEANUP SYSTEM REGEN HEAT EXCH OUTLET TEMP" |
|---|---|
| Device Type: | Type T Copper – Constantan (CU/CN) |
| Manufacturer/Model No.: | California Alloy Co/Model 117C3485P073 |
| Element Range: | (-)200° to (+)700 °F |
| Input Range | 0° - 600°F |
| Rated Accuracy: | ± 0.75°F |
| Output Range | (-) 0.674 mV to (+)15.769 mV |
| Safety Classification: | N/A |
| Pipe Class Service No.: | ECC-105 "RWCU Regen HX to HV-1F042 |
| Normal Operating Temperature based on actual plant data | 440 °F (See Note 2) |
| Normal Operating Temperature: | 438 °F |
| Design Temperature: | 434 °F |
| Maximum Operating Temperature: | 434 °F |
| Normal Operating Pressure: | 1168 psig |
| Design Pressure: | 1290 psig |
| Maximum Operating Pressure: | 1542 psig |
| Normal flow Rate: | 360 gpm |

Note 2: Reactor Engineering provided normal operating temperature based on 100% power

operation for both Units. Data was retrieved once per hour for one week.

2.3.3   RWCU System Plant Process Computer (PPC) (Ref. 4.5.6, 4.5.16, and Attachment 4):

Table 2-9.
RWCU System Thermocouple PPC Analog Input Card Unit 1

| Component I.D.: | A1718 and A1742 |
|---|---|
| Location: | 10-C603 (H12-P603) |
| Device Type: | PPC - Potentiometer (Analog) Input Card |
| Manufacturer/Model No.: | Analogic/ANDS5500 |
| Quality Classification: | N/A |
| Accident Service: | N/A |
| Seismic Category: | N |
| Tech Spec Requirement: | N/A |
| Selected Range: | Upper: -25 mV to + 25mV |
| Calibration Span: | (-) 0.674 mV to (+)15.769 mV |
| Calibration Period: | 24 months |
| Accuracy (A2): | ± 0.5 % of full scale span |
| Input Impedance (resistance): | 10 Meg Ohms |
| Analog to Digital Converter: | Not Specified |
| Signal Source Resistance: | 2800 Ω maximum |
| Power Supply Effect (PSE2): | N/A |
| EMI/RFI Effect: | N/A |
| Response time (damping): | N/A |
| Operating Temperature Limits: | 32 to 122 °F (0 to 50 °C) |
| Humidity limits: | Not Specified |
| Safety Classification: | Non Safety-Related |

2.3.4   RWCU System Local Service Environments (Ref. 4.4.2):

Table 2-10.
RWCU System Thermocouple Local Service Environments

| | Thermocouple | Plant Process Computer |
|---|---|---|
| Area / Room. | Area 016 | Area 008 – Control Room |
| Location | 506C – Cont. H2 Recombiner | Control Room (Comp. Rm. 553 ) |
| Normal Temp. Range (°F) | 65 min / 112 max / 104 norm | 65 min / 78 max / norm N/A |
| Normal Pressure | (-) 0.25 inches WG | + 0.25 inches WG |

| Normal Humidity (RH %) | 50 average / 90 maximum | 50 average / 90 maximum |
|---|---|---|
| Radiation | 2.50E-03 Rads/hr, 8.78E+02 TID | N/A |

## 2.4 CRD FLOW RATE UNCERTAINTY

2.4.1 CRD Hydraulic System Flow Loop Diagram

Each analyzed instrument loop consists of a flow element supplying a differential pressure to a pressure transmitter, and a PPC input/output (I/O) module with a precision resistor (8 $\Omega$) across the input. The loop is shown as follows:
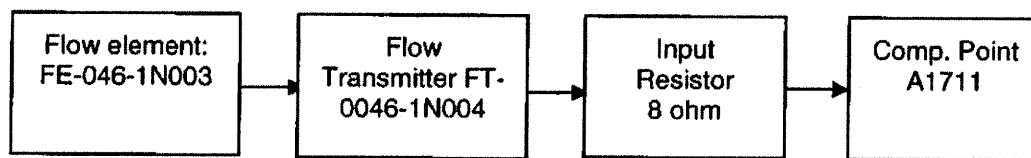


The loop components evaluated in this document (and the applicable performance specification and process parameter data):

2.4.2 CRD Hydraulic System Flow Element (Ref. 4.4.1, 4.5.8, 4.5.12, 4.6.2, 4.6.3, 4.8.5, and 4.9.5)

Table 2-11.
CRD Hydraulic System Flow Element – Unit 1

| Component I.D.: | FE-046-1N003 "CRD HYDRAULIC SYS DRIVE WTR FLOW CONT" |
|---|---|
| Device Type: | Flow Nozzle |
| Manufacturer/Model No.: | GE - Vickery Simms Inc./ 158B7077AP016 |
| Reference Accuracy (A1): | ± 1.0 % flow |
| Design Temperature: | 150°F |
| Design Pressure: | 2000 psig |
| Pipe Size: | 2 inch schedule 80 |
| Material | Stainless Steel |
| Maximum Flow | 100 gpm |
| Pipe Class Service No.: | DCD-112, "Control Rod Drive Hyd. from DBD-I 08 to Hydraulic Control Units |
| Normal Operating Temperature: | 100 °F |
| Design Temperature: | 150 °F |
| Maximum Operating Temperature: | 150 °F |
| Normal Operating Pressure: | 1448 psig |
| Design Pressure: | 1750 psig |
| Maximum Operating Pressure: | 1750 psig |

Table 2-11.
CRD Hydraulic System Flow Element – Unit 1

| Normal flow Rate: | 105 gpm @ 1515.8 psig |
|---|---|
| ΔP @ Max. Flow Rate: | 200 inches $H_2O$ @ 100 gpm |

2.4.3    CRD Hydraulic System Flow Transmitter (Ref. 4.5.8, 4.5.12, 4.6.2, 4.6.3, 4.7.4 and 4.9.5)

Table 2-12.
CRD Hydraulic System Differential Pressure Transmitter

| Component I.D.: | FT-046-1N004 "CRD HYDRAULIC SYS DRIVE WTR FLOW CONT" |
|---|---|
| Location (AREA / EVEL / RM): | 015 / 253' / 402 |
| Device Type: | Differential Pressure Transmitter |
| Manufacturer/Model No.: | Rosemount/ 1151DP5D22PB |
| Quality Assurance Classification: | N |
| Accident Service & Seismic Category: | N/A |
| Tech Spec Requirement: | N/A |
| Upper Range Limit: | 750 inches $H_2O$ |
| Lower Range Limit: | 0–125 inches $H_2O$ |
| Calibrated Span: | 0 to 197.5 inches $H_2O$ - static pressure corrected |
| Operating Span: | 0 to 200 inches $H_2O$ at 100 gpm |
| Output Signal: | 4 – 20 mA, Corresponding to 0 – 100 gpm |
| Calibration Period: | 24 months |
| Accuracy (A2): | ± 0.25 % calibrated span |
| Calibration Accuracy: | ± 0.5 % |
| Stability (Drift, D2): | ± 0.25 % of URL for 6 months [2σ] |
| Temperature Effect (DTE1), per 100°F | ± 1.5% of URL per 100 °F<br>± 2.5 % for low range (URL/6)<br>This taken to be equal to 2.4 % at 197.5 inches $H_2O$ span |
| Temperature Normal Operating Limits: | (-)40 to 150 °F (Amplifier) |
| Overpressure Effect: | Zero shift of less than ± 2.0 % |
| Static Pressure Zero Effect: | ± 0.5 % of upper range limit for 2000 psi |
| Static Pressure Span Effect (SPNE2): | (-) 0.5 % ± 0.1% input reading per 1,000 psi. This is a systematic error which can be calibrated out for a particular pressure before installation. |

Table 2-12.
CRD Hydraulic System Differential Pressure Transmitter

| | |
|---|---|
| Seismic (vibration) Effect (SEIS2): | ± 0.05 % of URL per g at 200 Hz in any axis. |
| Power Supply Effect (PSE2): | < 0.005 % of calibrated span per volt. |
| Mounting Position Effect: | No span effect. Zero-shift can be calibrated out. |
| EMI/RFI Effect: | Not Specified |
| Response time (damping): | Not Specified |
| Harsh temperature effect (HTE2): | Not Applicable |
| Humidity limits: | 0 to 100 % RH |
| Safety Classification: | Non-safety related |
| Radiation Effect (e2R): | Not Specified |

2.4.4    CRD Hydraulic System Flow Signal Resistor Unit (Ref. 4.1.1, 4.5.12, Attachment 12, and 4.7.3):

Table 2-13.
CRD Hydraulic System PPC Precision Signal Resistor Unit

| | |
|---|---|
| Dwg. Designation: | 8 Ω |
| Device Type: | Precision signal resistor unit (wire-wound) |
| Manufacturer/Model No.: | Bailey Type 766 |
| Selected Range: | 8 Ohm |
| Accuracy: | ± 0.008 ohm (± 0.1 %) |
| Safety Classification: | N/A |
| Temperature Effect: | ± 0.5 % for 40 – 120°F |
| Input Signal Range: | 4 to 20 mAdc |

2.4.5    CRD Hydraulic System Flow PPC I/O (Refs. 4.5.8, 4.5.12, and Attachment 4):

Table 2-14.
CRD Hydraulic System PPC Analog Input Card Unit 1

| | |
|---|---|
| Component I.D.: | A1711 |
| Location: | 10-C603 (H12-P603) |
| Device Type: | PPC - Potentiometer (Analog) Input Card |
| Manufacturer/Model No.: | Analogic/ANDS5500 |
| Quality Classification: | N/A |
| Accident Service & Seismic Category: | N/A |

Table 2-14.
CRD Hydraulic System PPC Analog Input Card Unit 1

| Tech Spec Requirement: | N/A |
|---|---|
| Selected Full Scale Span: | ± 160 mV |
| Calibration Span: | (-) 160 mV to (+) 160 mV |
| Calibration Period: | 24 months |
| Accuracy (A3): | ± 0.5 % of full scale span |
| Calibration Accuracy: | N/A |
| Input Impedance (resistance): | 10 Meg Ohms |
| Analog to Digital Converter: | Not Specified |
| Power Supply Effect (PSE3): | N/A |
| EMI/RFI Effect: | N/A |
| Operating Temperature Limits: | 32 to 122 °F (0 to 50 °C) |
| Humidity limits: | Not Specified |
| Safety Classification: | Non Safety-Related |

2.4.6   CRD Hydraulic System Flow Process Parameters (Refs. 4.3.2 and 4.8.5):

Process Temp Maximum:        150 °F
Process Temp Minimum         45°F

The minimum water temperature is based on the CST being outside and exposed to winter elements. The maximum temperature is based on 140°F of the condensate and condenser system plus 10°F nominal heat addition from the CRD Water pump. (Ref. 4.3.2)

2.4.7   CRD Hydraulic System Local Service Environments (Ref. 4.4.2):

Table 2-15.
CRD Hydraulic System Local Service Environments

|  | Flow Transmitter | Plant Process Computer |
|---|---|---|
| Area / Room. | Area 015 / Room 402 | Area 008 – Control Room |
| Location | Room 402 | Control Room (Comp. Rm. 553) |
| Normal Temp. Range (°F) | 65 min / 106 max / 90 norm | 65 min / 78 max / norm N/A |
| Normal Pressure | (-) 0.25 inches WG | + 0.25 inches WG |
| Normal Humidity (RH %) | 50 average / 90 maximum | 50 average / 90 maximum |
| Radiation | 1.00E-01 Rads/hr, 3.51E+04 TID | N/A |

**Exelon.**

## 2.5    RECIRCULATION PUMP MOTOR UNCERTAINTY

2.5.1    Recirculation Pump Motor Loop Diagram

Each analyzed instrument loop consists of a Watt Transducer, and a PPC input/output (I/O) module. The uncertainty magnitude of the CT and PT is negligible for this calculation.
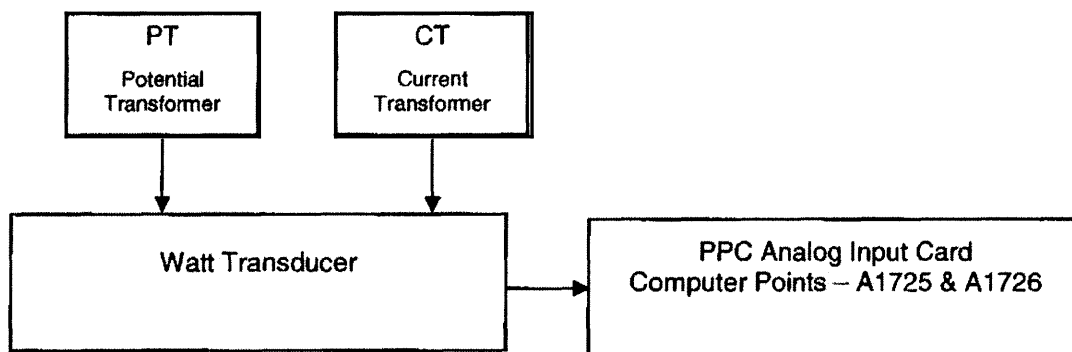


2.5.2    Recirculation Pump Motor Watt Transducer (Ref. 4.5.13 to 4.5.15, Attachment 9, 4.9.5, and 4.9.7)

Table 2-16.
Recirculation Pump Motor Watt Transducer

| Component I.D.: | MT1A and MT1B |
|---|---|
| Location: | 10-C603 (H12-P603) |
| Device Type: | Watt Transducer |
| Manufacturer/Model No.: | Ametek Power Systems / XL3-1K5A2-25 |
| Quality Classification: | N/A |
| Accident Service & Seismic Category: | N/A |
| Tech Spec Requirement: | N/A |
| Rated Output (RO) | 10.5 MW |
| Current Input (Current Transformer): | 0 – 5 Amps (1500/5) |
| Voltage Input (Potential Transformer): | 0 - 120 V (4160/120) |
| Output Range: | 0 - 1 mAdc |
| Calibration Period: | 24 months |
| Accuracy (A1): | ± (0.2% Reading + 0.01% Rated Output) at 0-200% Rated Output |
| Stability (Drift, D1) per year: | ± 0.1% RO, Non-cumulative |
| Temperature Effect: | ± 0.005 % / ° C |
| PF Effect on Accuracy | ± 0.1% VA (maximum) |
| EMI/RFI Effect: | N/A |

Table 2-16.
Recirculation Pump Motor Watt Transducer

| Operating Temperature Limits: | (-)4°F to 158 °F (-20° C to +70° C) |
|---|---|
| Operating Humidity: | 0 to 95 % RH non condensing |
| Safety Classification: | Non Safety-Related |

2.5.3    Recirculation Pump Motor Watt Meter Transducer Precision Signal Resistor (Ref. 4.5.13 to 4.5.15, and 4.9.7):

Table 2-17.
Recirculation Pump Motor Watt Transducer PPC Precision Signal Resistor Unit

| Dwg. Designation: | R3A & R3B |
|---|---|
| Device Type: | Precision signal resistor unit (wire-wound) |
| Manufacturer/Model No.: | GE / Type HR41D5B |
| Selected Rating: | 160 Ohm |
| Accuracy: | ± 0.1% of input signal range, 0.1 watt |
| Safety Classification: | N/A |
| Temperature Effect: | N/A |
| Input Signal Range: | 0 - 1 mAdc |

2.5.4    Recirculation Pump Motor Watt Transducer PPC Analog Input Card (Ref. Attachment 4):

Table 2-18.
Recirculation Pump Motor Watt Transducer PPC Analog Input Card Unit 1

| Component I.D.: | A1725 and A1726 |
|---|---|
| Location: | 10-C603 (H12-P603) |
| Device Type: | PPC - Potentiometer (Analog) Input Card |
| Manufacturer/Model No.: | Analogic/ANDS5500 |
| Quality Classification: | N/A |
| Accident Service & Seismic Category: | N/A |
| Tech Spec Requirement: | N/A |
| Selected Full Scale Span: | ± 160 mV |
| Calibration Span: | (-) 160 mV to (+) 160 mV |
| Calibration Period: | 24 months |
| Accuracy (A2): | ± 0.5 % of full scale span |

Table 2-18.
Recirculation Pump Motor Watt Transducer PPC Analog Input Card Unit 1

| | |
|---|---|
| Input Impedance (resistance): | 10 Meg Ohms |
| Analog to Digital Converter: | Not Specified |
| Power Supply Effect (PSE2): | N/A |
| EMI/RFI Effect: | N/A |
| Operating Temperature Limits: | 32 to 122 °F (0 to 50 °C) |
| Humidity limits: | Not Specified |
| Safety Classification: | Non Safety-Related |

### 3.0 ASSUMPTIONS AND LIMITATIONS

**3.1**  Standard practice is to specify calibration uncertainty in calculations equal to the uncertainty associated with the instruments under test (Ref. 4.1.1).

**3.2**  Instrumentation uncertainty caused by the operating environment's temperature, humidity, and pressure variations are evaluated when these error sources are specified by the instrument's vendor. If the instrument's operating environment specifications bound the in-service environmental conditions where the equipment is located and separate temperature, humidity, and pressure uncertainty terms are not specified for the instrument, then these uncertainties are assumed to be included in the manufacturer's reference accuracy specification.

**3.4**  Published instrument vendor specifications are considered to be based on sufficiently large samples so that the probability and confidence level meets the $2\sigma$ criteria, unless stated otherwise by the vendor.

**3.5**  Seismic effects are considered negligible or capable of being calibrated out unless the instrumentation is required to operate during and following a seismic event.

**3.6**  The insulation resistance error is considered negligible unless the instrumentation is required to operate in an abnormal or harsh environment.

**3.7**  Regulated instrument power supplies are assumed to function within specified voltage limits; therefore, power supply error is considered negligible with respect to other error terms unless the vendor specifically specifies a power supply effect.

**3.8**  Measurement of CRD hydraulic system purge water temperature is found to be accurate within $\pm 0.7$ °F per Attachment 1. The enthalpy of water at the CRD normal operating pressure of 1448 psig and normal operating temperature of 100 °F as listed in P-300 (reference 4.4.1) are used to determine uncertainty of the CRD hydraulic system enthalpy because this is more conservative than using the higher temperatures normally found during operation.

**3.9**  The CRD system uses a Rosemount 1151 differential pressure transmitter (Section 2.4.3), which is mounted in a radiation exposure area. A radiation exposure effect is not specified for the Model 1151 transmitter; therefore the radiation effect applicable to this transmitter is assumed to be 10 % of span. This assumption is considered conservative based on three factors: (1) periodic surveillance is performed on this transmitter and it is required to operate within 0.5 % of span or maintenance activities must be performed. Existing calibration records did not indicate anything unusual occurring with the calibration of these transmitters in this service. (2) A Rosemount Model 1153 series B transmitter is rated for radiation exposure and may be expected to have a radiation effect of $\pm 4$ % of upper range limit (URL) during and after exposure to $2.2 \times 10^7$ rad (Section 7.3.1.16). However, this exposure is over a 1000 times the expected exposure for the CRD system flow transmitter s during normal service. The estimated TID during normal service for the CRD flow transmitter is $3.51 \times 10^4$ rad (Section 4.4.2). The 10 % span estimated effect is more than an order of magnitude greater than the threshold for maintenance activity and of the same order of magnitude of the effect on a similar transmitter with 1000 times the exposure.

**3.10**  Interim results are rounded to the level of significance of the input data to avoid implying that a higher level of precision exists in the calculated values. For example, uncertainty may be specified by a supplier to one significant figure (e.g., 0.5 %). This value says that the level of significance associated with this uncertainty is one part in two hundred. The results are rounded when the numeric value of a result implies a higher level of significance than what the input data suggests.

**3.11**  An uncertainty of ± 10 psig is assumed for the feedwater pressure to cover the variations in the actual steam dome pressure.  The variation in pressure has a negligible effect on the enthalpy of the feedwater.

**3.12**  An uncertainty of 10 % is assumed for the RPV thermal radiation heat loss term, $Q_{RAD}$, based on a review of calculation LM-0553 (Reference 4.8.3).  LM-0553 determined the RPV heat loss by calculating the actual heat load in the drywell, subtracting the heat load attributed to any operating equipment in the drywell, and proportioning the heat load based on the shared chilled water system design flows assigned to Unit 1 drywell and Unit 2 drywell on a percentage basis.  LM-0553 assumes Unit 1 and Unit 2 are operating at 100 percent power and the drywell air cooling fans are aligned as designed.

**3.13**  Steam table excerpts have been provided for convenience as Attachment 5, National Institute for Standards and Technology (NIST) Saturated Properties of Water, and Attachment 6, NIST Isobaric and Isothermal Properties of Water, as extracted from the NIST fluid properties WebBook (Reference 4.9.3).  For conservatism, factors of one-half the least significant figure in the tables are used for the interpolation error.  The factors are 0.05 Btu/lbm for vapor and 0.005 Btu/lbm for liquid.

## 4.0 REFERENCES

### 4.1 METHODOLOGY

4.1.1 CC-MA-103-2001, Rev 0, "Setpoint Methodology for Peach Bottom Atomic Power Station and Limerick Generating Station

4.1.2 IC-11-00001, Rev. 4, Calibration of Plant Instrumentation and Equipment

### 4.2 PROCEDURES

4.2.1 ST-2-044-400-1, Rev. 23, Reactor Water Cleanup High Differential Flow Isolation Calibration

4.2.2 IC-C-11-00307, Rev. 5, Calibration of Rosemount Model 1153 and 1154 Transmitters

### 4.3 DESIGN BASIS DOCUMENTS

4.3.1 L-S-11, Rev. 15, DBD Feedwater System

4.3.2 L-S-15, Rev. 10, DBD Control Rod Drive System

4.3.3 L-S-19, Rev. 10, DBD Recirculation System

4.3.4 L-S-36, Rev. 10, DBD Reactor Water Makeup System

4.3.5 L-S-42, Rev. 09, DBD Nuclear Boiler System

### 4.4 SPECIFICATIONS, CODES, & STANDARDS

4.4.1 P-300, Rev. 45, Specification "Piping Materials and Instrument Piping Standards"

4.4.2 M-171, Rev. 16, Specification for Environmental Service Condition LGS Units 1 & 2

### 4.5 LIMERICK STATION DRAWINGS

4.5.1 M-06 Sheet 3, Rev. 58, P&ID Feedwater

4.5.2 M-23 Sheet 4, Rev. 33, P&ID Process Sampling

4.5.3 M-41 Sheets 1/2, Rev. 46/62, P&ID Nuclear Boiler

4.5.4 M-42 Sheets 1/2, Rev. 41/34, P&ID Nuclear Boiler Vessel Instrumentation

4.5.5 M-43 Sheets 1/2, Rev. 48/39, P&ID Reactor Recirculation Pump

4.5.6 M-44 Sheets 1/2, Rev. 56/47, P&ID Reactor Water Clean-up

4.5.7 M-45 Sheet 1, Rev. 30, P&ID Cleanup Filter and Demineralizer

4.5.8 M-46 Sheet 1, Rev. 51, P&ID Control Rod Drive Hydraulic-Part A

4.5.9 M-47 Sheet 1, Rev. 45, P&ID Control Rod Drive Hydraulic-Part B

4.5.10 B21-1050-E-008, Rev. 13, Elem. Diagram Steam Leak Detection Schematic

4.5.11 G31-N011-C-003, Rev 002, Purchased PT. ORF. PLT. SH 1

4.5.12 C11-1060-E-002, Rev. 23, Elem. Diagram CRD Hydraulic System, LGS U1

4.5.13 B32-1030-E-050, Sheet 18, Rev. 5, Elem. Diag. Reactor "A" Recirc Pump an MG Set, Unit 1

4.5.14   B32-1030-E-050, Sheet 19, Rev. 4, Elem. Diag. Reactor "B" Recirc Pump an MG Set, Unit 1

4.5.15   B32-1030-E-050, Sheet 3, Rev. 7, Elem. Diag. Reactor "A" & "B" Recirc Pump an MG Set, Parts List, Unit 1

4.5.16   G31-1040-E-003, Rev. 28, Elementary Diag. Reactor Water Cleanup System, Unit 1

4.5.17   C32-1020-E-003, Rev. 33, Elem. Diag. Feedwater Control System, Unit 1

4.5.18   B21-1040-E-003, Rev. 21, Elem. Diag. Nuclear Boiler Process

4.5.19   E-0701, Sheets 6/16, Rev. 9/8, Schematic & Connection Diagram NSSS/BOP Computer Analog Inputs, Unit 1

4.5.20   G31-1030-G-001, Rev. 20, Process Diagram Reactor Water Clean-Up System (High Pressure)

4.5.21   B32-C-001-J-023, Rev. 1, Recirculation Pump Curve (Attachment 10)


## 4.6      GENERAL ELECTRIC (GE) DOCUMENTS

4.6.1    C11-4010-H-004, Rev. 13, Control Rod Drive System

4.6.2    C11-N003-C-001 Rev 002 PPD-Flow Nozzle

4.6.3    C11-3050-H-001, Rev. 14, CRD Instrumentation System

4.6.4    G31-3050-H-001, Rev. 26, Reactor Water Clean-Up System

4.6.5    B21-3050-H-001, Rev. 27, Nuclear Boiler System

4.6.6    B32-3050-H-001, Rev. 6, Reactor Recirculation System


## 4.7      VENDOR INFORMATION

4.7.1    M-1-B32-C001-K7, Recirculation Pump Vendor Manual

4.7.2    Rosemount Product Data Sheet 00809-0100-4302, Rev BA, January 2008, Rosemount 1153 Series B Alphaline® Nuclear Pressure Transmitter

4.7.3    A41-8010-K-018.6 - Bailey Signal Resistor Unit (SRU) Type 766 (Attachment 12)

4.7.4    Rosemount Inc., Instruction Manual 4259, Model 1151 Alphaline® $\sqrt{\Delta P}$ Flow Transmitter, 1977 (Attachment 11)

4.7.5    C95-0000-K-002(1).2 - ANDS4810 - Data Acquisition System Instruction Manual

4.7.6    Rosemount Specification Drawing 01153-2734, "N0039 Option – Combination N0016 & N0037"

4.7.7    Rosemount Product Data Sheet 00813-0100-2655, Rev. AA June 1999 "N–Options for Use with the Model 1153 &l 1154 Alphaline® Nuclear Pressure Transmitters"

4.7.8    Fluke 8050A - Digital Multimeter Measurement P/N 530907 Rev 2 1984, Instruction Manual

4.7.9    Ametek Power Instruments, Digital & Analog Transducers, Power Measurement Catalog, Scientific Columbus Exceltronic AC Watt Transducer Specification (Attachment 9)


## 4.8      CALCULATIONS AND ENGINEERING ANALYSIS

4.8.1    LM-547, Rev. 2, Reactor Core Thermal Power Calculation Correction for Unaccounted Flow to Reactor Vessel

4.8.2    LM-552, Rev. 7, Reactor Heat Balance Calculation for Limerick Units 1 & 2

4.8.3   LM-553, Rev. 0, Determination of the Reactor Pressure Vessel (RPV) Heat Loss

4.8.4   EE-94LGS, Rev. 16, Proper Calibration of Feedwater Elements FE-006-1(2)N001A, B, C (GE SIL 452)

4.8.5   LM-562, Rev. 2, CRD Flow Rates and System Pressures

4.8.6   LEAE-MUR-0001, Rev. 0, Bounding Uncertainty Analysis for Thermal Power determination at Limerick Unit 1 Using the LEFM ✓+ System

4.8.7   LEAE-MUR-0002, Rev. 0, Pre-Commissioning Uncertainty Analysis for Thermal Power determination at Limerick Unit 1 Using the LEFM ✓+ System

4.8.8   LE-0116, Rev. 0, Reactor Dome Narrow Range Pressure Measurement Uncertainty

4.8.9   Limerick PEPSE™ MUR PU and EPU Heat Balances - Eval 2009-03880 R0

## 4.9   OTHER REFERENCES

4.9.1   ASME, "Fluid Meters Their Theory and Application" Sixth Edition, 1971.

4.9.2   Limerick Updated Final Safety Analysis Report, R14

4.9.3   Lemmon, E.W., McLinden, M.O., and Friend, D.G., "Thermophysical Properties of Fluid Systems", NIST Chemistry WebBook, NIST Standard Reference Database Number 69, Eds. P.J. Linstrom and W.G. Mallard, National Institute of Standards and Technology, Gaithersburg MD, 20899, http://webbook.nist.gov, (retrieved September 30, 2009)

4.9.4   NUREG/CR-3659, Dated January 1985, NRC Guidance, A Mathematical Model for Assessing the Uncertainties of Instrumentation Measurements for Power and Flow of PWR Reactors

4.9.5   Plant Information Management System (PIMS) Data

4.9.6   TODI Tracking No: SEAG #09-000167, Plant Process Computer Data of various plant parameters, to support Core Thermal Power Uncertainty Calculations, Station/Unit(s) U1/U2, 9/3/09

4.9.7   IISCP (Improved Instrument Setpoint Control Program) Datasheets) Version 7.5

4.9.8   Edwards, Jerry L. Rosemount Nuclear Instruments letter in reference to "Grand Gulf Nuclear Station message on INPO plant reports, subject Rosemount Instrument Setpoint Methodology, dated March 9, 2000". Letter dated 04/04/2000. (Attachment 3)

4.9.9   TODI A169446-80, subject "Steam Carryover Fraction on Process Computer Heat Balance Calculations" (Attachment 2)

## 5.0  IDENTIFICATION OF COMPUTER PROGRAMS

The results of calculations by special computer programs were not directly used in this design analysis. Microsoft® Office Excel 2003 SP 3 was used to confirm the arithmetic results.

## 6.0  METHOD OF ANALYSIS

### 6.1  METHODOLOGY

The methodology used to calculate Section 6 is based on CC-MA-103-2001, "Setpoint Methodology for Peach Bottom Power Station and Limerick Generating Station" (Ref. 4.1.1).

These are non-safety-related indication loops, but the indication is used to calculate Core Thermal Power, which is a licensing limit. This analysis will use the Square Root of the Sum of the Squares (SRSS) methodology for combining the random and independent uncertainties. The dependent uncertainties will be combined according to their dependency relationships and biases will be algebraically summed in accordance with the Reference 4.1.1. The level of confidence for each uncertainty will be normalized to a 2σ confidence level.

### 6.2  CORE THERMAL POWER (CTP) CALCULATION:

The process computer provides a calculation of the CTP based on a system heat balance, where CTP is the difference between the energy leaving the system and the energy input into the system from energy sources external to the core. The process computer steady state reactor heat balance equation is based on a summation of all heat sources raising the inlet feedwater and other cold water to steam exiting the pressure vessel. Figure 5-1 shows the Limerick heat balance control volume.
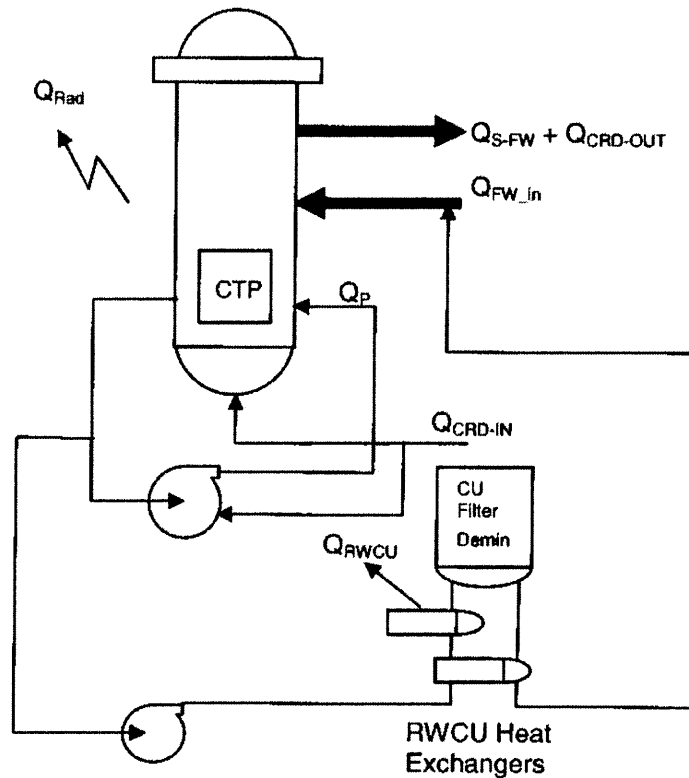
Figure 5-1, Limerick Heat Balance Control Volume Diagram

CTP = Energy out – Energy in                    (Equation 1)

Energy in = $Q_{FW\text{-}IN} + Q_{CRD\text{-}IN} + Q_P$                    (Equation 2)

Energy out = $Q_{S\text{-}FW} + Q_{CRD\text{-}OUT} + Q_{RAD} + Q_{RWCU}$                    (Equation 3)

Where,

| | |
|---|---|
| CTP | Core Thermal Power generated by nuclear fuel |
| $Q_{FW\text{-}IN}$ | Energy of feedwater required to raise inlet FW to Steam |
| $Q_{CRD\text{-}IN}$ | Energy of CRD purge water and recirculation pump seal purge water going to feedwater |
| $Q_P$ | Heat added by the recirculation pumps |
| $Q_{S\text{-}FW}$ | Energy of steam from feedwater supply |

$Q_{CRD\text{-}OUT}$    Energy of CRD purge water and recirculation pump seal purge water going to steam

$Q_{RAD}$    Radiative heat losses from the reactor pressure vessel

$Q_{RWCU}$    Heat removed by the RWCU system regenerative heat exchangers (includes both a heat removal term and a heat additions term)

### 6.2.1 Energy In

Each of the above heat contributors are individually evaluated as follows:

6.2.1.1 Energy of feedwater ($Q_{FW\text{-}IN}$) is equal to the feedwater mass flow rate ($w_{FW}$) multiplied by the enthalpy of the water at the bulk temperature of the feedwater ($h_{FW}(T_{FW})$) entering the reactor. Changes to the bulk temperature of the feedwater due to the influx of recirculation water and RWCU water are ignored because these mass flows represent less than 1 % of the total mass flow and the temperature change caused by their influx negligible.

$$Q_{FW\text{-}IN} = w_{FW} \cdot h_F(T_{FW}) \quad \text{(Equation 4)}$$

6.2.1.2 Energy of Control Rod Drive purge water and recirculation pump seal purge water ($Q_{CRD\text{-}IN}$) is taken to be fixed at the enthalpy of water for a given temperature and pressure.

$$Q_{CRD\text{-}IN} = w_{CRD} \cdot h_F(T_{CRD}) \quad \text{(Equation 5)}$$

6.2.1.3 Energy of recirculation pumps ($Q_P$)

Energy of recirculation pumps ($Q_P$) is taken as the number of pump motors (n) multiplied by the efficiency of the pump motors ($\eta_m$) multiplied by the power of the pump motors ($W_E$). This is a conservative value because the combined net energy of the two recirculation pump motors contributes to the energy of the recirculation water. This estimate is fixed relative to CTP because relatively large random variations in $Q_P$ will be negligible compared to $Q_{FW}$.

$$Q_P = n \cdot \eta_m \cdot W_E \quad \text{(Equation 6)}$$

### 6.2.2 Energy out

6.2.2.1 Energy of Steam

Energy of steam from feedwater ($Q_{S\text{-}FW}$) is equal to the feedwater mass flow rate ($W_{FW}$) multiplied by the enthalpy ($h_G(P_S)$) of the steam ($h_G$) at the steam dome pressure ($P_S$). The moisture carryover mass fraction is conservatively set to 0 (See Attachment 2).

$$Q_{S\text{-}FW} = w_{FW} \cdot h_G(P_S) \quad \text{(Equation 7)}$$

6.2.2.2 Energy of CRD Purge Water

In a Boiling Water Reactor (BWR), the energy of CRD purge water and recirculation pump seal purge water going to steam ($Q_{CRD\text{-}OUT}$) is equal to the mass flow rate of control rod drive and recirculation pump seal purge water ($w_{CRD}$) multiplied by its enthalpy. However, the Feedwater mass flow rate will makes up greater than 99 % of the steam mass flow rate; therefore, $W_{CRD}$ will be quantified as a fixed number because relatively large random variations in $W_{CRD}$ will be negligible in determining $Q_S$.

$$Q_{CRD\text{-}OUT} = w_{CRD} \cdot h_G(P_S) \quad \text{(Equation 8)}$$

### 6.2.2.3 Energy of Reactor Pressure Vessel Radiative Heat Loss

Energy of reactor pressure vessel radiative heat loss ($Q_{RAD}$) includes both heat loss due to thermal radiation as well as heat loss through convection. This value is fixed relative to CTP because relatively large random variations in $Q_{RAD}$ will be negligible in determining $Q_S$.

### 6.2.2.4 Energy of Reactor Water Clean-up

Energy of reactor water clean up ($Q_{RWCU}$) is based on the net heat removed by the non-regenerative heat exchanges from the recirculated water stream bypassed from Recirculation Loop B to the RWCU. The actual contribution to the heat removed from the reactor pressure vessel is negligible because the non-regenerative heat exchangers cool the stream going to the cleanup filters and demineralizers and the regenerative heat exchangers use the incoming stream to reheat the RWCU flow back up to the feedwater temperature. The mass flow rate is equal to the nominal pump flow rate the higher of Pump A or the combination of Pump B & C. The pump flow rate is fixed relative to CTP because relatively large random variations in $Q_{RWCU}$ will be negligible in determining $Q_S$. The net heat removed is equal to the mass flow rate ($W_{RWCU}$) multiplied by difference of enthalpies across the RWCU.

$$Q_{RWCU} = w_{RWCU} \cdot [h_F(T_{RPV}) - h_F(T_{FW})] \qquad \text{(Equation 9)}$$

## 6.2.3 Heat Balance Equation

The reactor heat balance is based on the principle that heat input to the reactor water equals heat out. Substituting Equations 2 and 3 into Equation 1 yields:

$$(Q_{S-FW} + Q_{CRD-OUT} + Q_{RAD} + Q_{RWCU}) = CTP + (Q_{FW-IN} + Q_{CRD-IN} + Q_P) \qquad \text{(Equation 10)}$$

Solving for CTP yields,

$$CTP = (Q_{S-FW} + Q_{CRD-OUT} + Q_{RAD} + Q_{RWCU}) - (Q_{FW-IN} + Q_{CRD-IN} + Q_P)$$

$$= [w_{FW} \cdot h_G(P_S) + w_{CRD} \cdot h_G(P_S) + Q_{RAD} + w_{RWCU} \cdot [h_F(T_{RPV}) - h_F(T_{FW})]$$

$$- [w_{FW} \cdot h_F(T_{FW}) + w_{CRD} \cdot h_F(T_{CRD}) + n \cdot \eta_m \cdot W_E] \qquad \text{(Equation 11)}$$

Combining like terms,

$$CTP = [[w_{FW} \cdot h_G(P_S) - w_{FW} \cdot h_F(T_{FW})] + [w_{CRD} \cdot h_G(P_S) - w_{CRD} \cdot h_F(T_{CRD})]$$

$$+ Q_{RAD} + w_{RWCU} \cdot [h_F(T_{RPV}) - h_F(T_{FW})] - n \cdot \eta_m \cdot W_E] \qquad \text{(Equation 12)}$$

$$CTP = w_{FW} \cdot [h_G(P_S) - h_F(T_{FW})] + w_{CRD} \cdot [h_G(P_S) - h_F(T_{CRD})]$$

$$+ Q_{RAD} + w_{RWCU} \cdot [h_F(T_{RPV}) - h_F(T_{FW})] - n \cdot \eta_m \cdot W_E \qquad \text{(Equation 13)}$$

Equation 13 is the form of the equation used by the Plant Process Computer (PPC) to calculate CTP (Reference 4.8.2). The CTP can now be expressed as a function of $W_{FW}$, $h_G(P_S)$, $Q_{CRD-OUT}$, $Q_{RAD}$, $Q_{RWCU}$, $h_F(T_{FW})$, $Q_{CRD-IN}$, $Q_P$.

$$CTP = f\ (w_{FW}\ ,\ h_G(P_S),\ Q_{CRD\text{-}OUT}\ ,\ Q_{RAD}\ ,\ Q_{RWCU}\ ,\ h_F(T_{FW}),\ Q_{CRD\text{-}IN}\ ,\ Q_P) \qquad \text{(Equation 14)}$$

Further simplification of Equation 14 can be made by setting variables with negligible input into the uncertainty of the CTP to constant values. The variables that have negligible contribution to the determination of the uncertainty of the heat from CTP are $Q_{CRD\text{-}OUT}$, $Q_{RAD}$, $Q_{RWCU}$, $Q_{CRD\text{-}IN}$, and $Q_P$ as discussed above (Sections 6.2.2.2, 6.2.2.3, 6.2.2.4, 6.2.1.2, and 6.2.1.3).

$$CTP = [w_{FW} * h_G(P_S) + Q_{CRD\text{-}OUT} + Q_{RAD} + Q_{RWCU}] - [w_{FW} * h_F(T_{FW}) + Q_{CRD\text{-}IN} + Q_P]$$

$$= w_{FW} * [h_G(P_S) - h_F(T_{FW})] + (Q_{CRD\text{-}OUT} - Q_{CRD\text{-}IN}) + Q_{RAD} + Q_{RWCU} - Q_P \qquad \text{(Equation 15)}$$

### 6.2.4 Uncertainty Determination

From NUREG/CR-3659 (Ref. 4.9.4), the standard uncertainty (uc) of a function (y) containing multiple statistically independent terms may be expressed as follows:

$$y = f(x_1, x_2, \ldots, x_N)$$

$$u_c = \sqrt{\left(\sum_{i=1}^{N}[c_i u(x_i)]^2\right)} = \sqrt{\left(\sum_{i=1}^{N}u_i^2(y)\right)} \qquad \text{(Equation 16)}$$

Where,

$$c_i = \frac{\partial f}{\partial x_i} \quad \text{and } u_i(y) = |\ c_i\ |\ u(x_i) \qquad \text{(Equation 17)}$$

The standard uncertainty, $u_c$, is multiplied by a coverage factor, k, which is equivalent to the number of standard deviations for a given confidence level to arrive at the measurement uncertainty U and the expected value of y, Y, is taken as y plus or minus the measurement uncertainty.

$$U = ku_c(y) \text{ and } Y = y \pm U \qquad \text{(Equation 18)}$$

### 6.2.4.1 Standard Uncertainty for CTP

The standard uncertainty for CTP can be determined by taking the square root of the sum of the squares of the partial derivatives of each subcomponent of CTP multiplied by the square of the uncertainties of the subcomponents as shown in Equation 19 (Reference 4.9.4).

$$u_{CTP} = \sqrt{\begin{array}{l} \left[\left(\left|\frac{\partial CTP}{\partial w_{FW}}\right|\right)^2 * \left(\sigma_{w_{FW}}\right)^2\right] + \left[\left(\left|\frac{\partial CTP}{\partial h_G(P_S)}\right|\right)^2 * \left(\sigma_{h_G(P_S)}\right)^2\right] + \\[2mm] \left[\left(\left|\frac{\partial CTP}{\partial h_F(T_{FW})}\right|\right)^2 * \left(\sigma_{h_F(T_{FW})}\right)^2\right] + \left[\left(\left|\frac{\partial CTP}{\partial Q_{CRD\_OUT}}\right|\right)^2 * \left(\sigma_{Q_{CRD\_OUT}}\right)^2\right] + \\[2mm] \left[\left(\left|\frac{\partial CTP}{\partial Q_{CRD\_IN}}\right|\right)^2 * \left(\sigma_{Q_{CRD\_IN}}\right)^2\right] + \left[\left(\left|\frac{\partial CTP}{\partial Q_{RAD}}\right|\right)^2 * \left(\sigma_{Q_{RAD}}\right)^2\right] + \\[2mm] \left[\left(\left|\frac{\partial CTP}{\partial Q_{RWCU}}\right|\right)^2 * \left(\sigma_{Q_{RWCU}}\right)^2\right] + \left[\left(\left|\frac{\partial CTP}{\partial Q_P}\right|\right)^2 * \left(\sigma_{Q_P}\right)^2\right] \end{array}} \qquad \text{(Equation 19)}$$

The partial derivative terms can be solved for by recalling CTP from Equation 15.

$$CTP = w_{FW} \cdot (h_G(P_S) - h_F(T_{FW})) + (Q_{CRD\text{-}OUT} - Q_{CRD\text{-}IN}) + Q_{RAD} + Q_{RWCU} - Q_P$$

The partial derivatives are determined from Equation 15 and shown below, remembering that the terms $Q_{CRD\text{-}OUT}$, $Q_{CRD\text{-}IN}$, $Q_{RAD}$, $Q_{RWCU}$, and $Q_P$ are fixed relative to the determination of the uncertainty of CTP.

$$\frac{\partial CTP}{\partial w_{FW}} = \left( h_G(P_S) - h_F(T_{FW}) \right)$$

(Equation 20)

$$\frac{\partial CTP}{\partial h_G(P_S)} = w_{FW}$$

(Equation 21)

$$\frac{\partial CTP}{\partial h_F(T_{FW})} = -w_{FW}$$

(Equation 22)

$$\frac{\partial CTP}{\partial Q_{CRD\_OUT}} = 1$$

(Equation 23)

$$\frac{\partial CTP}{\partial Q_{CRD\_IN}} = -1$$

(Equation 24)

$$\frac{\partial CTP}{\partial Q_{RAD}} = 1$$

(Equation 25)

$$\frac{\partial CTP}{\partial Q_{RWCU}} = 1$$

(Equation 26)

$$\frac{\partial CTP}{\partial Q_P} = -1$$

(Equation 27)

The Feedwater mass flowrate uncertainty, $\sigma_{WFW}$, is equal to the measurement uncertainty as shown in Equation 28.

$$\sigma_{W_{FW}} = u_{FW} \cdot w_{FW}$$

(Equation 28)

The steam enthalpy uncertainty, $\sigma_{hG}$, is determined by Equation 29.

$$\sigma_{h_G}(P_S, T_S, I_o) = \sqrt{\left(\frac{\partial h_G}{\partial T}\right)^2 \cdot \sigma_T^2 + \left(\frac{\partial h_G}{\partial P}\right)^2 \cdot \sigma_P^2 + \left(\frac{\partial h_G}{\partial I_o}\right)^2 \cdot \sigma_{I_o}^2}$$

(Equation 29)

Substituting finite differences for the partial derivatives:

$$= \sqrt{\left(\frac{\Delta h_G}{\Delta T}\right)^2 \cdot \sigma_T^2 + \left(\frac{\Delta h_G}{\Delta P}\right)^2 \cdot \sigma_P^2 + \left(\frac{\Delta h_G}{\Delta I_o}\right)^2 \cdot \sigma_{I_o}^2}$$

(Equation 30)

Noting that for saturated steam, pressure determines the temperature of the steam; thus, $\sigma_T = 0$. In addition, the steam tables used were derived from NIST Chemistry WebBook (Reference 4.9.3).

The interpolation error for steam enthalpy, $\sigma_{I_o} = \pm 0.05$ Btu/lbm.

$$\sigma_{h_G}(P_S, I_o) = \sqrt{\left(\frac{\Delta h_G(P_S)}{\Delta P_S}\right)^2 * \sigma_P^2 + \left(\frac{\Delta h_G(I_o)}{\Delta I_o}\right)^2 * \sigma_{I_o}^2}$$ (Equation 31)

The Feedwater enthalpy uncertainty, $\sigma_{hF}$, is determined by Equation 32.

$$\sigma_{h_F}(T_{FW}, P_{FW}, I_o) = \sqrt{\left(\frac{\partial h_F}{\partial T}\right)^2 * \sigma_T^2 + \left(\frac{\partial h_F}{\partial P}\right)^2 * \sigma_P^2 + \left(\frac{\partial h_F}{\partial I_o}\right)^2 * \sigma_{I_o}^2}$$ (Equation 32)

Substituting finite differences for the partial derivatives yields

$$= \sqrt{\left(\frac{\Delta h_F}{\Delta T}\right)^2 * \sigma_T^2 + \left(\frac{\Delta h_F}{\Delta P}\right)^2 * \sigma_P^2 + \left(\frac{\Delta h_F}{\Delta I_o}\right)^2 * \sigma_{I_o}^2}$$

The interpolation error for liquid enthalpy, $\sigma_{I_o} = \pm 0.005$ BTU/lb, and that the enthalpy of subcooled water varies with temperature and slightly with pressure; thus,

$$\sigma_{h_F}(T_{FW}, P_{FW}, I_o) = \sqrt{\left(\frac{\Delta h_F(T)}{\Delta T}\right)^2 * \sigma_T^2 + \left(\frac{\Delta h_F(P)}{\Delta P}\right)^2 * \sigma_P^2 + \left(\frac{\Delta h_F}{\Delta I_o}\right)^2 * \sigma_{I_o}^2}$$ (Equation 33)

The following uncertainty terms are relatively insignificant in the determination of CTP uncertainty; therefore, it is only necessary to quantify the uncertainty to within a reasonably conservative value. Refinement of the uncertainty of these items after this initial determination is not required given that the uncertainty is within the tolerances shown in the sensitivity analysis (See Attachment 7).

The Control Rod Drive (CRD) outlet energy uncertainty, $\sigma_{QCRD\_OUT}$, is determined by Equation 34, where $x_{CRD}$ is the uncertainty calculated for the CRD flow stream.

$$\sigma_{Q_{CRD\_OUT}} = x_{CRD}\% \cdot Q_{CRD\_OUT}$$ (Equation 34)

The CRD inlet energy uncertainty, $\sigma_{QCRD\_IN}$, is determined by Equation 35, where $x_{CRD}$ is the uncertainty calculated for the CRD flow stream.

$$\sigma_{Q_{CRD\_IN}} = x_{CRD}\% \cdot Q_{CRD\_IN}$$ (Equation 35)

The reactor pressure vessel heat loss uncertainty, $\sigma_{QRAD}$, is determined by Equation 36, where $x_{RAD}$ is the uncertainty assigned to the heat loss value calculated by LM-0553 (Reference 4.8.3).

$$\sigma_{Q_{RAD}} = x_{RAD}\% \cdot Q_{RAD}$$ (Equation 36)

The RWCU heat removal uncertainty, $\sigma_{QRWCU}$, is determined by Equation 37, where $x_{RWCU}$ is the uncertainty calculated for the RWCU heat balance terms.

$$\sigma_{Q_{RWCU}} = x_{RWCU}\% \cdot Q_{RWCU}$$ (Equation 37)

The Recirculation Pump heat addition uncertainty, $\sigma_{QP}$, is determined by Equation 38, where $x_P$ is the uncertainty calculated for measurement of the recirculation pump motor power.

$$\sigma_{Q_P} = x_P\% \cdot Q_P$$ (Equation 38)

6.2.5   Extended Instrument Drift

Instrument drift specifications are usually published for a defined period of time. The instrument drift for one period of time is independent from the instrument drift of any other equivalent period of time. Therefore, the drift specification D for a period of X months can be expanded to n·X months (where n

is the station surveillance interval divided by the vendor drift interval and n is an integer greater than zero) by the SRSS method. Instrument drift for surveillance intervals exceeding the instrument suppliers' specified drift interval is calculated using Equation 39 (Section 4.1.1 of reference 4.1.1,).

$$D_n = [n \cdot (D_x)^2]^{1/2} \quad \text{(Equation 39)}$$

## 7.0    <u>NUMERIC ANALYSIS</u>

### 7.1    FEEDWATER FLOW UNCERTAINTY

The uncertainty of the feedwater mass flow rate measurement for the Caldon® Ultrasonics Leading Edge Flow Meter Check Plus (LEFM✓+) system is taken from Reference 4.8.6, Section 2.0, using Equation 28.

$$\sigma_{W_{FW}} = U_{FW\,measurement} * W_{FW} = 0.32\% * W_{FW}$$
$$= 0.0032 * 15{,}090{,}000 \ lbm/hr$$
$$= 48{,}288 \ lbm/hr$$

### 7.2    STEAM DOME PRESSURE MEASUREMENT UNCERTAINTY

The uncertainty of the steam dome pressure measurement is taken from Reference 4.8.8.

$$\sigma_{P_S} = \pm\,20\,psig$$

### 7.3    REACTOR WATER CLEAN-UP (RWCU) FLOW LOOP UNCERTAINTY

#### 7.3.1    RWCU Flow Loop Accuracy ($LA_{RWCU\_Flow}$)

##### 7.3.1.1    RWCU Flow Element Reference Accuracy (A1)

Reference Accuracy is specified as ± 1.50% of actual rate of flow (Section 2.2.3).

$$A1_{2\sigma} \quad = \quad \pm\,1.50\% \ Flow$$

##### 7.3.1.2    RWCU Flow Element Installation Effect (IE1)

The flow elements meet the installation requirements of Ref. 4.6.5. Therefore,

$$IE1 \quad = \pm\,0.50\% \ Flow$$

##### 7.3.1.3    RWCU Flow Element Temperature Effect on Flow Element Expansion (TN1)

Per section 2.2.3, the maximum temperature of the water passing through the flow element is 582 °F and the normal temperature is 539 °F with the flow elements located just upstream of the RWCU Recirculation Pumps. Since the system temperature operation band is small, there is a minor change in the flow element expansion factor. The change is in order of 0.003 inches or less for the temperature range of 515 °F to 560 °F. Therefore the temperature effect on flow element expansion can be neglected.

$$TN1 \quad = \pm\,0\% \ Flow$$

##### 7.3.1.4    RWCU Flow Element Temperature Effect on Density (TD1)

During normal operations the temperature band for the fluid passing through the flow element at the inlet of the RWCU system is approximately 530 °F. The effect temperature has on density will be evaluated at ± 4.37 °F (Section 7.4.6) from the base condition of 530 °F at 1060 psig at the flow element (Section 2.2.3). Density is relatively constant at 1060 psig; however, for conservatism a variation of ± 10 psig is used to show that the pressure effect is negligible even at four times the nominally specified transmitter reference accuracy of 0.25 %. The uncertainty in the density, $\sigma_P(T,P)$, as a function of temperature and pressure will follow Equation 33.

$$\sigma_\rho(T_{RWCU}) = \sqrt{\left(\frac{\rho(534.4) - \rho(525.6)}{534.4 - 525.6}\right)^2 \left(\frac{\frac{lbm}{ft^3}}{°F}\right)^2 * (4.4\,°F)^2 + \left(\frac{\rho(1070) - \rho(1050)}{1070 - 1050}\right)^2 \left(\frac{\frac{lbm}{ft^3}}{psi}\right)^2 * (10\,psi)^2}$$

$$= \sqrt{\left(\frac{47.046 - 47.612}{534.4 - 525.6}\right)^2 \left(\frac{\frac{lbm}{ft^3}}{°F}\right)^2 * (4.4\,°F)^2 + \left(\frac{47.339 - 47.326}{1070 - 1050}\right)^2 \left(\frac{\frac{lbm}{ft^3}}{psi}\right)^2 * (10\,psi)^2}$$

$$= \sqrt{\left(\frac{-0.57}{8.8}\right)^2 \left(\frac{\frac{lbm}{ft^3}}{°F}\right)^2 * (4.4\,°F)^2 + \left(\frac{0.01}{20}\right)^2 \left(\frac{\frac{lbm}{ft^3}}{psi}\right)^2 * (10\,psi)^2}$$

$$= \sqrt{0.08009\left(\frac{lbm}{ft^3}\right)^2 + 0.00004\left(\frac{lbm}{ft^3}\right)^2}$$

$$\sigma_\rho(T_{FW}) = 0.28307\,\frac{lbm}{ft^3}$$

*Divide by the base density to convert to a percentage value*

$$\sigma_\rho(T_{RWCU}, P_{10}) = \frac{0.283}{47.333}\,@\,530\,°F = 0.00598 = 0.598\,\%$$

The percent change in density, $\sigma_x$, as a function of the percent change in flow, $\sigma_1$, is given by the following equation (Reference Attachment 8, Equation A8-10):

$$\sigma_x \approx 2 * \sigma_1$$

Rearranging Equation A8-10 and substituting $\sigma_\rho$ for $\sigma_x$ to solve for the unknown flow uncertainty, $\sigma_1$:

$$TD1_{\% flow} = \frac{1}{2} \cdot TD1_{\% density}$$

$$= \frac{1}{2} \cdot 0.598 \%$$

$$= 0.299 \%$$

$$TD1_{\% flow} = 0.3 \% \text{ of flow}$$

### 7.3.1.5 RWCU Flow Element Humidity Error (e1H)

The flow element is a mechanical device installed within the process. Therefore, humidity effects are not applicable.

$$e1H = 0$$

### 7.3.1.6 RWCU Flow Element Radiation Error (e1R)

The flow element is a mechanical device installed within the process. Therefore, radiation effects are not applicable.

$$e1R = 0$$

### 7.3.1.7 RWCU Flow Element Seismic Error (e1S)

For normal error analysis, normal vibrations and seismic effects are considered negligible or capable of being calibrated out. Therefore, there is no seismic error for normal operating conditions (Section 3.5).

$$e1S = 0$$

### 7.3.1.8 RWCU Flow Element Static Pressure Offset Error (e1SP)

The flow element is a mechanical device installed within the process. Therefore, static pressure effects are not applicable.

$$e1SP = 0$$

### 7.3.1.9 RWCU Flow Element Ambient Pressure Error (e1P)

The flow element is a mechanical device installed within the process. Therefore, therefore the flow element is not subject to ambient pressure variations.

$$e1P = 0$$

### 7.3.1.10 RWCU Flow Element Process Error (e1Pr)

Any process errors have been accounted for as errors associated with Temperature Effect on Density. Therefore,

$$e1Pr = 0$$

### 7.3.1.11 RWCU Flow Element Temperature Error (e1T)

Temperature error is considered to be a random variable for the flow elements and is addressed under Temperature Effect on Flow Element Expansion (Section 7.3.1.3). Therefore,

$$e1T = 0$$

### 7.3.1.12 RWCU Flow Transmitter Reference Accuracy (A2)

Reference Accuracy is specified as ± 0.25 % of span considered to be a 3σ value (Section 2.2.4). The reference accuracy is set to the calibration accuracy per plant procedure (Reference 4.1.1).

$A2_{3\sigma}$ = ± 0.50 % [3σ]

Converting to a 2σ value

$A2_{2\sigma}$ = ± 0.50 % * 2 / 3

$A2_{2\sigma}$ = ± 0.3333 % of span

Converting % span to % flow

Rearranging Equation A8-10, $\sigma_{\Delta P} = 2 * \sigma_{FLOW}$, to solve for flow (Reference Attachment 8):

$A2_{2\sigma\%Flow}$ = $A2_{\%Span}$ / 2

= ± 0.3333 % of span / 2

= ± 0.1667 % of Flow

$A2_{2\sigma\%Flow}$ = ± 0.1667 % of Flow

### 7.3.1.13 RWCU Flow Transmitter Power Supply Effects (σ2PS2)

Power supply effects are considered to be negligible (Section 3.7). Therefore,

σ2PS2 = ± 0

### 7.3.1.14 RWCU Flow Transmitter Ambient Temperature Error (σ2T)

The temperature effect is ± (0.75 % URL + 0.5 % span)/100°F [3σ] (Section 2.2.4). The maximum temperature at the transmitter location is 106 °F, and minimum temperature during calibration could be 65 °F, so the maximum difference = 106 − 65 °F = 41 °F (Section 2.3.4)

$\sigma2T_{3\sigma}$ = ± [(0.0075 * 750 INWC + 0.005 * 220 INWC) * 41 °F/ 100 °F]

= ± [(5.625 INWC + 1.1 INWC) * 0.41]

$\sigma2T_{3\sigma}$ = ± 2.76 INWC [3σ], rounded to level of significance

Converting to a 2σ value

$\sigma2T_{2\sigma}$ = ± 2.76 INWC * 2 / 3

$\sigma2T_{2\sigma}$ = ± 1.8382 INWC

Converting to % span

$\sigma2T_{2\sigma}$ = ± 1.8382 INWC / 220 INWC

= ± 0.008355 = 0.8355 %

Converting % span to % flow

Rearranging Equation A8-10, $\sigma_{\Delta P} = 2 * \sigma_{FLOW}$, to solve for flow (Reference Attachment 8):

$\sigma2T_{2\sigma\%Flow}$ = $\sigma2T_{2\sigma\%Span}$ / 2

= ± 0.8355 % / 2

= ± 0.4178 %

$\sigma2T_{2\sigma\%Flow}$ = ± 0.418 %

### 7.3.1.15 RWCU Flow Transmitter Humidity Error (e2H)

The manufacturer specifies the transmitter operating humidity limits between 0 and 100 % RH (Section 2.2.4). The transmitter is located in Containment H2 Recombiner Room 506C, Area 16 where humidity may vary from 50 to 90% RH (Reference 4.4.2). Humidity errors are set to zero because they are considered to be included within the reference accuracy specification under these conditions. (Section 3.2)

$$e2H \quad = \quad 0$$

### 7.3.1.16 RWCU Flow Transmitter Radiation Error (e2R)

The manufacturer specifies the transmitter operating radiation effect during and after exposure to $2.2 \times 10^7$ rads TID (Section 2.2.4). The transmitter is located in Containment H2 Recombiner Room 506C, Area 16, where total integrated dose (TID) could be as high as $8.78 \times 10^2$ rad (Reference Section 4.4.2). Therefore,

$$e2R \quad = \quad \pm (4.0 \text{ % of URL}) \text{ * dose / rated dose}$$
$$= \quad \pm (0.04 \cdot 750 \text{ INWC}) \text{ * } 8.78 \times 10^2 / 2.2 \times 10^7$$
$$= \quad \pm 30 \text{ INWC * } 3.99 \times 10^{-5}$$
$$e2R \quad = \quad \pm 1.20 \times 10^{-3} \text{ INWC}$$

Converting to % span

$$e2R_{\%Span} \quad = \quad \pm 1.20 \times 10^{-3} \text{INWC} / 220 \text{ INWC}$$
$$= \quad \pm 5.44 \times 10^{-6} = 5.44 \times 10^{-4} \text{ %}$$

Converting % span to % flow

Rearranging Equation A8-10, $\sigma_{\Delta P} = 2 \text{ * } \sigma_{FLOW}$, to solve for flow (Reference Attachment 8):

$$e2R_{\%Flow} \quad = \quad e2R_{\%Span} / 2$$
$$= \quad \pm 5.44 \times 10^{-4} \text{ %} / 2$$
$$= \quad \pm 2.72 \times 10^{-4} \text{ %}$$
$$= \quad \pm 2.72 \times 10^{-4} \text{ %, which is negligible}$$
$$e2R_{\%Flow} \quad = \quad 0$$

### 7.3.1.17 RWCU Flow Transmitter Seismic Error (e2S)

The transmitter's accuracy is within $\pm 0.5\%$ of URL (upper range limit) during and after a seismic disturbance defined by a required response spectrum with a ZPA of 4 g's. A seismic event defines a particular type of accident condition. Therefore, there is no seismic error for normal operating conditions (Section 3.5)

$$e2S \quad = \quad 0$$

### 7.3.1.18 RWCU Flow Transmitter Ambient Pressure Error (e2P)

The flow transmitter is an electrical device and therefore not affected by ambient pressure.

$$e2P \quad = \quad 0$$

### 7.3.1.19 RWCU Flow Transmitter Temperature Error (e2T)

Temperature error is considered to be a random variable for a Rosemount transmitter. Therefore

$$e2T \quad = \quad 0$$

### 7.3.1.20  RWCU PPC I/O Module and SRU Reference Accuracy (A3)

Reference accuracy of the computer input is taken to be the SRSS of the reference accuracies of the SRU and the I/O module. The reference accuracy of the SRU is 0.1 % of span (Section 2.2.5). Reference Accuracy for the I/O module is specified as ± 0.25 % of span (Section 2.2.6).

$$A3_{2\sigma} = \sqrt{0.1^2 + 0.5^2} = 0.5099 = 0.51 \text{ % span}$$

Converting % span to % flow

Rearranging Equation A8-10, $\sigma_{\Delta P} = 2 \ast \sigma_{FLOW}$, to solve for flow (Reference Attachment 8):

$$A3_{\%Flow} = A3_{\%Span} / 2$$
$$= \pm 0.51\% / 2$$
$$A3_{\%Flow} = \pm 0.255 \text{ %}$$

### 7.3.1.21  RWCU PPC I/O Module Humidity Error (e3H)

The manufacturer specifies the I/O module operating humidity limits between 0 and 95 % RH (Section 2.2.6). The I/O module is located in the Control Room 533, where humidity may vary from 50 to 90% RH (Reference 4.4.2). Humidity errors are set to zero because they are considered to be included within the reference accuracy specification under these conditions (Section 3.2).

$$e3H = 0$$

### 7.3.1.22  RWCU PPC I/O Module Radiation Error (e3R)

No radiation errors are specified in the manufacturer's specifications. The instrument is located in the Control Room 533, a mild environment (Section 4.4.2). Therefore, it is reasonable to consider the normal radiation effect as being included in the reference accuracy.

$$e3R = 0$$

### 7.3.1.23  RWCU PPC I/O Module Seismic Error (e3S)

No seismic effect errors are specified in the manufacturer's specifications. A seismic event defines a particular type of accident condition. Therefore, there is no seismic error for normal operating conditions (Section 3.5).

$$e3S = 0$$

### 7.3.1.24  RWCU PPC I/O Module Static Pressure Offset Error (e3SP)

The I/O module is an electrical device and therefore not affected by static pressure.

$$e3SP = 0$$

### 7.3.1.25  RWCU PPC I/O Module Ambient Pressure Error (e3P)

The I/O module is an electrical device and therefore not affected by ambient pressure.

$$e3P = 0$$

### 7.3.1.26  RWCU PPC I/O Module Process Error (e3Pr)

The I/O module receives an analog current input from the flow transmitter proportional to the pressure sensed. Any process errors associated with the conversion of pressure to a current signal have been accounted for as errors associated with Flow Element. Therefore,

$$e3Pr = 0$$

### 7.3.1.27 RWCU Flow Loop Accuracy (LA$_{RWCU\_Flow}$)

$$
\begin{aligned}
LA_{RWCU\_Flow} = &\pm [(A1)^2 + (IE1)^2 + (TN1)^2 + (TD1)^2 + (e1H)^2 + (e1R)^2 + (e1S)^2 + (e1SP)^2 + (e1P)^2 + \\
&(e1Pr)^2 + (e1T)^2 + (A2)^2 + (s2PS2)^2 + (s2T)^2 + (e2H)^2 + (e2R)^2 + (e2S)^2 + (e2P)^2 + \\
&(e2T)^2 + (A3)^2 + (e3H)^2 + (e3R)^2 + (e3S)^2 + (e3SP)^2 + (e3P)^2 + (e3Pr)^2]^{1/2}
\end{aligned}
$$

$$
\begin{aligned}
= &\pm [(1.5)^2 + (0.5)^2 + (0)^2 + (0.3)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + \\
&(0.1667)^2 + (0)^2 + (0.418)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0.255)^2 + (0)^2 + (0)^2 + \\
&(0)^2 + (0)^2 + (0)^2 + (0)^2]^{1/2}
\end{aligned}
$$

$$
\begin{aligned}
= &\pm [2.25 + 0.25 + 0 + 0.09 + 0 + 0 + 0 + 0 + 0 + 0 + 0 + 0.027789 + 0 + 0.174724 + \\
&0 + 0 + 0 + 0 + 0 + 0.065025 + 0 + 0 + 0 + 0 + 0 + 0]^{1/2}
\end{aligned}
$$

$$= \pm [2.85754]^{1/2}$$

$$= \pm 1.690425 \%$$

$$LA_{RWCU\_Flow} = \pm 1.7 \%$$

### 7.3.2 RWCU Flow Loop Drift (LD$_{RWCU\_Flow}$)

### 7.3.2.1 RWCU Flow Element Drift Error (D1)

The flow element is a mechanical device; drift error is not applicable for the flow elements. Therefore,

D1 $= \pm 0.00\%$ Flow

### 7.3.2.2 RWCU Flow Transmitter Drift Error (D2)

Drift error for the transmitter is $\pm 0.2\%$ of URL / 30 months, taken as a random $2\sigma$ value (Section 2.2.4). The calibration frequency is 2 years, with a late factor of 6 months.

$$D2_{2\sigma} = \pm (0.2\% * URL)$$

Drift is applied to the surveillance interval (SI) using Equation 39 (Section 6.2.5) as follows

$$D2_{2\sigma} = \pm [n(D_x)^2]^{1/2},$$

$$= \pm ([(24 \text{ months} + 6 \text{ months}) / 30 \text{ months}] \cdot [0.002 \text{ URL}]^2)^{1/2}$$

$$= \pm ([(30 / 30)] \cdot [1.5 \text{ INWC}]^2)^{1/2}$$

$$D2_{2\sigma} = \pm 1.50 \text{ INWC}$$

Converting to % span

$$D2_{\%Span} = \pm 1.5 \text{ INWC} / 219.8 \text{ INWC}$$

$$= \pm 0.00682439 = 0.682439 \%$$

Converting % span to % flow

Rearranging Equation A8-10, $\sigma_{\Delta P} = 2 * \sigma_{FLOW}$, to solve for flow (Reference Attachment 8):

$$D2_{\%Flow} = D2_{\%Span} / 2$$

$$= \pm 0.682439\% / 2$$

$$= \pm 0.341219 \%$$

$$D2_{\%Flow} = \pm 0.34 \%$$

### 7.3.2.3 RWCU Flow PPC I/O Module Drift Error (D3)

The vendor does not specify a drift error for the I/O module. Therefore, per Ref. 4.1.1 Section I, it is considered to be included in the reference accuracy.

D3 $= \pm 0$

7.3.2.4 RWCU Flow Loop Drift ($LD_{RWCU\_Flow}$)

$$LD_{RWCU\_Flow} = [(D1)^2 + (D2)^2 + (D3)^2]^{1/2}$$
$$= [(0)^2 + (0.34)^2 + (0)^2]^{1/2}$$
$$= \pm [0 + 0.116431 + 0]^{1/2}$$
$$= \pm [0.116431]^{1/2}$$
$$= \pm 0.341219 \%$$

$$LD_{RWCU\_Flow} = \pm 0.34 \%$$

7.3.3 RWCU Flow Loop Process Measurement Accuracy ($PMA_{RWCU\_Flow}$)

No additional PMA effects beyond the effects specified in the calculation of loop accuracy.

$$PMA_{RWCU\_Flow} = 0$$

7.3.4 RWCU Flow Loop Primary Element Accuracy ($PEA_{RWCU\_Flow}$)

No additional PEM effects beyond the effects specified in the calculation of loop accuracy.

$$PEA_{RWCU\_Flow} = 0$$

7.3.5 RWCU Flow Loop Calibration Accuracy ($CA_{RWCU\_Flow}$)

Standard practice is to specify calibration uncertainty in calculations equal to the uncertainty associated with the instruments under test (Reference 4.1.1).

Therefore,

$$CA_{RWCU\_Flow} = [(A1)^2 + (A2)^2 + (A3)^2]^{1/2}$$
$$= [(1.5 \%)^2 + (0.1667 \%)^2 + (0.255 \%)^2]^{1/2}$$
$$= [2.3428 \%^2]^{1/2}$$
$$= 1.5306 \%$$

$$CA_{RWCU\_Flow} = 1.5 \%$$

7.3.6 Total Uncertainty RWCU Flow Loop ($TU_{RWCU\_Flow}$)

$$TU_{RWCU\_Flow} = \pm [(LA)^2 + (LD)^2 + (PMA)^2 + (PEA)^2 + (CA)^2]^{1/2}$$
$$= \pm [(1.7)^2 + (0.34)^2 + (0)^2 + (0)^2 + (1.5)^2]^{1/2}$$
$$= \pm [2.89 + 0.1156 + 0 + 0 + 2.25]^{1/2}$$
$$= \pm [5.2556]^{1/2}$$
$$= \pm 2.29251\%$$

$$TU_{RWCU\_Flow} = \pm 2.3 \%$$

## 7.4 RWCU TEMPERATURE LOOP UNCERTAINTY

7.4.1 RWCU Temperature Loop Accuracy ($LA_{RWCU\_T}$)

7.4.1.1 RWCU Temperature Element Reference Accuracy (A1)

RWCU Temperature Element Reference Accuracy is provided in Section 2.3.1.

$$A1 = \pm 0.75 \,°F$$

7.4.1.2   RWCU Temperature Element Power Supply Effects ($\sigma 1PS$)

Power supply effects are considered to be negligible (Section 3.7). Therefore,

$\sigma 1PS$   =   0

7.4.1.3   RWCU Temperature Element Ambient Temperature Error ($\sigma 1T$)

All thermocouple extension wire junctions are on adjacent terminals and are assumed to be at the same temperature. Therefore, for the thermocouple,

$\sigma 1T_{1\sigma} = 0$

7.4.1.4   RWCU Temperature Element Humidity Error (e1H)

The manufacturer does not specify the thermocouple operating humidity limits (Section 2.3.1). The thermocouple is located in the RWCU System Room 506, where humidity may vary from 50 to 90% RH (Reference 4.4.2). Humidity errors are set to zero because they are considered to be included within the reference accuracy specification under these conditions (Section 3.2).

e1H   =   0

7.4.1.5   RWCU Temperature Element Radiation Error (e1R)

No radiation errors are specified in the manufacturer's specifications. The instrument is located in the Control Room 533, a mild environment (Reference 4.4.2). Therefore, it is reasonable to consider the normal radiation effect as being included in the reference accuracy. Therefore,

e1R   =   0

7.4.1.6   RWCU Temperature Element Seismic Error (e1S)

No seismic effect errors are specified in the manufacturer's specifications. A seismic event defines a particular type of accident condition. Therefore, there is no seismic error for normal operating conditions (Section 3.5).

e1S   =   0

7.4.1.7   RWCU Temperature Element Vibration Effect (e1V)

The error due to vibration is considered to be negligible because it is small and unaffected by vibrations in the system.

e1V   =   0

7.4.1.8   RWCU Temperature Element Static Pressure Error (e1SP)

The thermocouple output is not subject to pressure variations.

$e1SP_{1\sigma} = 0$

7.4.1.9   RWCU Temperature Element Ambient Pressure Error (e1P)

The thermocouple is an electrical device and therefore not affected by ambient pressure.

e1P   =   0

7.4.1.10  RWCU Temperature Element Temperature Error (e1T)

The temperature error is assumed to be included in the reference accuracy (Reference 4.1.1). Therefore,

e1T   =   0

7.4.1.11  RWCU Temperature Loop PPC I/O Module Reference Accuracy (A2)

Reference Accuracy is specified as $\pm 3.0$ °F (Section 2.3.3) and considered to be a $2\sigma$ value (Section 3.4)

$A2_{2\sigma} \quad = \quad \pm 3.0 \ ^\circ F$

### 7.4.1.12  RWCU Temperature Loop PPC I/O Module Humidity Error (e2H)

The manufacturer specifies the I/O module operating humidity limits between 0 and 95 % RH (Section 2.3.3). The I/O module is located in the Control Room 533, where humidity may vary from 50 to 90% RH (Reference Section 4.4.2). Humidity errors are set to zero because they are considered to be included within the reference accuracy specification under these conditions. (Section 3.2)

$e2H \quad = \quad 0$

### 7.4.1.13  RWCU Temperature Loop PPC I/O Module Radiation Error (e2R)

No radiation errors are specified in the manufacturer's specifications. The instrument is located in the Control Room 533, a mild environment [Section 4.4.2]. Therefore, it is reasonable to consider the normal radiation effect as being included in the reference accuracy. Therefore,

$e2R \quad = \quad 0$

### 7.4.1.14  RWCU Temperature Loop PPC I/O Module Seismic Error (e2S)

No seismic effect errors are specified in the manufacturer's specifications. A seismic event defines a particular type of accident condition. Therefore, there is no seismic error for normal operating conditions (Section 2.8).

$e2S \quad = \quad 0$

### 7.4.1.15  RWCU Temperature Loop PPC I/O Module Static Pressure Offset Error (e2SP)

The I/O module is an electrical device installed in the control room and is not subject to pressure effects.

$e2SP \quad = \quad 0$

### 7.4.1.16  RWCU Temperature Loop PPC I/O Module Ambient Pressure Error (e2P)

The I/O module is an electrical device and therefore not affected by ambient pressure.

$e2P \quad = \quad 0$

### 7.4.1.17  RWCU Temperature Loop Accuracy (LA$_{RWCU\_Flow}$)

$$LA_{RWCU\_T} = \pm [(A1)^2 + (\sigma1PS)^2 + (\sigma1T)^2 + (e1H)^2 + (e1R)^2 + (e1S)^2 + (e1V)^2 + (e1SP)^2 + (e1P)^2 + (e1T)^2 + (A2)^2 + (e2H)^2 + (e2R)^2 + (e2S)^2 + (e2SP)^2 + (e2P)^2]^{1/2}$$

$$= \pm [(0.75)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (3.0)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2]^{1/2}$$

$$= \pm [0.5625 + 0 + 0 + 0 + 0 + 0 + 0 + 0 + 0 + 0 + 9.0 + 0 + 0 + 0 + 0 + 0]^{1/2}$$

$$= \pm [9.5625 \ ^\circ F^2]^{1/2}$$

$LA_{RWCU\_T} \quad = \pm 3.09 \ ^\circ F$

### 7.4.2  RWCU Temperature Loop Drift

### 7.4.2.1  RWCU Temperature Element Drift Error (D1)

The error associated with the thermocouple is already included in the reference accuracy (Section 3.2). Therefore, for the thermocouple,

$D1 \quad = \quad \pm 0$

7.4.2.2    RWCU Temperature Loop PPC I/O Module Drift Error (D2)

The vendors do not specify drift errors for the SRU and I/O module. Therefore, per Section 3.2, it is considered to be included in the reference accuracy.

$$D2 = \pm 0$$

7.4.2.3    RWCU Temperature Loop Drift ($LD_{RWCU\_T}$)

$$LD_{RWCU\_T} = [(D1)^2 + (D2)^2]^{1/2}$$
$$= [(0)^2 + (0)^2]^{1/2}$$
$$= \pm [0 + 0]^{1/2}$$
$$= \pm [0]^{1/2}$$
$$= \pm 0.0 \%$$

$$LD_{RWCU\_T} = \pm 0 \%$$

7.4.3    RWCU Temperature Loop ($PMA_{RWCU\_T}$)

No additional PMA effects beyond the effects specified in the calculation of loop accuracy.

$$PMA_{RWCU\_T} = \pm 0$$

7.4.4    RWCU Temperature Loop ($PEA_{RWCU\_T}$)

No additional PMA effects beyond the effects specified in the calculation of loop accuracy.

$$PEA_{RWCU\_T} = 0$$

7.4.5    RWCU Temperature Loop Calibration Accuracy ($CA_{RWCU\_T}$)

Standard practice is to specify calibration uncertainty in calculations equal to the uncertainty associated with the instruments under test (Reference 4.1.1).

Therefore,

$$CA_{RWCU\_T} = [(A1)^2 + (A2)^2 + (A3)^2]^{1/2}$$
$$= [(0.75 \,°F)^2 + (3.09 \,°F)^2]^{1/2}$$
$$= [0.5625 + 9]^{1/2}$$
$$= [9.5625]^{1/2}$$

$$CA_{RWCU\_T} = 3.09 \,°F$$

7.4.6    Total Uncertainty RWCU Temperature Loop ($TU_{RWCU\_T}$)

$$TU_{RWCU\_T} = \pm [(LA)^2 + (LD)^2 + (PMA)^2 + (PEA)^2 + (CA)^2]^{1/2}$$
$$= \pm [(3.09)^2 + (0)^2 + (0)^2 + (0)^2 + (3.09)^2]^{1/2}$$
$$= \pm [9.5625 + 0 + 0 + 0 + 9.5625]^{1/2}$$
$$= \pm [19.125]^{1/2}$$
$$= \pm 4.373 \,°F$$

$$TU_{RWCU\_T} = \pm 4.37 \,°F$$

## 7.5    CRD FLOW RATE UNCERTAINTY

7.5.1    CRD Flow Rate Loop Accuracy ($LA_{CRD\_Flow}$)

7.5.1.1   CRD Flow Element Reference Accuracy (A1)

The accuracy of the flow element is ± 1% of actual rate of flow (Section 2.4.2).

Therefore,

A1   =   ± 1 % flow

7.5.1.2   CRD Flow Element Humidity, Radiation, Pressure, and Temperature Errors (e1H, e1R, e1P, e1T)

The flow element is a mechanical device mounted in the process and its output is not subject to environmental or vibration effects. Therefore;

e1H = e1R = e1P = e1T = 0

7.5.1.3   CRD Flow Element Seismic Error (e1S)

A seismic event is an abnormal operating condition and is not addressed by this calculation (Section 3.5). Therefore;

e1S   =   0

7.5.1.4   CRD Flow Element Static Pressure Error (e1SP)

The flow element is constructed of stainless steel and is not affected by process pressure. Therefore,

e1SP   =   0

7.5.1.5   CRD Flow Transmitter Reference Accuracy (A2)

Reference Accuracy is ± 0.25 % of span (Section 2.4.3). The reference accuracy is set to the calibration accuracy per plant procedure (Reference 4.1.1).

A2   =   ± 0.50 %

Converting % span to % flow

Rearranging Equation A8-10, $\sigma_{\Delta P} = 2 * \sigma_{FLOW}$, to solve for flow (Reference Attachment 8):

$A2_{\%Flow}$ =   $A2_{\%Span}$ / 2

=   ± 0.50 % of span / 2

=   ± 0.25 % of Flow

$A2_{\%Flow}$ =   ± 0.25 % of Flow

7.5.1.6   CRD Flow Transmitter Power Supply Effects (σ2PS)

Power supply effects are considered to be negligible (Section 3.7). Therefore,

σ2PS   =   ± 0

7.5.1.7   CRD Flow Transmitter Ambient Temperature Error (σ2T)

The temperature effect is ± 2.4 % of span per 100 °F at 197.5 INWC span (Section 2.4.3). The calibrated span is 197.5 INWC. The maximum temperature at the transmitter location is 106 °F, and minimum temperature during calibration could be 65 °F, so the maximum difference = 106 - 65 °F = 41 °F (Section 2.3.4).

σ2T   =   ± [(0.024 · 197.5 INWC) / 100 °F] · 41 °F          [3σ]

=   ± [(4.74 INWC)/100 °F] · 41 °F

=   ± 1.943 INWC

Converting to % span

$$\sigma 2T_{2\sigma} = \pm 1.943 \text{ INWC} / 197.5 \text{ INWC}$$

$$= \pm 0.0098$$

Converting % span to % flow

Rearranging Equation A8-10, $\sigma_{\Delta P} = 2 * \sigma_{FLOW}$, to solve for flow (Reference Attachment 8):

$$\sigma 2T_{2\sigma\%Flow} = \sigma 2T_{2\sigma\%Span} / 2$$

$$= \pm 0.98 \% / 2$$

$$= \pm 0.49 \%$$

$$\sigma 2T_{2\sigma\%Flow} = \pm 0.49 \%$$

7.5.1.8    CRD Flow Transmitter Humidity Error (e2H)

The manufacturer specifies the transmitter operating humidity limits between 0 and 100 % RH (Section 2.4.3). The transmitter is located in the CRD Equipment Area, Room 402, where humidity may vary from 50 to 90% RH (Reference 4.4.2). Humidity errors are set to zero because they are considered to be included within the reference accuracy specification under these conditions. (Section 3.2)

$$e2H = 0$$

7.5.1.9    CRD Flow Transmitter Radiation Error (e2R)

Radiation error is assumed to be 10 % of span (Section 3.9).

$$e2R = 10 \% \text{ of Span}$$

$$= 10 \% \cdot 197.5 \text{ INWC}$$

$$e2R = 19.75 \text{ INWC}$$

Converting to % span

$$\sigma 2R = \pm 19.75 \text{ INWC} / 197.5 \text{ INWC}$$

$$= \pm 0.10 = 10 \%$$

Converting % span to % flow

Rearranging Equation A8-10, $\sigma_{\Delta P} = 2 * \sigma_{FLOW}$, to solve for flow (Reference Attachment 8):

$$\sigma 2R_{\%Flow} = \sigma 2R_{2\sigma\%Span} / 2$$

$$= \pm 10.0\% / 2$$

$$= \pm 5.00\%$$

$$\sigma 2R_{\%Flow} = \pm 5.0\%$$

7.5.1.10   CRD Flow Transmitter Seismic Error (e2S)

No seismic effect errors are specified in the manufacturer's specifications. A seismic event defines a particular type of accident condition. Therefore, there is no seismic error for normal operating conditions (Section 3.5)

$$e2S = 0$$

7.5.1.11   CRD Flow Transmitter Vibration Effect (e2V)

The error due to vibration is considered to be negligible because it is small and unaffected by vibrations in the system.

$$e2V = 0$$

7.5.1.12  CRD Flow Transmitter Static Pressure Zero Error (e2SP)

The transmitter has a Zero Error of ± 0.5 % of URL for 2000 psi (Section 2.4.3).  The calibrated range shown in Table 2-12 shows the static pressure adjustment made to account for the span error effect.  Therefore, the total Static Pressure Error is

e2SP  =  ± 0.5 % of URL for 2000 psi

The normal operating pressure (Table 2-11) is 1448 psig.  Therefore,

e2SP  =  ± 0.5 % · 750 INWC · 1448 psig / 2000 psi

=  ± 2.715 INWC

e2SP  =  ± 2.72 INWC, rounded

Converting to % span

$\sigma$2SP  =  ± 2.72 INWC / 200 INWC

=  ± 0.01316 = 1.32 %

Converting % span to % flow

Rearranging Equation A8-10, $\sigma_{\Delta P} = 2 * \sigma_{FLOW}$, to solve for flow (Reference Attachment 8):

$\sigma$2SP$_{\%Flow}$  =  $\sigma$2SP$_{2\sigma\%Span}$ / 2

=  ± 1.32 % / 2

=  ± 0.66 %

$\sigma$2SP$_{\%Flow}$  =  ± 0.66 %

7.5.1.13  CRD Flow Transmitter Ambient Pressure Error (e2P)

The flow transmitter is an electrical device and therefore not affected by ambient pressure.

e2P  =  0

7.5.1.14  CRD Flow Transmitter Temperature Error (e2T)

Temperature error is considered to be a random variable for a Rosemount transmitter. Therefore

e2T  =  0

7.5.1.15  CRD Flow Loop PPC I/O Module Reference Accuracy (A3)

Reference accuracy of the computer input is taken to be the SRSS of the reference accuracies of the SRU and the I/O module.  The reference accuracy of the SRU is 0.1 % of span.  Reference Accuracy for the I/O module is specified as ± 0.5 % of span (Sections 2.4.4 and 2.4.5).

A3$_{2\sigma}$  =  $\sqrt{0.1^2 + 0.5^2}$ = 0.5099 = 0.51 % span

Converting % span to % flow

Rearranging Equation A8-10, $\sigma_{\Delta P} = 2 * \sigma_{FLOW}$, to solve for flow (Reference Attachment 8):

A3$_{\%Flow}$  =  A3$_{\%Span}$ / 2

=  ± 0.51% / 2

A3$_{\%Flow}$  =  ± 0.255 %

7.5.1.16  CRD Flow Loop PPC I/O Module Humidity Error (e3H)

The manufacturer specifies the I/O module operating humidity limits between 0 and 95 % RH (Section 2.4.4).  The I/O module is located in the Control Room 533, where humidity may vary from

50 to 90 % RH (Reference 4.4.2). Humidity errors are set to zero because they are considered to be included within the reference accuracy specification under these conditions. (Section 3.2)

$$e3H \quad = \quad 0$$

### 7.5.1.17 CRD Flow Loop PPC I/O Module Radiation Error (e3R)

No radiation errors are specified in the manufacturer's specifications. The instrument is located in the Control Room 533, a mild environment [Reference 4.4.2]. Therefore, it is reasonable to consider the normal radiation effect as being included in the reference accuracy. Therefore,

$$e3R \quad = \quad 0$$

### 7.5.1.18 CRD Flow Loop PPC I/O Module Seismic Error (e3S)

No seismic effect errors are specified in the manufacturer's specifications. A seismic event defines a particular type of accident condition. Therefore, there is no seismic error for normal operating conditions (Section 3.5).

$$e3S \quad = \quad 0$$

### 7.5.1.19 CRD Flow Loop PPC I/O Module Static Pressure Offset Error (e3SP)

The I/O module is an electrical device and therefore not affected by static pressure.

$$e3SP \quad = \quad 0$$

### 7.5.1.20 CRD Flow Loop PPC I/O Module Ambient Pressure Error (e3P)

The I/O module is an electrical device and therefore not affected by ambient pressure.

$$e3P \quad = \quad 0$$

### 7.5.1.21 CRD Flow Loop PPC I/O Module Process Error (e3Pr)

The I/O module receives an analog current input from the flow transmitter proportional to the pressure sensed. Any process errors associated with the conversion of pressure to a current signal have been accounted for as errors associated with flow transmitter. Therefore,

$$e3Pr \quad = \quad 0$$

### 7.5.1.22 CRD Flow Loop Accuracy ($LA_{CRD\_Flow}$)

$$LA_{CRD\_Flow} = [(A1)^2 + (e1H)^2 + (e1R)^2 + (e1P)^2 + (e1T)^2 + (e1S)^2 + (e1SP)^2 + (A2)^2 + (\sigma2PS2)^2 + (\sigma2T)^2 + (e2H)^2 + (e2R)^2 + (e2S)^2 + (e2V)^2 + (e2SP)^2 + (e2P)^2 + (e2T)^2 + (A3)^2 + (e3H)^2 + (e3R)^2 + (e3S)^2 + (e3SP)^2 + (e3P)^2 + (e3Pr)^2]^{1/2}$$

$$= [(1)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0.25)^2 + (0)^2 + (0.49)^2 + (0)^2 + (5.0)^2 + (0)^2 + (0)^2 + (0.66)^2 + (0)^2 + (0)^2 + (0.255)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2]^{1/2}$$

$$= \pm [1 + 0 + 0 + 0 + 0 + 0 + 0 + 0.015625 + 0 + 0.2401 + 0 + 25.0 + 0 + 0 + 0.4356 + 0 + 0 + 0.065025 + 0 + 0 + 0 + 0 + 0 + 0]^{1/2}$$

$$= \pm [26.80323]^{1/2}$$

$$= \pm 5.177183\ \%$$

$$LA_{CRD\_Flow} \quad = \pm 5.2\ \%$$

### 7.5.2 CRD Flow Loop Drift ($LD_{CRD\_Flow}$)

### 7.5.2.1 CRD Flow Element Drift Error (D1)

The flow element is a mechanical device; drift error is not applicable for the flow elements. Therefore,

$$D1 \quad = \pm 0.00\%\ Flow$$

**7.5.2.2** CRD Flow Loop Transmitter Drift Error (D2)

**7.5.2.3** CRD Flow Loop Drift Error (D2)

Drift error for the transmitter is ± 0.25 % of URL / 6 months, taken as a random $2\sigma$ value (Section 3.4). The calibration frequency is 2 years, with a late factor of 6 months.

$$D2_{2\sigma} \quad = \quad \pm (0.25\ \% * URL)$$

Drift is applied to the surveillance interval as follows (Section 6.2.5):

$$D2_{2\sigma} \quad = \quad \pm ([(24\ months + 6\ months) / 6\ months] * [0.0025\ URL]^2)^{1/2}$$
$$= \quad \pm ([30/6][0.0025 * 750\ INWC]^2)^{1/2}$$
$$= \quad \pm [17.578125]^{1/2}$$
$$= \quad \pm 4.192627458\ INWC$$

$$D2_{2\sigma} \quad = \quad \pm 4.19\ INWC,\ \text{rounded to level of significance}$$

Converting to % span

$$D2_{\%Span} = \quad \pm 4.19\ INWC / 197.5\ INWC$$
$$= \quad \pm 0.02121 = 2.121\ \%$$

Converting % span to % flow

Rearranging Equation A8-10, $\sigma_{\Delta P} = 2 * \sigma_{FLOW}$, to solve for flow (Reference Attachment 8):

$$D2_{\%Flow} = \quad D2_{\%Span} / 2$$
$$= \quad \pm 2.121\ \% / 2$$
$$= \quad \pm 1.0608\ \%$$

$$D2_{\%Flow} = \quad \pm 1.0\ \%$$

**7.5.2.4** CRD Flow Loop PPC I/O Module Drift Error (D3)

The vendor does not specify a drift error for the I/O module. Therefore, per Ref. 4.1.1 Section I, it is considered to be included in the reference accuracy.

$$D3 \quad = \quad \pm 0$$

**7.5.2.5** CRD Flow Loop Drift ($LD_{RWCU\_Flow}$)

$$LD_{CRD\_Flow} \quad = [(D1)^2 + (D2)^2 + (D3)^2]^{1/2}$$
$$= [(0)^2 + (1.0)^2 + (0)^2]^{1/2}$$
$$= \pm [0 + 1.0 + 0]^{1/2}$$
$$= \pm [1]^{1/2}$$

$$LD_{CRD\_Flow} \quad = \pm 1.0\ \%$$

**7.5.3** CRD Flow Loop Process Measurement Accuracy ($PMA_{CRD\_Flow}$)

No additional PMA effects beyond the effects specified in the calculation of loop accuracy.

$$PMA_{RWCU\_Flow} = 0$$

**7.5.4** CRD Flow Loop Primary Element Accuracy ($PEA_{CRD\_Flow}$)

No additional PEM effects beyond the effects specified in the calculation of loop accuracy.

$$PEA_{RWCU\_Flow} = 0$$

**7.5.5** CRD Flow Loop Calibration Accuracy ($CA_{CRD\_Flow}$)

**Exelon.**

Standard practice is to specify calibration uncertainty in calculations equal to the uncertainty associated with the instruments under test (Section 4.1.1).

Therefore,

$$CA_{RWCU\_Flow} = [(A1)^2 + (A2)^2 + (A3)^2]^{1/2}$$

$$= [(1\ \%)^2 + (0.25\ \%)^2 + (0.255\ \%)^2]^{1/2}$$

$$= [1.25\ \%^2]^{1/2}$$

$$= 1.12753\ \%$$

$$CA_{RWCU\_Flow} = 1.06185\ \% = \text{rounded to } 1.1$$

7.5.6    Total Uncertainty CRD Flow Loop ($TU_{CRD\_Flow}$)

$$TU_{CRD\_Flow} = [(LA)^2 + (LD)^2 + (PMA)^2 + (PEA)^2 + (CA)^2]^{1/2}$$

$$= [(5.2)^2 + (1.0)^2 + (0)^2 + (0)^2 + (1.1)^2]^{1/2}$$

$$= \pm [27.04 + 1 + 0 + 0 + 1.21]^{1/2}$$

$$= \pm [29.25]^{1/2}$$

$$= \pm 5.4083\ \%$$

$$TU_{CRD\_Flow} = \pm 5.4\ \%$$

## 7.6    RECIRCULATION PUMP HEAT UNCERTAINTY

7.6.1.1    Recirculation Pump Motor Power ($Q_P$)

The recirculation pump system consists of two parallel pumps that maintain forced circulation flow loops in the reactor core. The water originates in the core and returns to the core at a higher pressure. The work performed by the recirculation pumps includes the specific work of the pump plus the pump inefficiency. This energy can be estimated by measuring the power consumed by the pump motor and multiplying the pump motor power by the motor efficiency. The maximum design output of the recirculation motor M-G set is 7700 HP, which is monitored by the watts transducer. The 7700 HP is conservatively used in lieu of the motor 7500 HP rated in determining the recirculation pump heat uncertainty.
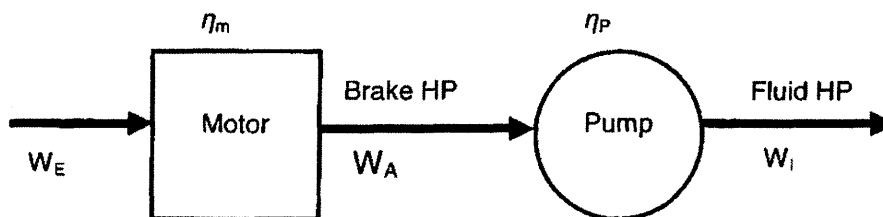


$$\eta_m = \frac{W_A}{W_E}\text{ , motor efficiency;}$$

where $W_A = \eta_m \cdot W_E$ , motor output to pump (brake horsepower (HP))

$$\eta_P = \frac{W_I}{W_A}\text{ , pump efficiency}$$

$W_I$ = ideal work energy input to fluid system (fluid HP)

$W_E$ = electric power input to motor (measured power, Watts)

The difference between the input (actual pump power) and the output (ideal) pump power is the power lost to friction in the pump. The heat added to the pump is due to inefficiency.

$$\text{Heat Added by Pump} = \left( {}^{(1 - \eta_P)}\!\!\Big/_{100} \right) \cdot W_A$$

The calculation of the total recirculation pump heat input, $Q_p$, is taken from Equation 6 (Section 6.2.1.3).

$$Q_P = 2 \cdot \eta_m \cdot W_E \qquad\qquad \text{(Equation 40)}$$

Motor Efficiency, $\eta_m$, is 94.8% at maximum speed of 1690 rpm (Reference 4.8.2)

$\qquad\qquad = \quad$ 2 * 0.948 * 5.74 MW (based on 7,700 Hp motor (Table 2-1)

$\qquad\qquad = \quad$ 10.8866 MW

Multiply by 3,412,000 Btu/hr per MW to convert to Btu/hr

$\qquad\qquad = \quad$ 10.8866 MW * 3,412,000 Btu/hr/MW

$\qquad\qquad = \quad$ 37,145,079 Btu/hr

$Q_P \qquad = \quad$ 37,145,000 Btu/hr, rounded to level of significance

Where, standard conversion factors are:

1 HP = 550 ft-lb$_f$/s

1 ft$^3$ = 7.48 gal

1 W = 3.412 Btu/hr

1 HP = 0.7457 kW

1HP = 2544.43 Btu/hr

### 7.6.2   Recirculation Pump Motor Watt Transducer Loop Uncertainty

### 7.6.2.1   Recirculation Pump Motor Watt Transducer Reference Accuracy (A1)

The accuracy of the transducer is ± 0.2 % of Reading + 0.01 % Rated Output at 0 to 200% of the Rated Output (reference Section 2.5.2).

Maximum error is when the reading is equal to the recirculation pump motor power rating in MW, i.e., 7700 HP (5.74 MW, Reference 4.3.3).

$A1_{2\sigma} = \qquad$ ± (0.2% * 5.74 MW + 0.01% * 10.5 MW)

$\qquad = \quad$ ± 0.01253 MW

$A1_{2\sigma} = \qquad$ ± 0.013 MW, rounded to level of significance

### 7.6.2.2   Recirculation Pump Motor Watt Transducer Power Supply Effects (σ1PS)

Power supply effects are considered to be negligible (Section 3.7). Therefore,

$\sigma1PS \quad = \quad 0$

### 7.6.2.3   Recirculation Pump Motor Watt Transducer Ambient Temperature Error (σ1T)

The Watt Transducer is located in the auxiliary electrical room. This is a controlled environment; therefore, temperature error can be neglected.

$\sigma 1T = 0$

### 7.6.3 Watt Transducer Humidity, Radiation, Pressure, and Temperature Errors (e1H, e1R, e1P, e1T)

The watt transducer is an electrical device and the output is not subject to environmental or vibration effects. Therefore;

$e1H = e1R = e1P = e1T = 0$

### 7.6.3.1 Recirculation Pump Motor Watt Transducer Seismic Error (e1S)

A seismic event is an abnormal operating condition and is not addressed by this calculation. Therefore;

$e1S = 0$

### 7.6.3.2 Recirculation Pump Motor Watt Transducer Static Pressure Error (e1SP)

The watt transducer is an electrical device not affected by process pressure. Therefore;

$e1SP = 0$

### 7.6.3.3 Recirculation Pump Motor Watt Transducer PPC I/O Module Reference Accuracy (A2)

Reference accuracy of the computer input is taken to be the SRSS of the reference accuracies of the SRU and the I/O module. The reference accuracy of the SRU is 0.1 % of span as given in Section 2.5.3. Reference Accuracy for the I/O module is specified as ± 0.5 % of span (Section 2.5.4) and considered to be a 2$\sigma$ value (Section 3.4).

$$A2_{2\sigma} = \sqrt{0.1^2 + 0.5^2} = 0.509901951 = 0.51\ \%$$

$$A2_{2\sigma} = \pm 0.51\% * \text{range}$$

$$A2_{2\sigma} = \pm 0.0051 * 10.5\ \text{MW} = 0.05355\ \text{MW}$$

### 7.6.3.4 Recirculation Pump Motor Watt Transducer PPC I/O Module Humidity Error (e2H)

The manufacturer specifies the I/O module operating humidity limits between 0 and 95 % RH (Section 2.4.4). The I/O module is located in the Control Room 533, where humidity may vary from 50 to 90 % RH (Reference 4.4.2). Humidity errors are set to zero because they are considered to be included within the reference accuracy specification under these conditions. (Section 3.2)

$e2H = 0$

### 7.6.3.5 Recirculation Pump Motor Watt Transducer PPC I/O Module Radiation Error (e2R)

No radiation errors are specified in the manufacturer's specifications. The instrument is located in the Control Room 533, a mild environment (Section 4.4.2). Therefore, it is reasonable to consider the normal radiation effect as being included in the reference accuracy. Therefore,

$e2R = 0$

### 7.6.3.6 Recirculation Pump Motor Watt Transducer PPC I/O Module Seismic Error (e2S)

No seismic effect errors are specified in the manufacturer's specifications. A seismic event defines a particular type of accident condition. Therefore, there is no seismic error for normal operating conditions (Section 3.5).

$e2S = 0$

### 7.6.3.7 Recirculation Pump Motor Watt Transducer PPC I/O Module Static Pressure Offset Error (e2SP)

The I/O module is an electrical device and therefore not affected by static pressure.

$e2SP = 0$

**7.6.3.8  Recirculation Pump Motor Watt Transducer PPC I/O Module Ambient Pressure Error (e2P)**

The I/O module is an electrical device and therefore not affected by ambient pressure.

$$e2P = 0$$

**7.6.3.9  Recirculation Pump Motor Watt Transducer PPC I/O Module Process Error (e2P)r**

Any process errors associated with the conversion of pressure to a current signal have been accounted for as errors associated with Watt Transducer. Therefore,

$$e2Pr = 0$$

**7.6.3.10  Recirculation Pump Motor Watt Transducer Loop Accuracy (LA$_P$)**

$$LA_P = \pm [(A1)^2 + (\sigma 1PS)^2 + (\sigma 1T)^2 + (e1H)^2 + (e1R)^2 + (e1P)^2 + (e1T)^2 + (e1S)^2 + (e1SP)^2 + (A2)^2 + (e2H)^2 + (e2R)^2 + (e2S)^2 + (e2SP)^2 + (e2P)^2 + (e2Pr)^2]^{1/2}$$

$$= \pm [(0.013)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0.05355)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0)]^{1/2}$$

$$= \pm [0.000169 + 0 + 0 + 0 + 0 + 0 + 0 + 0 + 0 + 0.002867603 + 0 + 0 + 0 + 0 + 0 + 0]^{1/2}$$

$$= \pm [0.003036603 \, MW^2]^{1/2}$$

$$= \pm 0.055105376 \, MW$$

$$LA_P = \pm 0.055 \, MW$$

**7.6.4  Recirculation Pump Motor Watt Transducer Loop Drift (LD$_P$)**

**7.6.4.1  Recirculation Pump Motor Watt Transducer Drift Error (D1)**

The drift will be considered random and independent over time.  The surveillance frequency is 30 months; therefore, drift error follows Equation 39 (Section 6.2.5 and reference 2.5.2).

$$D1 = \pm 0.1\% \text{ of RO per year}$$

$$= [(30/12) \cdot (\pm 0.1\% \, RO)^2]^{1/2}$$

$$= [2.5 \cdot 0.00011025 \, MW^2]^{1/2}$$

$$= 0.016601958 \, MW$$

$$D1 = 0.017 \, MW, \text{ rounded to level of significance}$$

**7.6.4.2  Recirculation Pump Motor Watt Transducer PPC I/O Module Drift Error (D2)**

The vendor does not specify a drift error for the I/O module.  Therefore, per Ref. 4.1.1 Section I, it is considered to be included in the reference accuracy.

$$D2 = \pm 0$$

**7.6.4.3  Recirculation Pump Motor Watt Transducer Loop Drift (LD$_{RWCU\_Flow}$)**

$$LD_P = \pm [(D1)^2 + (D2)^2]^{1/2}$$

$$= \pm [(0.017)^2 + (0)^2]^{1/2}$$

$$LD_P = \pm 0.017 \, MW$$

**7.6.5  Recirculation Pump Motor Watt Transducer Process Measurement Accuracy (PMA$_P$)**

No additional PMA effects beyond the effects specified in the calculation of loop accuracy.

$$PMA_P = 0$$

**7.6.6  Recirculation Pump Motor Watt Transducer Primary Element Accuracy (PEA$_P$)**

No additional PEM effects beyond the effects specified in the calculation of loop accuracy.

$PEA_P = 0$

### 7.6.7    Recirculation Pump Motor Watt Transducer Loop Calibration Accuracy (CA_P)

Standard practice is to specify calibration uncertainty in calculations equal to the uncertainty associated with the instruments under test.

Therefore,

$$CA_P = \pm [(A1)^2 + (A2)^2]^{1/2}$$
$$= \pm [(0.013)^2 + (0.05355)^2]^{1/2}$$
$$= \pm [0.000169 + 0.002867603]^{1/2}$$
$$= \pm [0.003036603]^{1/2}$$
$$= \pm 0.055105376$$
$$CA_P = \pm 0.055 \text{ MW}$$

### 7.6.8    Total Uncertainty Recirculation Pump Motor Watt Transducer Loop (TU_P)

$$TU_P = \pm [(LA)^2 + (LD)^2 + (PMA)^2 + (PEA)^2 + (CA)^2]^{1/2}$$
$$= \pm [(0.055)^2 + (0.017)^2 + (0)^2 + (0)^2 + (0.055)^2]^{1/2}$$
$$= \pm [0.003025 + 0.000289 + 0 + 0 + 0.003025]^{1/2}$$
$$= \pm [0.006339]^{1/2}$$
$$= \pm 0.079617837 \text{ MW}$$

Converting to % motor power

$$TU_P = \pm 0.08 \text{ MW} / 5.74 \text{ MW}$$
$$= \pm 0.013937282$$
$$= \pm 1.4 \%$$

## 7.7    DETERMINATION OF CTP UNCERTAINTY

### 7.7.1    Numerical Solutions for the Partial Derivative Terms

Solutions are found in two parts by first substituting values into Equations 20 through 27, as shown.

$$\frac{\partial CTP}{\partial W_{FW}} = \left(h_G \left(P_S\right) - h_F \left(T_{FW}\right)\right)$$

$$= \left(h_G \left(1043 \text{ psig}\right) - h_F \left(430.8 \text{ °F}\right)\right) \text{ Btu/lbm}$$

(Reference Equation 20)

$$= (1191.1 - 409.71) \text{ Btu/lbm}$$

$$= 781.39 \text{ Btu/lbm}$$

$$\frac{\partial CTP}{\partial h_G (P_S)} = W_{FW} = 15,090,000 \text{ lbm/hr}$$    (Reference Equation 21)

$$\frac{\partial CTP}{\partial h_F(T_{FW})} = -W_{FW} = -15,090,000 \text{ lbm/hr} \qquad \text{(Reference Equation 22)}$$

$$\frac{\partial CTP}{\partial Q_{CRD\_OUT}} = 1 \qquad \text{(Reference Equation 23)}$$

$$\frac{\partial CTP}{\partial Q_{CRD\_IN}} = -1 \qquad \text{(Reference Equation 24)}$$

$$\frac{\partial CTP}{\partial Q_{RAD}} = 1 \qquad \text{(Reference Equation 25)}$$

$$\frac{\partial CTP}{\partial Q_{RWCU}} = 1 \qquad \text{(Reference Equation 26)}$$

$$\frac{\partial CTP}{\partial Q_P} = -1 \qquad \text{(Reference Equation 27)}$$

## 7.7.2    Component Uncertainty Terms

The component uncertainty terms, $u_c$, are found by substituting values into Equations 31, 33 through 37, as shown.

### 7.7.2.1    Feedwater Mass Flowrate Uncertainty

$$\sigma_{W_{FW}} = 48,288 \text{ lbm/hr} \quad \text{(Section 7.1)}$$

### 7.7.2.2    Steam Enthalpy Uncertainty

$$\sigma_{h_G}(P_S, I_o) = \left(\frac{\Delta h_G(P_S)}{\Delta P_S}\right)^2 * \sigma_P{}^2 + \left(\frac{\Delta h_G(I_o)}{\Delta I_o}\right)^2 * \sigma_{I_o}{}^2 \qquad \text{(Reference Equation 31)}$$

The nominal steam dome pressure is evaluated at 1043 psig (Reference 4.8.8) with an uncertainty of ± 20 psig (Section 7.2). Steam table interpolation error is taken to be one-half of the least significant figure shown, i.e., ± 0.05 Btu/lbm.

$$\sigma_{h_G}(P_S, I_o) = \sqrt{\begin{array}{l} \left(\dfrac{h_G(1063) - h_G(1023)}{1063 - 1023}\right)^2 \left(\dfrac{Btu/lbm}{psi}\right)^2 * (20\ psi)^2 + \\[3mm] \left(\dfrac{[h_G(1190.3) + 0.05] - [h_G(1191.9) - 0.05]}{0.05 - (-0.05)}\right)^2 \left(\dfrac{Btu/lbm}{\dfrac{Btu}{hr}}\right)^2 * \left(0.05\dfrac{Btu}{hr}\right)^2 \end{array}}$$

$$= \sqrt{\begin{array}{l} \left(\dfrac{1190.3 - 1191.9}{1063 - 1023}\right)^2 \left(\dfrac{Btu/lbm}{psi}\right)^2 * (20\ psi)^2 + \\[3mm] \left(\dfrac{1191.2 - 1191.1}{0.05 + 0.05}\right)^2 \left(\dfrac{Btu/lbm}{\dfrac{Btu}{hr}}\right)^2 * \left(0.05\dfrac{Btu}{hr}\right)^2 \end{array}}$$

$$= \sqrt{\begin{array}{l} \left(\dfrac{-1.60}{40}\right)^2 \left(\dfrac{Btu/lbm}{psi}\right)^2 * (20\,psi^2) + \\[3mm] \left(\dfrac{0.1}{0.1}\right)^2 \left(\dfrac{Btu/lbm}{\dfrac{Btu}{hr}}\right)^2 * \left(0.05\dfrac{Btu}{hr}\right)^2 \end{array}}$$

$$= \sqrt{0.064\frac{Btu^2}{lbm^2} + 0.0025\frac{Btu^2}{lbm^2}}$$

$$= 0.80156\frac{Btu}{lbm}$$

$\sigma_{h_G}(P_S, I_o) = 0.802\ \dfrac{Btu}{lbm}$ , rounded to the inherent uncertainty of the steam table.

### 7.7.2.3  Feedwater Enthalpy Uncertainty

$$\sigma_{h_F}(T_{FW}, P_{FW}, I_o) = \sqrt{\left(\frac{\Delta h_F(T)}{\Delta T}\right)^2 \cdot \sigma_T{}^2 + \left(\frac{\Delta h_F(P)}{\Delta P}\right)^2 * \sigma_P{}^2 + \left(\frac{\Delta h_F}{\Delta I_o}\right)^2 \cdot \sigma_{I_o}{}^2} \quad \text{(Reference Equation 33)}$$

From Table 2-1, feedwater pressure is given as 1155 ± 10 psig.  From Table 2-1, feedwater temperature is given as 430.8 ± 0.57 °F.  Enthalpy of water is from Attachment 6.  Steam table interpolation error is taken to be one-half of the least significant figure shown, i.e., ± 0.005 Btu/lbm.

$$\sigma_{h_F}(T_{FW}, P_{FW}, I_o) = \sqrt{\begin{array}{l} \left(\dfrac{h_F(431.37) - h_F(430.23)}{431.37 - 430.23}\right)^2 \left(\dfrac{Btu/lbm}{^\circ F}\right)^2 * (0.57\,^\circ F)^2 + \\[4mm] \left(\dfrac{h_F(1165) - h_F(1145)}{1165 - 1145}\right)^2 \left(\dfrac{Btu/lbm}{psi}\right)^2 * (10\,psi)^2 + \\[4mm] \left(\dfrac{[h_F(430.8) + 0.005] - [h_F(430.8) - 0.005]}{0.005 - (-0.005)}\right)^2 \left(\dfrac{Btu/lbm}{\frac{Btu}{lbm}}\right)^2 * \left(0.005\,\dfrac{Btu}{lbm}\right)^2 \end{array}}$$

$$= \sqrt{\begin{array}{l} \left(\dfrac{410.33 - 409.08}{431.37 - 430.23}\right)^2 \left(\dfrac{Btu/lbm}{^\circ F}\right)^2 * (0.57\,^\circ F)^2 + \\[4mm] \left(\dfrac{409.71 - 409.70}{1165 - 1145}\right)^2 \left(\dfrac{Btu/lbm}{psi}\right)^2 * (10\,psi)^2 + \\[4mm] \left(\dfrac{409.72 - 409.71}{0.005 + 0.005}\right)^2 \left(\dfrac{Btu/lbm}{\frac{Btu}{lbm}}\right)^2 * \left(0.005\,\dfrac{Btu}{lbm}\right)^2 \end{array}}$$

$$= \sqrt{\begin{array}{l} \left(\dfrac{1.25}{1.14}\right)^2 \left(\dfrac{Btu/lbm}{^\circ F}\right)^2 * (0.57\,^\circ F)^2 + \\[4mm] \left(\dfrac{0.01}{20}\right)^2 \left(\dfrac{Btu/lbm}{psi}\right)^2 * (10\,psi)^2 + \\[4mm] \left(\dfrac{0.01}{0.01}\right)^2 \left(\dfrac{Btu/lbm}{\frac{Btu}{lbm}}\right)^2 * \left(0.005\,\dfrac{Btu}{lbm}\right)^2 \end{array}}$$

$$\approx \sqrt{0.39063\,\frac{Btu^2}{lbm^2} + 0.00002\,\frac{Btu^2}{lbm^2} + 0.00002\,\frac{Btu^2}{lbm^2}}$$

$$= 0.62504000\,\frac{BTU}{lbm}$$

$$\sigma_{h_F}(T_{FW}, P_{FW}, I_o) = 0.625\,\frac{BTU}{lbm}$$ , rounded to the inherent uncertainty of the steam table.

The accuracy of the temperature measurement determines the feedwater enthalpy uncertainty. Variations in pressure and steam table interpolation are negligible.

### 7.7.2.4  Control Rod Drive Outlet Energy Uncertainty

The control rod drive outlet energy uncertainty is dominated by the uncertainty of the mass flow rate. The steam table interpolation error is negligible and is not used in the following computation. CRD flow rate uncertainty, $x_{CRD}$, is 5.4 % of flow (Section 7.5.6).

The variation in $h_f$ is shown below.

$$\sigma_{hf}(T_{CRD}) = \sqrt{\left(\frac{hf(100.7) - hf(99.3)}{100.7 - 99.3}\right)^2 \left(\frac{Btu/lbm}{°F}\right)^2 *(0.7°F)^2 + \left(\frac{hf(1458) - hf(1438)}{1458 - 1438}\right)^2 \left(\frac{Btu/lbm}{°F}\right)*(10\,psi)^2}$$

$$\sqrt{\left(\frac{(72.63) - (71.24)}{100.7 - 99.3}\right)^2 \left(\frac{Btu/lbm}{°F}\right)^2 *(0.7°F)^2 + \left(\frac{(71.96) - (71.91)}{1458 - 1438}\right)^2 \left(\frac{Btu/lbm}{°F}\right)*(10psi)^2}$$

$$\sqrt{\left(\frac{(1.39)}{140}\right)^2 \left(\frac{Btu/lbm}{°F}\right)^2 *(0.7°F)^2 + \left(\frac{(0.05)}{20}\right)^2 \left(\frac{Btu/lbm}{°F}\right)*(10psi)^2}$$

$$= \sqrt{0.483025\,Btu^2/lbm^2 + 0.000676\,Btu^2/lbm^2}$$

$$= \sqrt{0.4837401\,Btu^2/lbm^2}$$

$$= 0.69549 \text{ Btu/lbm, rounded } 0.70 \text{ Btu/lbm}$$

Converting $\sigma_{hf}$ to % of $h_f$

$= \pm 0.70$ Btu/lbm / 71.93 Btu/lbm

$= \pm 0.00973 = 0.97$ %

The SRSS method is used to combine the flow rate and enthalpy uncertainty terms.

$x_{CRD\_OUT}$ % $= \sqrt{5.4^2 + 0.97^2} = \sqrt{30.1009} = 5.486429$ % = 6 %, conservatively rounded up

$\sigma_{Q_{CRD\_OUT}}$ $= x_{CRD\_OUT}$ % $\cdot Q_{CRD\_OUT}$  (Reference Equation 34)

$= 6$ % * $h_G(1043$ psig) * $w_{CRD}$

$= 6$ % * 1191.1 Btu/lbm * 105 gal/min * 60 min/hr * 62.265 lbm/ft$^3$ / 7.48 gal/ft3

$= 3,747,851.883$ Btu/hr

$= 3,748,000$ Btu/hr, rounded to level of significance

7.7.2.5    Control Rod Drive Inlet Energy Uncertainty

The control rod drive inlet energy uncertainty is dominated by the uncertainty of the mass flow rate. CRD flow rate uncertainty, $x_{CRD}$, is 6 %, which was conservatively rounded up from 5.5%, of flow (Section 7.7.2.4).  CRD normal operating temperature and pressure is 100 °F and 1448 psig (Section 4.4.1).

$$\sigma_{Q_{CRD\_IN}} = x_{CRD\_IN} \% \cdot Q_{CRD\_IN} \qquad \text{(Reference Equation 35)}$$

$$= 6 \% * h_f(100\ °F\ at\ 1448\ psig) * w_{CRD}$$

$$= 6 \% * 71.93\ Btu/lbm * 105\ gal/min * 60\ min/hr * 62.265\ lbm/ft^3 / 7.48\ gal/ ft^3$$

$$= 226{,}331.111\ Btu/hr$$

$$= 226{,}000\ Btu/hr,\ \text{rounded to level of significance}$$

7.7.2.6    Reactor Pressure Vessel Heat Loss Uncertainty

The determination of reactor heat loss was done in Reference 4.8.3 for both Unit 1 and Unit 2.  The Unit 1 heat loss was calculated to be 0.89 MWt.  The Unit 2 heat loss was calculated to be 1.04 MWt.  A conservative variance of 10 % of the heat loss rate is used to estimate the heat loss uncertainty.

$$\sigma_{Q_{RAD}} = x_{RAD} \% \cdot Q_{RAD} \qquad \text{(Reference Equation 36)}$$

$$= 10 \% * 0.89\ MWt * 3{,}412{,}000\ Btu/hr / MWt$$

$$= 303{,}668\ Btu/hr$$

7.7.2.7    RWCU Heat Removal Uncertainty

The RWCU flow loop uncertainty is ± 2.3 % of flow (Section 7.3.6).  The RWCU temperature measurement uncertainty is ± 4.37 °F (Section 7.4.6).  The variation in enthalpy over the range of temperatures in this loop of about 0.5 % is negligible compared to the 2.3 % flow variation.  RWCU normal operating temperatures and pressures are 530 °F and 1060 psig (RWCU suction) and 438 °F and 1168 psig (RWCU discharge) (Reference 4.4.1).  Temperature values of 530 °F (suction) and 440 °F (discharge) are used to be more in line with actual measurements.

$x_{RWCU}$ is set 2.3 % based on the flow loop uncertainty.

$$\sigma_{Q_{RWCU}} = x_{RWCU} \% \cdot Q_{RWCU} \qquad \text{(Reference Equation 37)}$$

Remembering that $Q_{RWCU} = w_{RWCU} * [h_F(T_{Recirc\_in}) - h_F(T_{FW})]$ (See Equation 9)

$$\sigma_{Q_{RWCU}} = 2.3 \% \cdot w_{RWCU} \cdot [h_f(T_{RECIRC\_IN}) - h_f(T_{FW})]$$

$$w_{RWCU} = 154{,}000\ \frac{lbm}{hr}\ (Pump\ A)\ and\ 133{,}000\ \frac{lbm}{hr}\ (Pump\ B\ and\ C) \qquad \text{(Section 2.2.1)}$$

Maximum heat removal occurs with Pump A running , therefore, $w_{RWCU} = 154{,}000\ lbm/hr$.

$$h_f(T_{RECIRC\_IN}) = 524.39 \frac{Btu}{lbm} \text{ (at 530 °F and 1060 psig)}$$

$$h_f(T_{FW}) = 419.83 \frac{Btu}{lbm} \text{ (at 440 °F and 1168 psig)}$$

$$\sigma_{Q_{RWCU}} = 2.3\% \cdot 154{,}000 \frac{lbm}{hr} \cdot (524.39 - 419.83)\frac{Btu}{lbm} = 370{,}352 \text{ Btu/hr}$$

$$= 370{,}400 \text{ Btu/hr, rounded to level of significance}$$

### 7.7.2.8 Recirculation Pump Heat Addition Uncertainty

The power of the recirculation pumps ($W_E$) is measured by a watt-meter with a calculated uncertainty of 1.4 % (Section 7.6.8).

$$X_P = \pm 1.4 \%$$

The uncertainty of the power measurement multiplied by the pump power, $Q_P$, is the uncertainty of the pump power, $\sigma_{QP}$. $Q_P$ is 37,145,000 Btu/hr (Section 7.6.1.1).

$$\sigma_{Q_P} = \pm X_P \% \cdot Q_P \qquad \text{(See Equation 38)}$$
$$= \pm 1.4\% * 37{,}145{,}000 \text{ Btu/hr}$$
$$= \pm 520{,}030 \text{ Btu/hr}$$

$$\sigma_{Q_P} = \pm 520{,}000 \text{ Btu/hr, rounded to level of significance}$$

## 7.8 TOTAL CTP UNCERTAINTY CALCULATION

Total CTP uncertainty, $U_{CTP}$, is calculated by using Equations 19, 20 through 27, 28, 31, 33, and 34 through 37.

(Reference Equation 19)

$$U_{CTP} = \left[ \begin{array}{l} \left[\left(\left|\frac{\partial CTP}{\partial W_{FW}}\right|\right)^2 * \left(\sigma_{W_{FW}}\right)^2\right] + \left[\left(\left|\frac{\partial CTP}{\partial h_G(P_S)}\right|\right)^2 * \left(\sigma_{h_G(P_S)}\right)^2\right] + \\[2ex] \left[\left(\left|\frac{\partial CTP}{\partial h_F(T_{FW})}\right|\right)^2 * \left(\sigma_{h_F(T_{FW})}\right)^2\right] + \left[\left(\left|\frac{\partial CTP}{\partial Q_{CRD\_OUT}}\right|\right)^2 * \left(\sigma_{Q_{CRD\_OUT}}\right)^2\right] + \\[2ex] \left[\left(\left|\frac{\partial CTP}{\partial Q_{CRD\_IN}}\right|\right)^2 * \left(\sigma_{Q_{CRD\_IN}}\right)^2\right] + \left[\left(\left|\frac{\partial CTP}{\partial Q_{RAD}}\right|\right)^2 * \left(\sigma_{Q_{RAD}}\right)^2\right] + \\[2ex] \left[\left(\left|\frac{\partial CTP}{\partial Q_{RWCU}}\right|\right)^2 * \left(\sigma_{Q_{RWCU}}\right)^2\right] + \left[\left(\left|\frac{\partial CTP}{\partial Q_P}\right|\right)^2 * \left(\sigma_{Q_P}\right)^2\right] \end{array} \right]^{1/2}$$

$$\frac{\partial CTP}{\partial w_{FW}} = \left(h_G\left(P_S\right) - h_F\left(T_{FW}\right)\right)$$ (Reference Equation 20)

$$\frac{\partial CTP}{\partial h_G(P_S)} = w_{FW}$$ (Reference Equation 21)

$$\frac{\partial CTP}{\partial h_F(T_{FW})} = -w_{FW}$$ (Reference Equation 22)

$$\frac{\partial CTP}{\partial Q_{CRD\_OUT}} = 1$$ (Reference Equation 23)

$$\frac{\partial CTP}{\partial Q_{CRD\_IN}} = -1$$ (Reference Equation 24)

$$\frac{\partial CTP}{\partial Q_{RAD}} = 1$$ (Reference Equation 25)

$$\frac{\partial CTP}{\partial Q_{RWCU}} = 1$$ (Reference Equation 26)

$$\frac{\partial CTP}{\partial Q_P} = -1$$ (Reference Equation 27)

Substituting the previously determined values for the variables shown gives:

$$u_{CTP} = \left[ \begin{array}{l} \left(\left(\left|781.39\frac{Btu}{lbm}\right|\right)^2 * \left(48{,}288\,\frac{lbm}{hr}\right)^2\right) + \left(\left(\left|15{,}090{,}000\frac{lbm}{hr}\right|\right)^2 * \left(0.802\,\frac{Btu}{lbm}\right)^2\right) + \\[2mm] \left(\left(\left|-15{,}090{,}000\frac{lbm}{hr}\right|\right)^2 * \left(0.625\frac{Btu}{lbm}\right)^2\right) + \left(\left(|1|\right)^2 * \left(3{,}748{,}000\frac{Btu}{hr}\right)^2\right) + \\[2mm] \left(\left(|-1|\right)^2 * \left(226{,}000\,\frac{Btu}{hr}\right)^2\right) + \left(\left(|1|\right)^2 * \left(303{,}668\frac{Btu}{hr}\right)^2\right)^2 + \\[2mm] \left(\left(|1|\right)^2 * \left(370{,}400\frac{Btu}{hr}\right)^2\right) + \left(\left(|1|\right)^2 * \left(520{,}000\frac{Btu}{hr}\right)^2\right) \end{array} \right]^{1/2}$$

$$u_{CTP} = \left[ \begin{array}{l} \left(610{,}570\,\frac{Btu}{lbm^2}^2 * 2.3317 \times 10^9\,\frac{lbm^2}{hr^2}\right) + \left(2.2771 \times 10^{14}\,\frac{lbm}{hr^2}^2 * 0.6432\frac{Btu}{lbm^2}^2\right) + \\[2mm] \left(2.27710 \times 10^{14}\,\frac{lbm}{hr^2}^2 * 0.3906\,\frac{Btu}{lbm^2}^2\right) + \left(1 * 1.4048 \times 10^{13}\,\frac{Btu}{hr^2}^2\right) + \\[2mm] \left(1 * 5.1076 \times 10^{10}\,\frac{Btu}{hr^2}^2\right) + \left(1 * 9.2210 \times 10^{10}\,\frac{Btu}{hr^2}^2\right) + \\[2mm] \left(1 * 1.3700 \times 10^{11}\,\frac{Btu^2}{hr^2}\right) + \left(1 * 2.7040 \times 10^{11}\,\frac{Btu^2}{hr^2}\right) \end{array} \right]^{1/2}$$

$$u_{CTP} = \sqrt{\begin{array}{l} \left(1.4237 \times 10^{15} \frac{Btu^2}{hr^2}\right) + \left(1.4646 \times 10^{14} \frac{Btu^2}{hr^2}\right) + \\ \left(8.8940 \times 10^{13} \frac{Btu^2}{hr^2}\right) + \left(1.4048 \times 10^{13} \frac{Btu^2}{hr^2}\right) + \\ \left(5.1080 \times 10^{10} \frac{Btu^2}{hr^2}\right) + \left(9.2210 \times 10^{10} \frac{Btu^2}{hr^2}\right) + \\ \left(1.3700 \times 10^{11} \frac{Btu^2}{hr^2}\right) + \left(2.7040 \times 10^{11} \frac{Btu^2}{hr^2}\right) \end{array}}$$

$$u_{CTP} = \sqrt{1.6740 \times 10^{15} \frac{Btu^2}{hr^2}}$$

$$= 40{,}914{,}572 \frac{Btu}{hr}$$

$$u_{CTP} = 40{,}910{,}000 \frac{Btu}{hr}, \text{ rounded to level of significance}$$

Divide $U_{CTP}$ by 3,412,000 Btu/hr to convert units to megawatts thermal (MWt)

$$u_{CTP} = \frac{40{,}910{,}000 \frac{Btu}{hr}}{3{,}412{,}000 \frac{\frac{Btu}{hr}}{MWt}}$$

$u_{CTP} = 11.99138$ MWt $= 11.99$ MWt, rounded

Divide $U_{CTP}$ by 3,458 Btu/hr to convert to percent of rated reactor thermal power.

$$u_{CTP} = \frac{11.99 \text{ MWt}}{3{,}458 \text{MWt}} \cdot 100\%$$

$u_{CTP} = 0.347 \%$

The determination of total CTP uncertainty is sensitive to two measured parameters, feedwater mass flowrate measurement uncertainty and feedwater temperature measurement uncertainty.

**8.0** <u>**CONCLUSIONS**</u>

The total uncertainty associated with reactor core thermal power calculation performed by the Plant Process Computer is 0.347 % of rated reactor thermal power ($2\sigma$).

Measurement Uncertainty Recapture (MUR) is based on the Nuclear Regulatory Commission (NRC) amended 10CFR50, Appendix K "Emergency Core Cooling System Evaluation Models" on June 1, 2000. The original regulation did not require the power measurement uncertainty be demonstrated, but rather mandated a 2% margin. The new rule allows licensees to justify a smaller margin for power measurement uncertainty based on the installed highly accurate feedwater flow measurement instrumentation.

Therefore, the Core Thermal Power (CTP) uncertainty of 0.347% allows the original 2% margin to be reduced to 1.653 % (2.0 % - 0.347 % = 1.653 %), which is conservatively rounded down to 1.65%.

## 9.0 ATTACHMENTS

## Attachment 1
Telecon URS and TemTex Accuracy of RTDs for TE-046-103

### Shah, Pravin

| | |
|---|---|
| From: | Pehush, John |
| Sent: | Friday, September 25, 2009 9:58 AM |
| To: | Kimura, Stephen; Shah, Pravin |
| Cc: | Oconnor, John; Low, Richard |
| Subject: | CRD Drive Water Discharge Temperature |

Pravin:

CRD Drive Water Discharge Temperature is measured by TE-046-103 (Unit 2 TE-046-203), which is supplied by:

TemTex Temperature Systems, Inc.
700 E. Houston St.
Sherman, TX 75090
Phone: (903) 813-1500
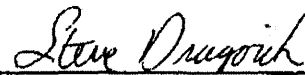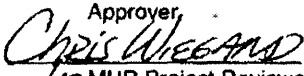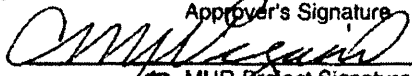
Per telecom between John Pehush and TemTex application engineering on 09/24/09, the RTDs supplied to Limerick Unit 1 are 100 ohm platinum. The model number 10457-8785 specified in PIMS is the TemTex drawing number. The RTD was manufactured to the industry standard IEC-751, which means the accuracy is + /- 0.12% (of resistance) at 0°C, commonly known as Class B. Therefore the RTD will provide an accuracy of + /- 0.3°C at 0°C (+/- 0.54°F at 32°F). The "Temperature Coefficient of Resistance" (TCR), as so called the ALPHA, is the average increase in resistance per degree increase. The TCR of a platinum RTD is 0.00385 $\Omega/\Omega/C°$.

The range of TE-046-103 is 0 to 200°F (-17.78 to 93.33°C). The overall accuracy is conservatively calculated at 93.33°C (200°F), which is +/- 0.359°C (+/- 0.65°F). Therefore, temperature accuracy of TE-046-103 used is rounded to +/- 0.7°F.

John E. Pehush, P.E.
Washington Group URS
Supervising Discipline Engineer - I&C
(609) 720-2274 w
(609) 216-1392 c
John.Pehush@wgint.com

1

**Attachment 2**
TODI A1695446-80I - Steam Carryover Fraction Design Input (1 page)

| EXELON TRANSMITTAL OF DESIGN INFORMATION | | |
|---|---|---|
| ☐SAFETY-RELATED<br>☒NON-SAFETY-RELATED<br>☐REGULATORY RELATED | Originating Organization<br>☒Exelon<br>☐Other (specify) | Tracking No:<br><br>A1695446-80 |
| Station/Unit(s) Limerick Units 1 & 2 | | Page 1 of 1 |
| | | To: John Pehush<br>WGI - Mid Atlantic |

Subject: Transmittal of information.

| | | |
|---|---|---|
| Steve Dragovich<br>Preparer | _Steve Dragovich_<br>Preparer's Signature | 11/25/09<br>Date |
| Chris Wiegand<br>Approver<br>_Chris Wiegand_ | _signature_<br>Approver's Signature | 11/25/09<br>Date |
| MUR Project Reviewer<br>For Quality/Completeness | MUR Project Signature | 11/25/09<br>Date |

Status of Information:  ☒Approved for Use          ☐Unverified

**Description of Information:**

The following information was requested by URS Washington Division (WGI) for input to Limerick's core thermal power (CTP) uncertainty calculations (units 1 & 2).

The steam carryover fraction that should be used as design input to the calculations is zero.

**Purpose of Issuance and Limitations on Use:** This information is being supplied solely for the use as design input for the Limerick CTP uncertainty calculations (units 1 & 2).

**Source Documents:**
G.E. Document "Impact of Steam Carryover Fraction on Process Computer Heat Balance Calculations", September 2001.

Distribution:
Original: Limerick file
CC: Ray George, Electrical Design Manager, Limerick
John Pehush, I&C Lead, WGI – Mid Atlantic

## Attachment 3
Rosemount Nuclear Instruments customer letter to Grand Gulf (2 pages)

## Rosemount Nuclear Instruments

Rosemount Nuclear Instruments, inc.
12001 Technology Drive
Eden Prairie MN 55344 USA
Tel 1 (612) 828-8252
Fax 1 (612) 828-8280

4 April 2000

Ref: Grand Gulf Nuclear Station message on INPO plant reports, subject Rosemount Instrument Setpoint Methodology, dated March 9, 2000

Dear Customer:

This letter is intended to eliminate any confusion that may have arisen as a result of the reference message from Grand Gulf. The message was concerned with statistical variation associated with published performance variables and how the variation relates to the published specifications in Rosemount Nuclear Instruments, Inc.(RNII) pressure transmitter models 1152, 1153 Series B, 1153 Series D, 1154 and 1154 Series H. According to our understanding, the performance variables of primary concern are those discussed in GE Instrument Setpoint Methodology document NEDC 31336, namely

1. Reference Accuracy
2. Ambient Temperature Effect
3. Overpressure Effect
4. Static Pressure Effects
5. Power Supply Effect

It is RNII's understanding that GE and the NRC have accepted the methodology of using transmitter testing to insure specifications are met as a basis for confirming specifications are $+3\sigma$. The conclusions we draw regarding specifications being $+3\sigma$ are based on manufacturing testing and screening, final assembly acceptance testing, periodic (e.g., every 3 months) audit testing of transmitter samples and limited statistical analysis. Please note that all performance specifications are based on zero-based ranges under reference conditions. Finally, we wish to make clear that no inferences are made with respect to confidence levels associated with any specification.

1. **Reference Accuracy**.

    All (100%) RNII transmitters, including models 1152, 1153 Series B, 1153 Series D, 1154 and 1154 Series H, are tested to verify accuracy to $\pm0.25\%$ of span at 0%, 20%, 40%, 60%, 80% and 100% of span. Therefore, the reference accuracy published in our specifications is considered $+3\sigma$.

2. **Ambient Temperature Effect**

    All (100%) amplifier boards are tested for compliance with their temperature effect specifications prior to final assembly. All sensor modules, with the exception of model 1154, are temperature compensated to assure compliance with their temperature effect specifications. All (100%) model 1154, model 1154 Series H and model 1153 gage and absolute pressure transmitters are tested following final assembly to verify compliance with specification. Additionally, a review of audit test data performed on final assemblies of model 1152 and model 1153 transmitters not tested following final assembly indicate

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conformance to specification. Therefore, the ambient temperature effect published in our specifications is considered +3σ.

3.  **Overpressure Effect**

    Testing of this variable is done at the module stage. All (100%) range 3 through 8 sensor modules are tested for compliance to specifications. We do not test range 9 or 10 modules for overpressure for safety reasons. However, design similarity permits us to conclude that statements made for ranges 3 through 8 would also apply to ranges 9 and 10. Therefore, the overpressure effect published in our specifications is considered +3σ.

4.  **Static Pressure Effects**
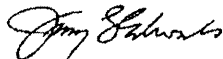
    All (100%) differential pressure sensor modules are tested for compliance with static pressure zero errors. Additionally, Models 1153 and 1154 Ranges 3, 6,7 and 8 are 100% tested after final assembly for added assurance of specification compliance. Audit testing performed on ranges 4 and 5 have shown compliance to the specification. Therefore, static pressure effects published in our specifications are considered +3σ.

5.  **Power Supply Effect**

    Testing for conformance to this specification is performed on all transmitters undergoing sample (audit) testing. This variable has historically exhibited extremely small performance errors and small standard deviation (essentially a mean error of zero with a standard deviation typically less than 10% of the specification). All transmitters tested were found in compliance with the specification. Therefore, power supply effect published in our specifications is considered +3σ.

Should you have any further questions, please contact Jerry Edwards at (612) 828-3951.

Sincerely,

*Jerry Edwards*

Jerry L. Edwards
Manager, Sales, Marketing and Contracts
Rosemount Nuclear Instruments, Inc.

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**Attachment 4**
Analogic Analog Input Card ANDS5500 (4 pages)

# ANALOGIC®

PEABODY, MA 01960

| POTENTIOMETER INPUT CARD ANDS5500 SPECIFICATION | | |
|---|---|---|
| **2-15227    REV 01** | | |
| First Used On: ANDS5500 | | Page 1 of 8 |
| Code Ident: 1BM00 | File Name: 2-15227rev01.doc | Printed:   April 4, 2003 |

## REVISION HISTORY

| REV | DESCRIPTION | DWN | APVD | DATE |
|---|---|---|---|---|
| 01 | SEE E.C.O | K.Q | RWA | 08/25/83 |
| | | | | |

## Approvals for Release:

| Richard Lane | 2/13/03 |
|---|---|
| Originator | Date |

| Richard Lane | 3/31/03 |
|---|---|
| Engineer | Date |

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ANDS5500

POTENTIOMETER INPUT CARD

## SPECIFICATION

### 2-15227

RELATED DOCUMENTS:

| | |
|---|---|
| Schematic | D5-8814 |
| Theory of Operation | A2-5568 |

### I. GENERAL DESCRIPTION

The Potentiometer Card is a user card for the ANDS 5500 Data Acquisition System. It consists of a power supply and voltage reference, an output multiplexer and four identical signal conditioning channels. There are two 44-pin edge-card connectors (male) on the PC board, one is connected internally to the system and the other is for user connection.

Each signal channel consists of an excitation output section and a signal input section. The latter can be preset to accept a variety of voltage ranges and types via jumpers. It provides a DC voltage to, and permits low frequency and DC measurement of the signals from, appropriate external devices such as piezoelectric accelerometers.

### II. SPECIFICATIONS

#### 1. GENERAL

| | |
|---|---|
| Number of Channels: | 4 |
| Size and Shape: | Approximately 7 ½" x 4 ½" x ½" (similar to Analogic D4-7443) |
| Operating Temperature: | 0 – 50 Degrees C. |
| Storage Temperature: | -40 – 85 Degrees C. |
| Input & Output Connection: | EDGECARD, gold plated |

#### 2. ELECTRICAL

| | |
|---|---|
| a) Power Requirement: | +5v (+/-5%) at 100mA<br>+15v (+/-5%) at 100mA<br>-15v (+/-5%) at 100mA |

**Exelon.**

| | |
|---|---|
| ANALOGIC - PEABODY, MA 01960 | 2-15227   REV 01 |
| POTENTIOMETER INPUT CARD ANDS5500 | Page 4 of 9 |
| Code Ident: 1BM00     File Name: 2-15227rev01.doc | Printed:   April 4, 2003 |

b) Excitation Voltage Output (1 per channel)

| | |
|---|---|
| Voltage Level: | +5v and –5v |
| Voltage Accuracy: | +/- 0.2% over operating temperature range |
| Output Current: | 10mA max. |
| Output Impedance: | < 0.1 ohm |
| Protection: | Tolerate direct short circuit or short to +/-30vdc protected up to 250v by a thermistor |

c) Signal Input (1 per channel)

| | |
|---|---|
| Input Impedance: | 10Meg ohm |
| Input Signal Ranges: | +/-5v, +/-2.5v, +/-1.25v, +/-500mv, +/-250mv, +/-125mv Jumper selected (see Table 1) and fine adjustment by trimpot |
| Primary Frequency Content: | DC to 100Hz |
| Signal Source Resistance: | 2800 ohm max. |
| Overall Accurancy: (includes excitation accurancy) | +/- 0.5% over operating temperature range |
| Protection: | Input protected up to 250v continuous |
| **Amplifier** Upper Bandwidth: | 10Hz, 45Hz and 100Hz (2-pole filter) Jumper selected (see Table 2) |
| Input Coupling | Jumper selected for either, AC OR DC. Lower AC bandwidth is 0.5Hz (see Table 2). |

| INPUT RANGE (F.S) | GAIN | JUMPER 2 | JUMPER 3 |
|---|---|---|---|
| +/- 5v | 2 | 6 to 7 | 9 to 10 |
| +/- 2.5v | 4 | 5 to 7 | 9 to 10 |
| +/- 1.5v | 8 | 4 to 6 | 9 to 10 |

| ANALOGIC - PEABODY, MA 01960 POTENTIOMETER INPUT CARD ANDS5500 Code Ident: 1BM00    File Name: 2-15227rev01.doc | 2-15227    REV 01 Page 5 of 9 Printed:   April 4, 2003 |
|---|---|

| | | | |
|---|---|---|---|
| +/- 500mv | 20 | 6 to 7 | 8 to 9 |
| +/- 250mv | 40 | 5 to 7 | 8 to 9 |
| +/- 125mv | 80 | 4 to 6 | 8 to 9 |

**TABLE 1.**

**INPUT RANGE (CHANNEL GAIN) VS. JUMPER POSITION**

| BANDWIDTH | JUMPER 1 | JUMPER 4 | JUMPER 5 |
|---|---|---|---|
| DC to 10Hz | 2 to 3 | 12 to 13 | 16 to 17 |
| DC to 45Hz | 2 to 3 | 13 to 14 | 11 to 12 |
| DC to 100Hz | 2 to 3 | 17 to 18 | 15 to 16 |
| 0.5 to 10Hz | 1 to 2 | 12 to 13 | 16 to 17 |
| 0.5 to 45Hz | 1 to 2 | 13 to 14 | 11 to 12 |
| 0.5 to 100Hz | 1 to 2 | 17 to 18 | 15 to 16 |

**TABLE 2.**

**CHANNEL BANDWIDTH VS. JUMPER POSITION**

d) Analog Signal Output to Bus

| | |
|---|---|
| Analog Output Signal: | Ch.1, Ch.2, Ch.3, Ch.4 or Hiz (high impedance state), digitally selected |
| Output Offset: | +/- 5mv over operating temperature Range, adjustable to zero by trimpot |
| Full Scale Output Range: | +/- 10v (+/-0.5%) with full scale input |
| Maximum Output Voltage in Hiz state: | +/- 15v |
| e) Digital Signal Input From Bus: | Channel select (see Table 3) |

## Attachment 5
### NIST Saturated Properties of Water

Thermodynamic Properties of Water[ε]

| Saturated Properties - Pressure | | | | | |
|---|---|---|---|---|---|
| Pressure (psig)[†] | Temperature (F) | Enthalpy (v, Btu/lbm) | Density (v, lbm/ft³) | Enthalpy (l, Btu/lbm) | Density (l, lbm/ft³) |
| 1023.0 | 549.16 | 1191.9 | 2.337 | 548.77 | 46.008 |
| 1032.7 | 550.3 | 1191.6 | 2.361 | 550.23 | 45.934 |
| 1033.0 | 550.3 | 1191.5 | 2.362 | 550.27 | 45.931 |
| 1033.5 | 550.4 | 1191.5 | 2.364 | 550.35 | 45.927 |
| 1034.4 | 550.5 | 1191.5 | 2.366 | 550.48 | 45.921 |
| 1035.3 | 550.6 | 1191.5 | 2.368 | 550.61 | 45.914 |
| 1036.0 | 550.7 | 1191.4 | 2.370 | 550.72 | 45.909 |
| 1036.1 | 550.7 | 1191.4 | 2.370 | 550.74 | 45.908 |
| 1037.0 | 550.8 | 1191.4 | 2.372 | 550.87 | 45.901 |
| 1037.8 | 550.9 | 1191.4 | 2.374 | 551.00 | 45.895 |
| 1038.0 | 550.9 | 1191.3 | 2.375 | 551.02 | 45.893 |
| 1038.7 | 551.0 | 1191.3 | 2.377 | 551.12 | 45.888 |
| 1039.5 | 551.1 | 1191.3 | 2.379 | 551.25 | 45.882 |
| 1040.4 | 551.2 | 1191.2 | 2.381 | 551.38 | 45.875 |
| 1041.3 | 551.3 | 1191.2 | 2.383 | 551.51 | 45.869 |
| 1042.1 | 551.4 | 1191.2 | 2.385 | 551.64 | 45.862 |
| 1043.0 | 551.5 | 1191.1 | 2.387 | 551.77 | 45.856 |
| 1043.8 | 551.6 | 1191.1 | 2.390 | 551.89 | 45.849 |
| 1044.7 | 551.7 | 1191.1 | 2.392 | 552.02 | 45.842 |
| 1045.6 | 551.8 | 1191.0 | 2.394 | 552.15 | 45.836 |
| 1046.4 | 551.9 | 1191.0 | 2.396 | 552.28 | 45.829 |
| 1047.3 | 552.0 | 1191.0 | 2.398 | 552.41 | 45.823 |
| 1048.0 | 552.1 | 1190.9 | 2.400 | 552.52 | 45.817 |
| 1048.1 | 552.1 | 1190.9 | 2.401 | 552.54 | 45.816 |
| 1049.0 | 552.2 | 1190.9 | 2.403 | 552.67 | 45.810 |
| 1049.9 | 552.3 | 1190.9 | 2.405 | 552.80 | 45.803 |
| 1050.0 | 552.3 | 1190.9 | 2.405 | 552.81 | 45.802 |
| 1052.5 | 552.60 | 1190.8 | 2.412 | 553.18 | 45.783 |
| 1053.0 | 552.66 | 1190.7 | 2.413 | 553.26 | 45.779 |
| 1053.3 | 552.70 | 1190.7 | 2.414 | 553.31 | 45.777 |
| 1063.0 | 553.81 | 1190.3 | 2.439 | 554.74 | 45.704 |

[ε]Lemmon, E.W., McLinden, M.O., and Friend, D.G., "Thermophysical Properties of Fluid Systems",
NIST Chemistry WebBook, NIST Standard Reference Database Number 69, Eds. P.J. Linstrom and
W.G. Mallard, National Institute of Standards and Technology, Gaithersburg MD, 20899,
http://webbook.nist.gov, (retrieved September 30, 2009)

[†]psig = psia - 14.696, rounded.

## Attachment 6
### NIST Isobaric and Isothermal Properties of Water

Thermodynamic Properties of Water[4]

| Isobaric Properties | | | | | |
|---|---|---|---|---|---|
| Temperature (F) | Pressure[f] (psig) | Enthalpy (Btu/lbm) | Density (lbm/ft3) | Volume (ft3/lbm) | Phase |
| **Feedwater In** | | | | | |
| 428.8 | 1155.0 | 407.52 | 52.729 | 0.018965 | liquid |
| 429.8 | 1155.0 | 408.61 | 52.685 | 0.018981 | liquid |
| 430.2 | 1155.0 | 409.05 | 52.667 | 0.018987 | liquid |
| 430.23 | 1169.7 | 409.08 | 52.666 | 0.018988 | liquid |
| 430.8 | 1155.0 | 409.71 | 52.640 | 0.018997 | liquid |
| 431.37 | 1169.7 | 410.33 | 52.615 | 0.019006 | liquid |
| 431.4 | 1155.0 | 410.36 | 52.613 | 0.019007 | liquid |
| 431.8 | 1155.0 | 410.80 | 52.595 | 0.019013 | liquid |
| 432.8 | 1155.0 | 411.90 | 52.551 | 0.019029 | liquid |
| **RWCU Suction** | | | | | |
| 525.6 | 1060.0 | 518.94 | 47.612 | 0.021003 | liquid |
| 530.0 | 1060.0 | 524.39 | 47.333 | 0.021127 | liquid |
| 534.4 | 1060.0 | 529.88 | 47.046 | 0.021256 | liquid |
| **RWCU Discharge** | | | | | |
| 438.0 | 1168.0 | 417.62 | 52.32 | 0.019113 | liquid |
| 440.0 | 1168.0 | 419.83 | 52.229 | 0.019147 | liquid |
| 442.0 | 1168.0 | 422.04 | 52.137 | 0.01918 | liquid |
| **Recirculation** | | | | | |
| 532.0 | 1280.0 | 526.57 | 47.352 | 0.021119 | liquid |
| 533.0 | 1280.0 | 527.81 | 47.288 | 0.021147 | liquid |
| 534.0 | 1280.0 | 529.06 | 47.223 | 0.021176 | liquid |
| 535.0 | 1280.0 | 530.30 | 47.159 | 0.021205 | liquid |
| 536.0 | 1280.0 | 531.55 | 47.094 | 0.021234 | liquid |
| **CRD** | | | | | |
| 99.3 | 1448.0 | 71.24 | 62.274 | 0.016058 | liquid |
| 100.0 | 1448.0 | 71.93 | 62.265 | 0.016060 | liquid |
| 100.7 | 1448.0 | 72.63 | 62.256 | 0.016063 | liquid |
| Isothermal Properties | | | | | |
| **Feedwater In** | | | | | |
| 430.8 | 1145.0 | 409.70 | 52.636 | 0.018998 | liquid |
| 430.8 | 1155.0 | 409.71 | 52.640 | 0.018997 | liquid |
| 430.8 | 1165.0 | 409.71 | 52.644 | 0.018996 | liquid |
| **RWCU Suction** | | | | | |
| 530.0 | 1050.0 | 524.40 | 47.326 | 0.021130 | liquid |
| 530.0 | 1060.0 | 524.39 | 47.333 | 0.021127 | liquid |
| 530.0 | 1070.0 | 524.37 | 47.339 | 0.021124 | liquid |
| **RWCU Discharge** | | | | | |
| 440.0 | 1158.0 | 419.82 | 52.225 | 0.019148 | liquid |
| 440.0 | 1168.0 | 419.83 | 52.229 | 0.019147 | liquid |
| 440.0 | 1178.0 | 419.83 | 52.233 | 0.019145 | liquid |
| **Recirculation** | | | | | |
| 534.0 | 1270.0 | 529.07 | 47.217 | 0.021179 | liquid |
| 534.0 | 1280.0 | 529.06 | 47.223 | 0.021176 | liquid |
| 534.0 | 1290.0 | 529.04 | 47.230 | 0.021173 | liquid |
| **CRD** | | | | | |
| 100.0 | 1438.0 | 71.91 | 62.263 | 0.016061 | liquid |
| 100.0 | 1448.0 | 71.93 | 62.265 | 0.016060 | liquid |
| 100.0 | 1458.0 | 71.96 | 62.267 | 0.016060 | liquid |

[4]Lemmon, E.W., McLinden, M.O., and Friend, D.G., "Thermophysical Properties of Fluid Systems", NIST Chemistry WebBook, NIST Standard Reference Database Number 69, Eds. P.J. Linstrom and W.G. Mallard, National Institute of Standards and Technology, Gaithersburg MD, 20899, http://webbook.nist.gov, (retrieved September 30, 2009)

[f]psig = psia - 14.696, rounded.

## Attachment 7
### CTP Calculation Results Sensitivity Analysis

The sensitivity of the calculation of core thermal power to variations in the energy terms is determined using estimated values for the energy out, energy in, and CTP.

Table A7-1 shows the results from Cases 1, 2 and 3. For this analysis, the error rate assumed for $Q_S$ is set equal to a predicted error for the measurement of feedwater flow.

In Case 1 and Case 2, the $Q_S$ error is kept the same; even though, the errors for the $Q_{RAD}$, $Q_{RWCU}$, $Q_P$, and $Q_{CRD}$ terms are varied from 1 % to 19 % (29 % for $Q_{crd}$). Case 1 and Case 2 show that CTP is relatively insensitive to the accuracy of the $Q_{RAD}$, $Q_{RWCU}$, $Q_P$, and $C_{CRD}$ terms, when the CTP error is rounded to level of significance.

Case 3 varied the error rate assumed for $Q_S$. A step change in the mass flow error rate of 0.01 % (from 0.31 % to 0.32 %) was found necessary to change the CTP error by 0.02 % (a change of 1 MW from 17 MWt to 18 MWt and 0.500 % to 0.520 %).

The step change error rate was calculated to determine how fine the parameters used to calculate $Q_S$ and $Q_{FW}$ need to be to effect the results. Parameter changes that would result in changes in the parameter's overall error rate less than 0.02 % were found to be negligible. Small variations in the flow measurement uncertainty were found to affect the CTP uncertainty.

For example, CTP is the difference between the energy leaving the reactor and the energy put into the reactor from other sources outside of the core. The enthalpy of saturated water varies with changes in pressure. For every 1 % change in pressure, the enthalpy of saturated water vapor (and by inference the energy of the flow) between 800 and 1,300 psig will vary by an average of 0.03 %. This change in enthalpy is less than the 0.04 % found necessary to cause a significant change in the CTP error rate. Thus, CTP can be said to be tolerant of the steam dome pressure measurement error specified the pressure measurement loop is shown to be accurate to about ~10 psig, which is approximately 1 % of the maximum allowable steam dome pressure.

### Table A7-1. CTP Calculation Sensitivity Analysis

| | | | Sensitivity Analysis | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Case 1 | | | Case 2 | | Case 3 | | |
| | | | Energy in percent of CTP | Assumed error rate Case 1 | Predicted error as Percent of CTP | Assumed error rate Case 2 | Predicted error as Percent of CTP | Assumed error rate Case 3 | Predicted error as Percent of CTP |
| | **Energy Out** | | | | | | | | | |
| $Q_s$ | 18,030,078,635 | Btu/hr | 152.70% | 0.31% | 0.473% | 0.31% | 0.473% | 0.32% | 0.489% |
| $Q_{RAD}$ | 3,754,300 | Btu/hr | 0.03% | 1% | 0.0003% | 10% | 0.003% | 1% | 0.000% |
| $Q_{cu}$ | 16,407,160 | Btu/hr | 0.14% | 1% | 0.0014% | 10% | 0.014% | 1% | 0.001% |
| Q out | 18,050,240,095 | Btu/hr | 152.87% | | | | | | |
| | **Energy In** | | | | | | | | | |
| $Q_{FW}$ | 6,201,235,621 | Btu/hr | 52.52% | 0.31% | 0.163% | 0.31% | 0.163% | 0.32% | 0.168% |
| $Q_p$ | 37,146,642 | Btu/hr | 0.31% | 1% | 0.0031% | 10% | 0.031% | 1% | 0.003% |
| $Q_{crd}$ | 4,578,000 | Btu/hr | 0.04% | 1% | 0.0004% | 10% | 0.004% | 1% | 0.000% |
| Q in | 6,242,960,263 | Btu/hr | 52.87% | | | | | | |
| | **CTP** | | | | | | | | | |
| $Q_{CTP}$ | 11,807,279,832 | Btu/hr | SRSS all error terms[†] | 0.500% | | 0.500% | | 0.520% | |
| | | | SRSS only Qs and Qfw error terms[†] | 0.500% | | 0.500% | | 0.520% | |

[†]Error rounded to 3 significant figures

**Convert to MW**

| | | |
|---|---|---|
| Btu/hr per W | 3.412 | |
| Btu/hr per MW | 3,412,000 | |
| | **In MWt** | |
| Q out | 5,290 | MWt |
| Q in | 1,830 | MWt |
| CTP | 3,461 | MWt |

[†]Error rounded to 2 significant figures

| | Relative errors MWt | | |
|---|---|---|---|
| | Case 1 | Case 2 | Case 3 |
| | ± 17.31 MWt | ± 17.31 MWt | ± 18.00 MWt |

## Attachment 8
Derivation of the relationship between flow, ΔP, and density

### A8-1    Basic Flow Equation

Given that the basic flow equation (Reference A8.3-1) applicable to orifice plates, flow nozzles, and venturis is

$$Q = C \cdot \sqrt{\rho \cdot \Delta P}$$ , where C is a constant          (Equation A8-1).

Then the relationship between flow (Q) and differential pressure (ΔP) and density ($\rho$) can be derived.

### A8-1.1.    Relationship between Q, ΔP and $\rho$

For constant density, the flow can be shown to vary with the square root of ΔP such that,

$$\frac{Q_1}{Q_2} = \sqrt{\frac{\Delta P_1}{\Delta P_2}}$$

(Equation A8-2)

If the variation around some nominal flow, $Q_0$, is equal to some known uncertainty, $\sigma_1$, then

$$Q_1 = Q_0 \, {}^{*}(1 - \sigma_1) \text{ and } Q_2 = Q_0 \, {}^{*}(1 + \sigma_1)$$

(Equation A8-3)

Similarly, if the variation around some nominal differential pressure, $\Delta P_0$, is equal to some unknown ΔP uncertainty, $\sigma_x$, then

$$\Delta P_1 = P_0 \, {}^{*}(1 - \sigma_x) \text{ and } \Delta P_2 = P_0 \, {}^{*}(1 + \sigma_x)$$

(Equation A8-4a)

For constant ΔP, if the variation around some nominal density, $\rho_0$, is equal to some unknown $\rho$ uncertainty, $\sigma_x$, then

$$\rho_1 = \rho_0 \, {}^{*}(1 - \sigma_x) \text{ and } \rho_2 = \rho_0 \, {}^{*}(1 + \sigma_x)$$

(Equation A8-4b)

These values can be substituted into Equation A8-2 and the equations manipulated to solve for $\sigma_x$.

$$\frac{Q_0 \, {}^{*}(1 - \sigma_1)}{Q_0 \, {}^{*}(1 + \sigma_1)} = \sqrt{\frac{P_0 \, {}^{*}(1 - \sigma_x)}{P_0 \, {}^{*}(1 + \sigma_x)}}$$ , ΔP          (Equation A8-5a)

$$\frac{Q_0 \, {}^{*}(1 - \sigma_1)}{Q_0 \, {}^{*}(1 + \sigma_1)} = \sqrt{\frac{\rho_0 \, {}^{*}(1 - \sigma_x)}{\rho_0 \, {}^{*}(1 + \sigma_x)}}$$ , for $\rho$          (Equation A8-5b)

Crossing out like terms from the numerator and denominator, rearranging, and squaring both sides yields

$$\left[\frac{(1 - \sigma_1)}{(1 + \sigma_1)}\right]^2 = \frac{(1 - \sigma_x)}{(1 + \sigma_x)}$$

(Equation A8-6)

Equation A8-6 can be simplified by defining a new function of $\sigma_1$:

$$Y(\sigma_1) = \frac{(1 - \sigma_1)}{(1 + \sigma_1)}$$

(Equation A8-7)

Substituting $Y(\sigma_1)$ into Equation A8-6 and rearranging, gives

$$Y(\sigma_1)^2 = \frac{(1 - \sigma_x)}{(1 + \sigma_x)}$$

(Equation A8-8)

$$(1 + \sigma_x) \cdot Y(\sigma_1)^2 = (1 - \sigma_x)$$

$$\left( Y(\sigma_1)^2 + Y(\sigma_1)^2 \cdot \sigma_x \right) = (1 - \sigma_x)$$

Solving for $\sigma_x$, gives the relationship between the uncertainty $\sigma_x$, for either $\Delta P$ or $\rho$, and the known uncertainty of flow, $\sigma_1$.

$$\sigma_x + Y(\sigma_1)^2 \cdot \sigma_x = \left( 1 - Y(\sigma_1)^2 \right)$$

$$\sigma_x \cdot \left( 1 + Y(\sigma_1)^2 \right) = \left( 1 - Y(\sigma_1)^2 \right)$$

$$\sigma_x = \frac{\left( 1 - Y(\sigma_1)^2 \right)}{\left( 1 + Y(\sigma_1)^2 \right)}$$

(Equation A8-9)

Table A8-1 shows the relationship between the uncertainties in pressure or density, $\sigma_x$, and the uncertainty in flow, $\sigma_1$, to be essentially linear with a constant of proportionality equal to 2, see A8-1.2, provided $\sigma_1$ is small, which is taken to be less than or equal to 15 %.

Thus for small flow uncertainties, small $\sigma_1$, Equation A8-9 can be simplified as a linear function $f(\sigma_1)$, Equation A8-10, which says the uncertainty in differential pressure or the uncertainty in density is approximately equal to 2 times the flow uncertainty. The inverse is also true; given a differential pressure or density uncertainty, the uncertainty of the flow is one-half the differential pressure or density uncertainty.

$$\sigma_x \approx n \cdot \sigma_1,$$

(Equation A8-10)

A8-1.2.  **The Limit of n**

The limit of the constant of proportionality, $n$, in Equation A8-10 as $\sigma_1$ approaches zero is found to confirm that $n$ can be considered as a constant within the range of $\sigma_1$ less than 15 % to 0.

$$\underset{\sigma_1 \to 0}{\text{Lim}}(n) = \underset{\sigma_1 \to 0}{\text{Lim}}\left( \frac{\sigma_x}{\sigma_1} \right) = \underset{\sigma_1 \to 0}{\text{Lim}}\left( \frac{\left( \frac{1 - Y(\sigma_1)^2}{1 + Y(\sigma_1)^2} \right)}{\sigma_1} \right) = \underset{\sigma_1 \to 0}{\text{Lim}}\left( \frac{1 - Y(\sigma_1)^2}{\sigma_1 \left( 1 + Y(\sigma_1)^2 \right)} \right)$$

Recalling $Y(\sigma_1)$ and expanding $Y(\sigma_1)^2$ in terms of $\sigma_1$

$$\underset{\sigma_1 \to 0}{\text{Lim}}\left( \frac{1 - Y(\sigma_1)^2}{\sigma_1 \left( 1 + Y(\sigma_1)^2 \right)} \right) = \underset{\sigma_1 \to 0}{\text{Lim}}\left( \frac{1 - \frac{\left( 1 - 2\sigma_1 + \sigma_1{}^2 \right)}{\left( 1 + 2\sigma_1 + \sigma_1{}^2 \right)}}{\sigma_1 \left[ 1 + \frac{\left( 1 - 2\sigma_1 + \sigma_1{}^2 \right)}{\left( 1 + 2\sigma_1 + \sigma_1{}^2 \right)} \right]} \right) =$$

$$\lim_{\sigma_1 \to 0}\left(\frac{\left(1+2\sigma_1+\sigma_1^2\right)-\left(1-2\sigma_1+\sigma_1^2\right)}{\sigma_1\left[\left(1+2\sigma_1+\sigma_1^2\right)+\left(1-2\sigma_1+\sigma_1^2\right)\right]}\right) = \lim_{\sigma_1 \to 0}\left(\frac{4\cdot\sigma_1}{\sigma_1\left(2+2\sigma_1^2\right)}\right) =$$

$$\lim_{\sigma_1 \to 0}\left(\frac{4}{\left(2+2\sigma_1^2\right)}\right)$$, which after substituting 0 for $\sigma_1$ gives

$$\lim_{\sigma_1 \to 0}(n) = 2$$

## A8-1.3.   **References**

1.   ASME PTC 19.5-2004, Flow Measurement, Performance Test Code, ASME International

Table A8-1.
Relationship between $\sigma_1$, $Y(\sigma_1)$, $\sigma_x$, and $n$

| $\sigma_1$ | $Y(\sigma_1) = \dfrac{(1-\sigma_1)}{(1+\sigma_1)}$ | $\sigma_x = \dfrac{1-Y(\sigma_1)^2}{1+Y(\sigma_1)^2}$ | $n = f(\sigma_x) = \dfrac{\sigma_x}{\sigma_1}$ |
|---|---|---|---|
| 0.0000001 % | 99.9999998 % | 2.0E-09 | 2.0000000585 |
| 0.001 % | 99.998 % | 2.0E-05 | 1.9999999998 |
| 0.4 % | 99.2 % | 0.008 | 2.0000000004 |
| 5.0 % | 90.5 % | 0.100 | 1.995 |
| 10.0 % | 81.8 % | 0.198 | 1.980 |
| 15.0 % | 73.9 % | 0.293 | 1.956 |
| 20.0 % | 66.7 % | 0.385 | 1.923 |
| 25.0 % | 60.0 % | 0.471 | 1.882 |
| 30.0 % | 53.8 % | 0.550 | 1.835 |
| 35.0 % | 48.1 % | 0.624 | 1.782 |
| 40.0 % | 42.9 % | 0.690 | 1.724 |
| 45.0 % | 37.9 % | 0.748 | 1.663 |
| 50.0 % | 33.3 % | 0.800 | 1.600 |
| 55.0 % | 29.0 % | 0.845 | 1.536 |
| 60.0 % | 25.0 % | 0.882 | 1.471 |
| 65.0 % | 21.2 % | 0.914 | 1.406 |
| 70.0 % | 17.6 % | 0.940 | 1.342 |
| 75.0 % | 14.3 % | 0.960 | 1.280 |
| 80.0 % | 11.1 % | 0.976 | 1.220 |
| 85.0 % | 8.1 % | 0.987 | 1.161 |
| 90.0 % | 5.3 % | 0.994 | 1.105 |
| 95.0 % | 2.6 % | 0.999 | 1.051 |
| 100.0 % | 0.0 % | 1.000 | 1.000 |

## Attachment 9
Ametek Scientific Columbus Exceltronic AC Watt Transducer Specification (4 pages)

# Exceltronic AC Watt or Var Transducers

## SCIENTIFIC COLUMBUS

Exceltronic watt and var transducers
provide utility and industrial users with a
high degree of accuracy for applications
requiring precise measurements. These
transducers provide a dc-output signal
proportional to input watts or vars. All
models are available with a wide range of
input and output options.
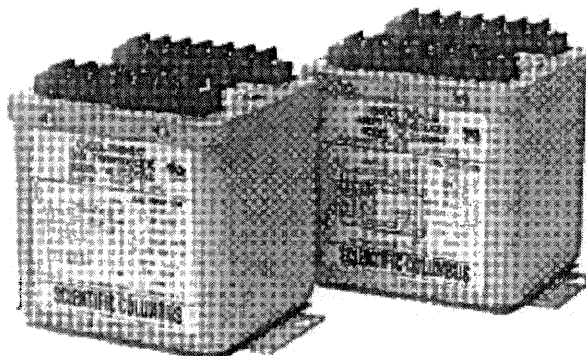
### Features
♦ Accuracy to 0.2% of reading
♦ Exceptional reliability
♦ Excellent long-term stability
♦ Self- or externally powered
♦ No zero adjustment required
♦ Most popular models are UL Recognized

### Applications
♦ Substation monitoring
♦ SCADA
♦ Energy-management systems
♦ Distribution monitoring
♦ Process control

### Outputs
♦ 0 to ±1 mAdc
♦ 1–5 or 1–3–5 mAdc
♦ 4–20 or 4–12–20 mAdc
♦ 10–50 or 10–30–50 mAdc
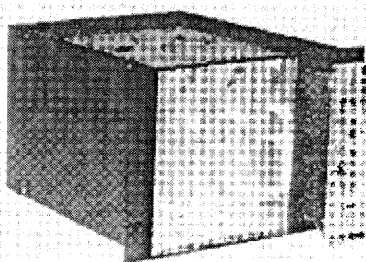
**Also available in XLP modular, plug-in format for limited-space applications requiring large numbers of transducers.**

♦ Two, four, or eight modules in one enclosure
♦ Easy to install, expand, or repair
♦ Convenient front-panel access for calibration and output-current jacks available

See pages 77–94 for more information.

## Specifications

### EXCELTRONIC AC WATT OR VAR TRANSDUCERS

| Specifications | | 0 to ±1 mAdc Watts (Watt Transducer) | P-Option* Watts (Watt Transducer) | 0 to ±1 mAdc Vars (Var Transducer) | P-Option* Vars (Var Transducer) |
|---|---|---|---|---|---|
| Current Input | Nominal Range** Overload Continuous Overload 1 Second/Hour Burden/Element | 5 A / 0–10 A / 20 A / 250 A / 0.2 VA (maximum) at 5 A | | | |
| Voltage Input | Nominal Range** Overload Continuous Burden/Element | 120 V / 0–150 V / 200 V / 0.035 VA (maximum) at 120 V | | | |
| External Auxiliary Power | Input Range Frequency Range Burden | 85–135 Vac 50–500 Hz 3 VA Nominal | 100–130 Vac 50–500 Hz 6 VA Nominal | 85–135 Vac 50–500 Hz 3 VA Nominal | 100–130 Vac 50–500 Hz 6 VA Nominal |
| Rated Output (RO) – 500 Watts or Vars/Element | | ±1 mAdc for Standard Calibration | 5, 20, or 50 mAdc for Std. Calibration, depending on selected output range* | ±1 mAdc for Standard Calibration | 5, 20, or 50 mAdc for Std. Calibration, depending on selected output range* |
| Accuracy | | ±(0.2% Reading + 0.01% RO) at 0–200% RO | ±(0.2% Reading + 0.05% RO) at 0–120% RO | ±(0.2% Reading + 0.02% RO) at 0–200% RO | ±(0.3% Reading + 0.05% RO) at 0–120% RO |
| Temperature Effect on Accuracy | | ±0.005% / °C | ±0.0075% / °C | ±0.005% / °C | ±0.012% / °C |
| Operating Temperature Range | | -20° C to +70° C | -20° C to +60° C | -20° C to +60° C | -20° C to +60° C |
| Compliance Voltage | | 10 Vdc | See Table 2 on page 40. | 10 Vdc | See Table 2 on page 40. |
| Load | | 0–10,000 Ω | | 0–10,000 Ω | |
| Output Ripple Peak | | < 0.5% RO | < 0.25% RO | < 0.5% RO | < 0.25% RO |
| Response Time | | < 400 ms to 99% | < 1 Second to 99% | < 400 ms to 99% | < 1 Second to 99% |
| Power Factor | | Any | | | |
| PF Effect on Accuracy | | ±0.1% VA (maximum) | | ±0.15% VA (maximum) | |
| Standard Calibration Adjustments | Gain Zero | ±2% of Reading (minimum) None Required | ±20% of Span (minimum) ±5% of Zero Point (minimum) | ±2% of Reading (minimum) None Required | ±20% of Span (minimum) ±5% of Zero Point (minimum) |
| Frequency Range | | 58–62 Hz | | 60 Hz | |
| Stability (per year) | | ±0.1% RO, Noncumulative | ±0.15% of Span, Noncumulative | ±0.2% RO, Noncumulative | ±0.25% of Span, Noncumulative |
| Operating Humidity | | 0–95% Noncondensing | | | |
| Isolation | | Complete (Input/Output/Power/Case) | | | |
| Dielectric Withstand | | 2500 VRMS*** at 60 Hz | | | |
| Surge Withstand | | ANSI/IEEE C37.90.1 | | | |
| Maximum Net Weight | | 3 lbs., 5 oz. (1.5 kg) | 4 lbs., 8 oz. (2 kg) | 3 lbs., 5 oz. (1.5 kg) | 4 lbs., 8 oz. (2 kg) |
| Approximate Dimensions (excluding mounting plate) | | 4.4" W x 3.9" D x 4.7" H (112 mm x 99 mm x 119 mm) Style II Case, see page 122 | 7.0" W x 3.7" D x 5.6" H (178 mm x 94 mm x 142 mm) Style I Case, see page 122 | 4.4" W x 3.9" D x 4.7" H (112 mm x 99 mm x 119 mm) Style II Case, see page 122 | 7.0" W x 3.7" D x 5.6" H (178 mm x 94 mm x 142 mm) Style I Case, see page 122 |
| Overrange with Linearity | | 500–1000 Watts/Element | 500–600 Watts/Element | 500–1000 Vars/Element | 500–600 Vars/Element |
| | | No additional error within voltage compliance. Reduce load resistance as required. | | | |

\* P-Option includes 1–5/1–3–5, 4–20/4–12–20, and 10–50/10–30–50 mAdc outputs.
\*\* Total input not to exceed 200% of standard-calibration watts or vars on units with 0 to ±1 mAdc output.
Total input not to exceed 120% of standard-calibration watts or vars on units with P-Option outputs.
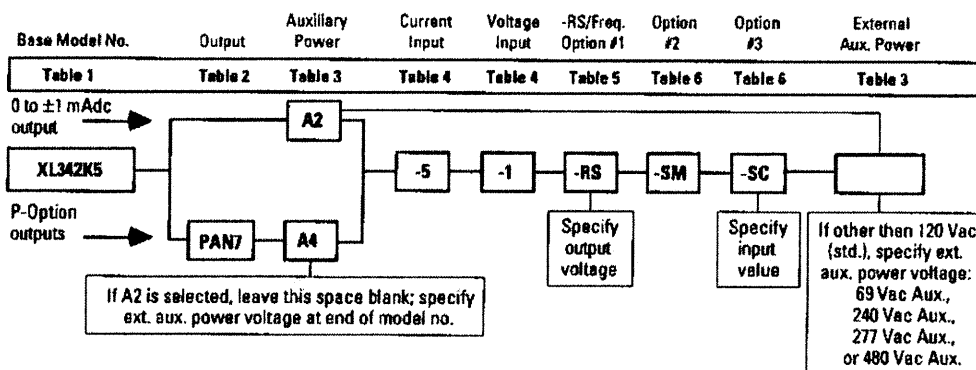\*\*\*Dielectric levels as indicated for UL Recognized models; levels may vary on non-UL Recognized models.

Specifications subject to change without notice.

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**Ordering Procedure
Exceltronic AC Watt or
Var Transducers**

## ORDERING PROCEDURE

Specify by base model number and appropriate selection or option suffixes in the order shown in the following example.

| Base Model No. | Output | Auxiliary Power | Current Input | Voltage Input | -RS/Freq. Option #1 | Option #2 | Option #3 | External Aux. Power |
|---|---|---|---|---|---|---|---|---|
| Table 1 | Table 2 | Table 3 | Table 4 | Table 4 | Table 5 | Table 6 | Table 6 | Table 3 |

0 to ±1 mAdc output → [A2]

[XL342K5] — [-5] — [-1] — [-RS] — [-SM] — [-SC]

P-Option outputs → [PAN7] — [A4]

-RS: Specify output voltage
-SM: Specify input value
External: If other than 120 Vac (std.), specify ext. aux. power voltage: 69 Vac Aux., 240 Vac Aux., 277 Vac Aux., or 480 Vac Aux.

If A2 is selected, leave this space blank; specify ext. aux. power voltage at end of model no.

EXAMPLES:    XL342K5A2-5-1-RS-SM-SC

3-element, 0 to ±1 mAdc Watt Transducer; 120 Vac external auxiliary power; 10 A input; 240 V input; resistor scaling (converts current output to voltage output); seismic brace; special calibration (example: 7200 W).

XL342K5PAN7A4-5-1-RS-SM-SC

3-element, 4-20 mAdc Watt Transducer; internal auxiliary power; 10 A input; 240 V input; resistor scaling (converts current output to voltage output); seismic brace; special calibration (example: 7200 W).

### Table 1  Base Model Number Selection

| Element | Watt Model No. | Var Model No. | Connection | Calibration at Rated Output (5 A, 120 V Nominal Input) | |
|---|---|---|---|---|---|
| 1 | XL5C5 | XLV5C5 | Single Phase | 500 W or Vars | |
| 1½* | XL5C51½ | XLV5C51½ | 3 Phase, 3 Wire | 1000 W or Vars | * 1½- and 2½-element units require a balanced voltage. |
| 2 | XL31K5 | XLV31K5 | 3 Phase, 3 Wire | 1000 W or Vars | |
| 2½* | XL31K52½ | XLV31K52½ | 3 Phase, 4 Wire | 1500 W or Vars | |
| 3 | XL342K5 | XLV342K5 | 3 Phase, 4 Wire | 1500 W or Vars | |

### Table 2  Output Selection

0 to ±1 mAdc output is standard, and is specified by the Base Model Numbers. For outputs other than 0 to ±1 mAdc, indicate the appropriate P-Option in the "Output" position of the complete model number.

| P-Option | Output Range | Compliance Voltage/ Maximum Load | Maximum Open Circuit Voltage |
|---|---|---|---|
| PAN6 | 1-5 mAdc | 15 Vdc/3000 Ω | 30 Vdc |
| PAN7 | 4-20 mAdc | 15 Vdc/750 Ω | 30 Vdc |
| PAN8 | 10-50 mAdc | 15 Vdc/300 Ω | 30 Vdc |
| PAN6-B | 1-3-5 mAdc | 15 Vdc/3000 Ω | 30 Vdc |
| PAN7-B | 4-12-20 mAdc | 15 Vdc/750 Ω | 30 Vdc |
| PAN8-B | 10-30-50 mAdc | 15 Vdc/300 Ω | 30 Vdc |
| PA6 | 1-5 mAdc | 40 Vdc/8000 Ω | 70 Vdc |
| PA7 | 4-20 mAdc | 40 Vdc/2000 Ω | 70 Vdc |
| PA8 | 10-50 mAdc | 30 Vdc/600 Ω | 70 Vdc |
| PA6-B | 1-3-5 mAdc | 40 Vdc/8000 Ω | 70 Vdc |
| PA7-B | 4-12-20 mAdc | 40 Vdc/2000 Ω | 70 Vdc |
| PA8-B | 10-30-50 mAdc | 30 Vdc/600 Ω | 70 Vdc |

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## Ordering Procedure
## Exceltronic AC Watt or
## Var Transducers

### Table 3  Auxiliary Power Supply Selection

| Option | Description | Input Range | Frequency Range | Burden |
|---|---|---|---|---|
| (0 to ±1 mAdc Units) | | | | |
| A2** | External Auxiliary Power (120 Vac std.) | 85-135 Vac | 50-500 Hz | 3 VA |
| A4 | Internal Auxiliary Power (self-powered) | 70-112% of Nominal Aux. Power Voltage | Equals Input Frequency | 3 VA |
| (P-Option Units) | | | | |
| A2** (leave blank) | External Auxiliary Power (120 Vac std.) | 100-130 Vac | 50-500 Hz | 6 VA |
| A4 | Internal Auxiliary Power (self-powered) | 84-108% of Nominal Aux. Power Voltage | Equals Input Frequency | 6 VA |

** For external auxiliary power voltages other than 120 Vac, specify the voltage in the last position of the complete model number. (Example: 240 Vac Aux.)

DC external auxiliary power available; see Special Options on page 128.

### Table 4  Input Selection

| | Current | | | | Voltage | | |
|---|---|---|---|---|---|---|---|
| Option | Nominal | Current Range w/ Accuracy | Calibration at Rated Output (5 A Nominal Input) | Option | Nominal | Voltage Range w/ Accuracy | Calibration at Rated Output (120 V Nominal Input) |
| -3 | 1 A | 0-2 A | 100 W or Vars/Element | -0 | 69 V | 0-75 V | 250 W or Vars/Element |
| -4 | 2.5 A | 0-5 A | 250 W or Vars/Element | Std.*** | 120 V | 0-150 V | 500 W or Vars/Element |
| Std.*** | 5 A | 0-10 A | 500 W or Vars/Element | -1 | 240 V | 0-300 V | 1000 W or Vars/Element |
| -11 | 7.5 A | 0-15 A | 750 W or Vars/Element | -9 | 277 V | 0-340 V | 1200 W or Vars/Element |
| -5 | 10 A | 0-20 A | 1000 W or Vars/Element | -2 | 480 V | 0-600 V | 2000 W or Vars/Element -7 |
| | 15 A | 0-20 A | 1500 W or Vars/Element | | | | |
| -8**** | 25 A | 0-30 A | 2500 W or Vars/Element | | | | |

*** Leave "Input" positions blank in the model number.

**** Option -8 requires a Style I case. (See page 122 for case dimensions. Maximum height of terminal strip(s) is 1.87" for units with -8 option.)

### Table 5  Scaling Resistor (-RS)/Frequency Options

| Option | Description |
|---|---|
| -RS† | Scaling Resistor |
| -6 | 400 Hz |
| -12 | 50 Hz (not UL Recognized) |
| -6-RS† | 400 Hz and Scaling Resistor |
| -12-RS† | 50 Hz and Scaling Resistor |

† You must specify the desired output voltage:
For 0 to ±1 mAdc units, specify range from 0 to ±10 Vdc. Load impedance is 1 MΩ/Vdc (minimum).
For P-Option units, specify range from 0-15 Vdc (PAN models) or 0-40 Vdc (PA models). Load impedance is 200, 50, or 20 (kΩ/Vdc) (minimum) for units with outputs of 5, 20, or 50 mAdc, respectively.
This information is not part of the model number, but must be provided to the factory when you place your order.

### Table 6  Other Options

| Option | Description |
|---|---|
| -20 | 50-200% Calibration Adjustment (current outputs) |
| -21 | 50-200% Calibration Adjustment (voltage outputs) (available only with 0 to ±1 mAdc units) |
| -24 | 24 Vdc Loop-Powered (PA7 and PA7-B models only) (consult factory for specifications) |
| -CE | Analog Output Shorting Relay (available only with 0 to ±1 mAdc units) |
| -SC†† | Special Calibration |
| -SM | Seismic Brace (available with 0 to ±1 mAdc units) (consult factory if you desire this option with a P-Option unit) |
| -Z | Zero-Based Output Calibration (ex.: PA7-Z = 0-20 mAdc) (available only with P-Option units, except PAN-B models) |

†† You must specify the desired input value:
0 to ±1 mAdc units can be calibrated within 90-100% of their standard-calibration input watts or vars. (Example: A 2-element watt transducer is calibrated to 1000 W standard. The -SC option can be added for input levels from 900 W (90%) to 1000 W (100%).) P-Option units can be calibrated within 50-100% of their standard-calibration input watts or vars.
This information is not part of the model number, but must be provided to the factory when you place your order.

If you require additional options not shown here, see Special Options on page 128. When ordering any special options, or more than three options, you must first consult the factory for pricing and delivery estimates.

## Attachment 10
B32-C-001-J-023, Rev. 1, Recirculation Pump Curve (1 pages)
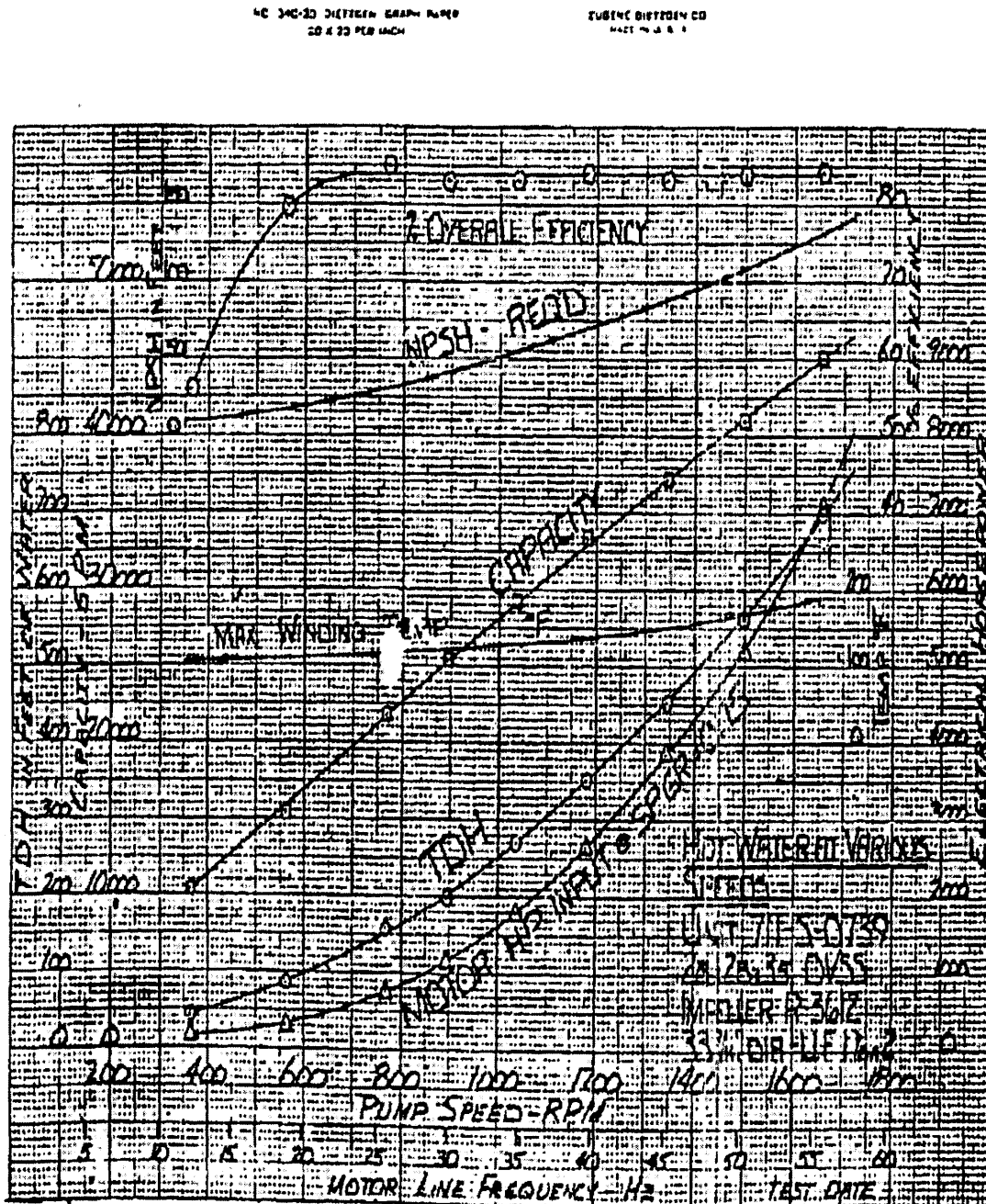


T-34081-3

## Attachment 11

Rosemount Inc., Instruction Manual 4259, Model 1151 Alphaline® $\sqrt{\Delta P}$ Flow Transmitter, 1977 (PAGES 1, 6, 14, 24, AND 29)

INSTRUCTION MANUAL 4259

# MODEL 1151DP
# ALPHALINE®
# $\sqrt{\Delta P}$
# FLOW TRANSMITTER

---

**CAUTION:**

**READ BEFORE ATTEMPTING
INSTALLATION OR MAINTENANCE
TO AVOID POSSIBLE
WARRANTY INVALIDATION**

---

## CONTENTS

# Specifications - 1151DP $\sqrt{\Delta P}$ Flow Transmitter

## Functional Specifications

### Service

Liquid, gas or vapor

### Ranges

0-5/30 inches $H_2O$
0-25/150 inches $H_2O$
0-125/750 inches $H_2O$

### Outputs

4-20 mADC, square root of input

### Power Supply

External power supply required. Up to 45 VDC. Transmitter operates on 12 VDC with no load.

### Load Limitations

See Figure 7.

### Indication

Optional meter with 1-3/4" linear scale, 0-100%. Indication accuracy is ±2% of span.

### Hazardous Locations

**Explosion proof:** Approved by Factory Mutual for Class I, Division 1, Groups B*, C and D; Class II, Division 1, Groups E, F and G; and Class III, Division 1. Certification by Canadian Standards Association (CSA) for Class I, Groups C and D available as an option. **Intrinsically safe:** FM certification optional for Class I, Division 1, Groups B, C and D when used with listed barrier systems.

### Span and Zero

Continuously adjustable externally.

### Zero Elevation and Suppression

Zero elevation or zero suppression up to 10% of calibrated span.

### Temperature Limits

-20°F to +150°F Amplifier operating.
-40°F to +220°F Sensing element operating.
-60°F to +180°F Storage.

### Static Pressure and Overpressure Limits

0 psia to 2000 psig on either side without damage to the transmitter. Operates within specifications between static line pressures of 1/2 psia and 2000 psig. 10,000 psig proof pressure on the flanges.

### Humidity Limits

0-100% RH.

### Volumetric Displacement

Less than 0.01 cubic inches.

*Optional meter not approved for Group B.

### Damping

Fixed response time of 1/3 second. (Corner frequency of 0.4 Hz)

### Turn-on Time

10 seconds. No warmup required.

## Performance Specifications

*(ZERO BASED SPANS, REFERENCE CONDITIONS, 316SS ISOLATING DIAPHRAGMS. APPLIES FROM 25 TO 100% FLOW).*

### Accuracy

±0.25% of calibrated span for a range of 25% to 100% of flow (6% to 100% of input pressure). Includes combined effects of hysteresis, repeatability and conformity of the square root function.

### Dead Band

None

### Stability

±0.25% of upper range limit for 6 months.

### Temperature Effect

The total effect including zero and span errors: ±1.5% of upper range limit per 100°F. (±2.5% for low range.)

### Overpressure Effect

Zero shift of less than ±0.5% of upper range limit for 2000 psi (±2.0% for range 5).

### Static Pressure Effect

Zero Error: ±0.5% of upper range limit for 2000 psi (±1.0% for range 3).

Span Error: -0.5±0.1% of reading per 1000 psi (-0.75±0.1% for range 3). This is a systematic error which can be calibrated out for a particular pressure before installation.

### Vibration Effect

±0.05% of upper range limit per g to 200 Hz in any axis.

### Power Supply Effect

Less than 0.005% of output span per volt.

### Load Effect

No load effect other than the change in power supplied to the transmitter.

### Mounting Position Effect

Zero shift of up to 1" $H_2O$ which can be calibrated out. No span effect. No effect in plane of diaphragm.

## Physical Specifications

### Materials of Construction †

**Isolating Diaphragms and Drain/Vent Valves:**

316SS, HASTELLOY C or MONEL.

### Process Flanges and Adapters:

Cadmium Plated Carbon Steel, 316SS, HASTELLOY C or MONEL.

### Wetted O-Rings

VITON.

### Fill Fluid:

Silicone Oil.

### Bolts:

Cadmium Plated Carbon Steel.

### Electronics Housing:

Low-copper aluminum (NEMA4)

### Paint:

Polyester-Epoxy.

### Process Connections

1/4-NPT on 2-1/8" centers on flanges. 1/2-NPT on 2", 2-1/8" or 2-1/4" centers with adapters.
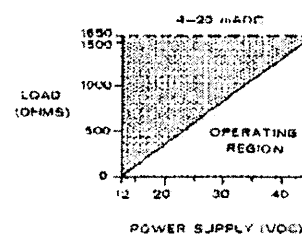
### Electrical Connections

1/2-inch conduit with screw terminals and integral test jacks compatible with miniature banana plugs (Pomona 2944, 3690 or equal)

### Weight

12 pounds excluding options.

**FIGURE 7**
**LOAD LIMITATIONS**

†MONEL is a trademark of International Nickel Co. HASTELLOY is a trademark of the Cabot Corp. VITON is a DuPont trademark. Terminology per SAMA Standard PMC20 1 1975.

# PARTS LIST/DRAWINGS SECTION

## Design Specifications

| MODEL 1151DP | ALPHALINE $\sqrt{\Delta P}$ FLOW TRANSMITTER |
|---|---|

| CODE | RANGES |
|---|---|
| 3 | 0-5 to 0-30 inches $H_2O$ (0-127 to 0-762 mm $H_2O$) |
| 4 | 0-25 to 0-150 inches $H_2O$ (0-635 to 0-3810 mm $H_2O$) |
| 5 | 0-125 to 0-750 inches $H_2O$ (0-3175 to 0-19050 mm $H_2O$) |

| CODE | OUTPUT |
|---|---|
| C | 4-20 mADC, square root of input |

### MATERIALS OF CONSTRUCTION

| CODE | FLANGES AND ADAPTERS | DRAIN-VENT VALVES | ISOLATING DIAPHRAGMS |
|---|---|---|---|
| 12 | Cadmium Plated C.S. | 316SS | 316SS |
| 13 | Cadmium Plated C.S. | HASTELLOY C | HASTELLOY C-276 |
| 14 | Cadmium Plated C.S. | MONEL | MONEL |
| 22 | 316SS | 316SS | 316SS |
| 23 | 316SS | 316SS | HASTELLOY C-276 |
| 24 | 316SS | 316SS | MONEL |
| 33 | HASTELLOY C | HASTELLOY C | HASTELLOY C-276 |
| 44 | MONEL | MONEL | MONEL |

| CODE | OPTIONS |
|---|---|
| LM | Linear Meter, 0-100% scale |
| MB | Optional Mounting Bracket for Mounting to 2" Pipe |
| PB | Optional Mounting Bracket for Panel Mounting |
| FB | Optional Flat Mounting Bracket for Mounting to 2" Pipe |
| D1 | Side Vent/Drain, Top |
| D2 | Side Vent/Drain, Bottom |
| CE | Canadian Standards Association (CSA) Explosion Proof Certification for Class I, Groups C and D; Class II, Groups E, F and G, Class III; (Encl. IV). |

### INTRINSIC SAFETY APPROVAL (All Are Approved By Factory Mutual)

| | AGENCY | BARRIER MANUFACTURER | BARRIER MODEL | CLASS I, DIV. 1, GROUPS B | C | D |
|---|---|---|---|---|---|---|
| F1 | FM | Foxboro | 2AI-12V-FGB, 2AI-13V-FGB | X | X | X |
| F2 | FM | Taylor | 124S1134, 124S1144 | X | X | X |
| | | | 124S931, 124S932 | | X | X |
| | | | 124S1254, 124S1264 | | X | X |
| F3 | FM | Westinghouse | 75SB01 | X | X | X |
| | | | 58FC12 | | X | X |
| F4 | FM | Leeds & Northrup | 316569, 316747 | X | X | X |
| F5 | FM | Fischer & Porter | 805H023U01, 805H027U01 | | X | X |
| | | | 805H027U02 | X | X | X |
| F6 | FM | Fisher Controls | AC302 | | X | X |
| F7 | FM | Honeywell | 38545-XXXX-0110 | | | |
| | | | -113-FSB5 | X | X | X |
| | | | -111/112-FSB5 | | X | X |

| 1151DP | 4 | C | 12 | LM, MB | ◄──────── COMPLETED DESIGN SPECIFICATION |
|---|---|---|---|---|---|

**STANDARD ACCESSORIES** All Models are shipped with flange adapter, vent/drain valves and one instruction manual per shipment.

**OPTIONAL THREE-VALVE MANIFOLDS (Packaged Separately)**

Part No. 1151-150-1: 3-Valve Manifold, Carbon Steel (Anderson, Greenwood & Co., M4AVC)
Part No. 1151-150-2: 3-Valve Manifold, 316SS (Anderson, Greenwood & Co., M4AVS)

**TAGGING** ALPHALINE Differential Pressure Transmitters will be tagged in accordance with customer requirements. All tags are stainless steel.

**CALIBRATION** Transmitters are factory calibrated to customer's specified span. If calibration is not specified, transmitters are calibrated at maximum range. Calibration is at ambient temperature and pressure.

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## Attachment 12
Bailey Signal Resistor Unit Type 766 (2 pages)

TABLE OF CONTENTS

| FIG. & INDEX NO. | PART NO. | REF. DES. | DESCRIPTION | UNITS PER/ASSY |
|---|---|---|---|---|
| 3 | 6146K15P277 | R3 | RESISTOR, 250 OHMS, ±0.1% FIXED, WIRE-WOUND, 2.5 WATTS (V91637, TYPE RS-2C) (V00213, TYPE 1200S) (V12463, TYPE T-2C) | 12 |
| 4 | 6146K15P280 | R3 | RESISTOR, 242 OHMS, ±0.1% FIXED, WIRE-WOUND, 2.5 WATTS (V91637, TYPE RS-2C) (V00213, TYPE 1200S) (V12463, TYPE T-2C) | 6 |
| 4 | 6148K68P015 | R4 | RESISTOR, 8 OHMS, ±0.1% FIXED, WIRE-WOUND, 0.66 WATT, (V17870, TYPE R1375) | 6 |
| 5 | 6149K92P303 | R1 | RESISTOR, 12100 OHMS, ±0.1% FIXED WIRE-WOUND, (V17870, TYPE R1391-0030), 0.25 WATT | 6 |
| 5 | 6148K60P217 | R2 | RESISTOR, 400 OHMS, 0.1% FIXED, WIRE-WOUND, 0.66 WATT, (V17870, TYPE 1375) | 6 |
| 6 | 6146K15P226 | R3 | RESISTOR, 100 OHMS, ±0.1% FIXED, WIRE-WOUND, 2.5 WATT, (V91637, TYPE RS-2C) (V00213, TYPE 1200S) (V12463, TYPE T-2C) | 12 |
| 7 | 6146K15P271 | R3 | RESISTOR, 96.8 OHMS, ±0.1% FIXED, WIRE-WOUND, 2.5 WATTS | 6 |
| 7 | 6148K68P522 | R4 | RESISTOR, 3.2 OHMS, ±0.1% FIXED, WIRE-WOUND, 0.66 WATT (V17870, TYPE R1375 | 6 |
| 8 | 6146K15P277 | R3 | RESISTOR, 250 OHMS, ·0.1% FIXED, WIRE-WOUND, 2.5 WATTS, (V91637, TYPE RS-2C) (V00213, TYPE 1200S) (V12463, TYPE T-2C) | 6 |
| 9 | 6146K15P280 | R3 | RESISTOR, 242 OHMS, ±0.1% FIXED, WIRE-WOUND, 2.5 WATTS (V91637, TYPE RS-2C) (V00213, TYPE 1200S) (V12463, TYPE T-2C) | 3 |
| 9 | 6148K68P015 | R4 | RESISTOR, 8 OHMS, ±0.1% FIXED, WIRE-WOUND, 0.66 WATT (V17870, TYPE R1375) | 3 |
| 10 | 6146K15P226 | R1 | RESISTOR, 100 OHMS, ±0.1% FIXED, WIRE-WOUND, 2.5 WATT (V91637, TYPE RS-2C) (V00213, TYPE 1200S) (V12463, TYPE T-2C) | 6 |
| 11 | 6146K15P271 | R1 | RESISTOR, 96.8 OHMS, ±0.1% FIXED, WIRE-WOUND, 2.5 WATTS, (V91637, TYPE RS-2C) (V00213, TYPE 1200S) (V12463, TYPE T-2C) | 3 |
| 11 | 6148K68P522 | R2 | RESISTOR, 3.2 OHMS, ±0.1% FIXED, WIRE-WOUND, 0.66 WATT, (V17870, TYPE R1375) | 3 |
| 12 | 6149K94P007 | R1 | RESISTOR, 150 OHMS, ±5% FIXED, WIRE-WOUND, 5 WATTS, (V44655, TYPE 995) | 6 |

**Attachment 13**
Rosemount Specification Drawing 01153-2734, N0039 Option -- Combination N0016 & N0037 (2 Pages)

| N0039 | LTR | DESCRIPTION | ECO NO. | APP'D | DATE |
|---|---|---|---|---|---|
| | A | Original Release | 626853 | *JmB* | 12/2/88 |
| | | | | | |

I. SCOPE

This specification defines a Model 1153 Series B pressure transmitter with combined options N0016 - a stainless steel 1/2 - 14 NPT pipe plug installed in one of the conduit hubs, and N0037 - a 4-20mA output signal with adjustable damping.

II. DETAILS

1. The pipe plug is to be assembled on the nameplate/vent valve side of the transmitter. The plug will be sealed with thread sealant and torqued to 150 in.-lbs.

2. The standard "R" calibration and amplifier boards are replaced with the special damping calibration and amplifier boards.

III. SPECIFICATIONS

Maximum damping for the electronics, measured at the 63% time constant is:

|  | Maximum Damping |
|---|---|
| Range 3 | not applicable |
| Range 4 | 1.2 seconds |
| Range 5-9 | 0.8 seconds |

The damping electronics are not intended for the range 3 because the slower response is not required for this transmitter pressure range.

IV. APPLICABILITY AND APPROVALS

This specification is limited to the Model 1153 Series B with "R" electronics. Qualification with the pipe plug was addressed in Rosemount Report 108026 (see paragraph 5.3.1). Qualification of the damping option was addressed in

| CLASS IE USAGE | Rosemount Inc. MINNEAPOLIS, MINNESOTA |
|---|---|
| DR. BY K. Hildebrandt | DATE 11/16/88 | TITLE |
| APP'D *Jan Baldry* | 12/2/88 | Specification Drawing |
| | | N0039 Option - Combination N0016 & N0037 |

MASTER DRAWING

| SIZE | CODE IDENT. NO. | DRAWING NO. | |
|---|---|---|---|
| A | 04274 | 01153-2734 | |
| | | | SHEET 1 OF 2 |

Form No. 60299-1, Rev. A

**Exelon.**

**Reactor Core Thermal
Power Uncertainty**

Rosemount Report D8800053. The damping option is qualified to the levels of the 1154 transmitter. However, when being used in the Model 1153 transmitter, the qualified requirements are those for the original Model 1153 transmitter. They are not altered because of the presence of the damping electronics.

MASTER DRAWING

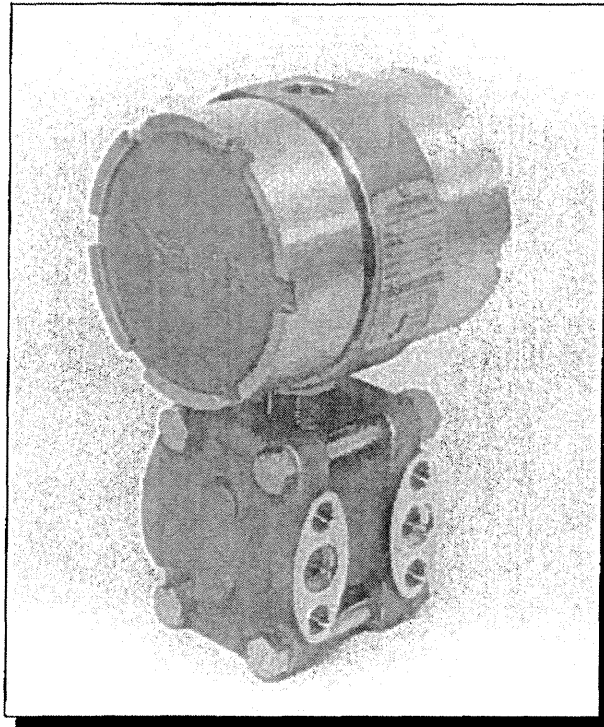| CLASS IE USAGE | SIZE | CODE IDENT. NO. | DRAWING NO. |
|---|---|---|---|
| | A | 04274 | 01153-2734 |
| | | | SHEET 2 OF 2 |

Form No. 60299-2, Rev. A

**Attachment 14**
Rosemount Product Data Sheet 00813-0100-2655, Rev. AA June 1999 "N-Options for Use with the Model
1153 & 1154 Alphaline® Nuclear Pressure Transmitters" (2 Pages)

# N-Options for Use with the Model 1153 and Model 1154 Alphaline® Nuclear Pressure Transmitters



# ROSEMOUNT® NUCLEAR

FISHER-ROSEMOUNT Managing The Process Better.™

## INTRODUCTION

Rosemount® Model 1153 and Model 1154 Alphaline® Nuclear Pressure Transmitters are designed for precise pressure measurements in nuclear applications which require reliable performance and safety over an extended service life. These transmitters have been qualified per IEEE Std 323-1974 and IEEE Std 344-1975 as documented in the corresponding Rosemount qualification reports.

Model 1153 and Model 1154 Transmitters are available in a variety of configurations for differential, flow, gage, absolute, and level measurements. To accommodate specific customer requirements, special N–Option features have been developed to provide greater application flexibility. For example, the N0010 option allows a transmitter to be calibrated up to 5% over its standard upper range limit. The N0026 option allows a Range Code 4 Transmitter to be calibrated up to 210 $inH_2O$ rather than the standard Range Code 4 upper range limit of 150 $inH_2O$.

Following is a summary of selected N–Options. For additional information on these and other N–Options, contact Rosemount Nuclear Instruments, Inc.

## SUMMARY OF N–OPTIONS

N0002    Specifies a reverse-acting gage pressure transmitter.

N0004    Specifies factory calibration of the transmitter at temperatures above or below room temperature. Transmitters may be calibrated at temperatures between 40 and 200 °F.

N0010    Allows the transmitter to be calibrated up to 5% above the standard upper range limit. For example, if the stated upper range limit of the transmitter is 1,000 psi, an N0010 transmitter may be calibrated up to 1,050 psi. This option is available on all ranges.

N0011    Allows 180° rotation of the electronics housing.

N0016    Specifies a stainless steel pipe plug installed on the nameplate/vent valve side of the 1153 Series B Transmitter.

N0018    Specifies a maximum static pressure rating of 3,200 psi rather than the standard 3,000 psi on any high-line differential pressure transmitter.

N0022    Specifies a welded ¼-in. Swagelok™ compression fitting on differential and high-line transmitters.

N0026    Allows an 1153 Series D or 1154 Range Code 4 transmitter to be calibrated up to 210 $inH_2O$ rather than the standard Range Code 4 upper range limit of 150 $inH_2O$. The maximum and minimum span limits are 155 and 75 $inH_2O$, respectively.

N0029    Specifies factory calibration of the transmitter at a customer-specified elevated line pressure.

N0032    Specifies a Range Code 3 or 8 differential pressure transmitter with a maximum static pressure rating of 2,500 psi rather than the standard 2,000 psi. Applicable to Model 1153 Series Transmitters only.

N0033    Allows 90° clockwise rotation of the electronics housing. The terminal block lines up with the vent/drain valve side.

N0034    Specifies a Model 1153 Series D or Model 1154 Transmitter with a special mounting bracket that has no panel mounting holes.

N0037    Specifies adjustable damping on any Model 1153 or Model 1154 Transmitter.

N0077    Specifies a Model 1153 Series F with a SST electronics housing, SST housing covers and SST mounting bracket.

N0078    Allows 180° rotation of the process flanges

N0088    Allows 90° counterclockwise rotation of the electronics housing. The terminal block lines up with the process connections.

## ORDERING INFORMATION

Consult the appropriate transmitter Product Data Sheet for a transmitter model number. Append the N–Option number to the end of the transmitter model number. An example of a typical model number with N–Option added is 1153DB5RAN0010.