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Cold Vacuum Drying (CVD) OCRWM Loop Error Determination

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200

Fluor Hanford

P.O. Box 1000

Richland, Washington

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Cold Vacuum Drying (CVD)

OCRWM Loop Error Determination

Project W-441

SNF-5900

June 2000

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REVIEW CHECKLIST**Document Reviewed:**

SNF-5900 Rev. 0, Cold Vacuum Drying (CVD) OCRWM Loop Error Determination Project W-441

Scope of Review:

Independent, Engineering review of all calculations.

Yes No NA

☒	☐	☐	* Previous reviews complete and cover analysis, up to scope of this review, with no gaps.
☒	☐	☐	Problem completely defined.
☐	☐	☒	Accident scenarios developed in a clear and logical manner.
☒	☐	☐	Necessary assumptions explicitly stated and supported.
☐	☐	☒	Computer codes and data files documented.
☒	☐	☐	Data used in calculations explicitly stated in document.
☒	☐	☐	Data checked for consistency with original source information as applicable.
☒	☐	☐	Mathematical derivation checked including dimensional consistency of results.
☐	☐	☒	Models appropriate and used within range of validity or use outside range of established validity justified.
☒	☐	☐	Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
☐	☐	☒	Software input correct and consistent with document reviewed.
☐	☐	☒	Software output consistent with input and with results reported in document reviewed.
☒	☐	☐	Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
☐	☐	☒	Safety margins consistent with good engineering practices.
☒	☐	☐	Conclusions consistent with analytical results and applicable limits.
☒	☐	☐	Results and conclusions address all points required in the problem statement.
☒	☐	☐	Format consistent with appropriate NRC Regulatory Guide or other standards.
☐	☐	☒	* Review calculations, comments, and/or notes are attached.
☒	☐	☐	Document approved.

R Whitehurst

Reviewer (Printed Name and Signature)

7/19/00

Date

*Any calculations, comments, or notes generated as part of this review should be signed, dated and attached to this checklist. Such material should be labeled and recorded in such a manner as to be intelligible to a technically qualified third party.

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List of Acronyms and Abbreviations

AL	Analytical Limit
AU	Accuracy Uncertainty
B	Bias
CS	Calibrated Span
CU	Channel Uncertainty
DAC	Data Acquisition
DR	Drift Effect
HE	Humidity Effect
FS	Full Scale
MCS	Monitoring and Control System
mR	milli-Rad
LT	Loop Tolerance
MTE	Measurement and Test Equipment
NPH	National Phenomena Hazard
PC	Performance Category:
Psig	Pounds per Square Inch – Gauge
PSE	Power Supply Effect
RA	Relative Accuracy
RD	Reading Error
Rdg	Reading
RE	Radiation Effect
RH	Relative Humidity
SA	Setting Accuracy
SC	Safety Class
SCC	Standard cubic centimeters
SCIC	Safety Class Instrumentation and Controls
SE	Seismic Effect
SMTE	Sensor Measurement and Test Equipment Effect
SP	Static Pressure Effect
TDR	Turn Down Ratio
TE	Temperature Effect
TEM	Test Equipment Error Maximum
TID	Total Integrated Dose
URL	Upper Range Limit
VDC	Volts – Direct Current

1 Introduction

1.1 General

Characterization is specifically identified by the Richland Operations Office (RL) for the Office of Civilian Radioactive Waste Management (OCRWM) of the U.S. Department of Energy (DOE), as requiring application of the requirements in the *Quality Assurance Requirements and Description* (QARD) (RW-0333P DOE 1997a). Those analyses that provide information that is necessary for repository acceptance require application of the QARD.

The CVD project identified the loops that measure, display, and record MCO vacuum pressure and Tempered Water (TW) temperature data as providing OCRWM data per Application of the Office of Civilian Radioactive Waste Management (OCRWM) Quality Assurance Requirements to the Hanford Spent Nuclear Fuel Project HNF-SD-SNF-RPT-007. Vacuum pressure transmitters (PT 1*08, 1*10) and TW temperature transmitters (TIT-3*05, 3*12) are used to verify drying and to determine the water content within the multi-canister overpack (MCO) after cold vacuum drying (CVD).

1.2 Summary of Results

Table 1-1 below summarizes the OCRWM data loop errors for the Pressure Test and the Proof Demonstration. For both of these assessments, the MCO annulus water temperature must be ≥ 40 °C as measured by TIT-3*05, 3*12, and the MCO pressure must be ≤ 12 torr. Additionally for the Final Rebound Pressure Rise Test, the pressure must be maintained ≤ 12 torr, and the MCO pressure rise must be ≤ 2.4 torr/hr for ≥ 1 hour.

Table 1-1. OCRWM Loop Error

OCRWM Evaluation	OCRWM Data to MCS	Field sensor	Total Expected reading error (during calibration period)
Proof Demonstration	MCO Vacuum pressure	PT 1*08, 1*10	± 1.98 torr with 2 torr system drop
Initial ¹ /Final Rebound Pressure Test	MCO Delta Vacuum pressure	PT 1*08, 1*10	± 0.23 torr
Proof Demonstration & Pressure Test	TW temperature	TIT-3*05, 3*12	± 0.58 °C

¹ Not OCRWM data. The Initial Rebound Pressure Test is safety related information used in processing.

Table 1-2 below summarizes the sensor tolerances required during calibration to support the OCRWM loop error calculations.

Table 1-2. Calibration Requirements

Field sensor	Ranges	Sensor Tolerance	Loop Tolerance (OCRWM)
PT 1*08, 1*10	≤10 Torr	± 0.02 torr	± 0.1 torr
	10 to 100 Torr	± 0.15 torr	± 0.2 torr
TIT-3*05, 3*12	0 to 100 °C	± 0.17 °C	± 0.2 °C

Table 1-3 below summarizes the Measurement and Test Equipment (M&TE) accuracies required during calibration to support the OCRWM loop error calculations. Total error (square root sum of squares) for the actual equipment used shall be less than or equal to the assumed instruments. Failure to meet these requirements may impact the total expected loop errors within the calibration period. Therefore, failure to meet these requirements may impact the data used for the Proof of Dryness acceptance criteria.

Table 1-3. M&TE Requirements

Test Equipment	Relative Accuracy		Reading Error	Test Equipment Error Maximum (TEM)
(Assumed unit)	M&TE (RA_{MTEI})	Calibration Standard (RA_{STD1})	Assume digital readout	Square Root Sum of Squares
Volt Meter (Fluke 743B)	±0.0415% CS	±0.0265% CS	0%FS	±0.05%CS
Vacuum Transfer Standard (MKS PBTS1)	±0.05% CS	±0.01% CS	0%FS	±0.05%CS
Temperature Transfer Standard (AMETEK 140SE JOFRA dry block)	±(0.4)%CS	±0.1%CS	0%FS	±0.4%CS

Selection of alternate M&TE instruments will require

- 1.) An assessment of the total instrument error contribution (as described in Table 1-3) to assure that the acceptance criteria is not affected or
- 2.) Development of an updated acceptance criteria.

Baratron Absolute Pressure Transmitter

2 MCO pressure transmitter to MCS

Figure 2.1 Baratron Absolute Pressure Simplified Block Diagram

2.1 Plant Operating Conditions

MCO absolute pressure, in combination with the tempered water (TW) water temperature, provides an indication of water content in the MCO. This information is required for the Office of Civilian Radioactive Waste Management (OCRWM).

2.1.1 Proof Mode and Final Pressure Test

Once the MCO passes a initial pressure rebound test, an evacuation to less than 12 torr for up to 28 hours (for an MCO with two scrap baskets) is then conducted with the expected system base pressure of <0.5 torr. This is called the “**PROOF**” mode of operation. The **proof** mode requires the use of the vacuum pump to remove any trapped water in cracks in the fuel. At the completion of the **PROOF MODE**, a final rebound test is conducted. This post drying operation at >40 °C is utilized to verify that <200 g (0.44 lb) of water is present in the MCO prior to shipment to the CSB (see HNF-1851, *Cold Vacuum Drying Residual Free Water Test Description*).

2.2 Absolute Pressure Transmitter (PT-1*08, PT-1*10)

The sensor chosen to monitor pressure for the 12 torr analytical limit is a high accuracy; temperature regulated Baratron™ Absolute Pressure Transmitters from MKS Instruments.

™ Baratron is a registered trademark of MKS Instruments, Inc, Andover, MA.

Baratron Absolute Pressure Transmitter

2.2.1 Instrument Data

Name: Baratron Absolute Pressure Transmitter

Manufacturer: MKS Instruments, Inc.

Model Number: 427A A 00100

Type: High Accuracy, Temperature Controlled (45 °C) Absolute Pressure Transmitter

2.2.2 Reference Specifications

(Bulletin 400-10/96, 1996 - MKS Instruments, Inc.)

Range: 0 to 100 Torr

Resolution: 1×10^{-4} of Full Scale

Accuracy: 0.15% of Reading $\pm$ temperature coefficient.

Temperature Effect: Zero 0.007% FS/°C

Span 0.020% Rdg/°C

Temperature Limits: 15 to 40 °C (60 to 105 °F)

Uncertainty below range 15°C (60°F) = ± 0.05 torr

(letter from R. Traverso MKS Applications Engineer 1/26/98)

Power Supply: ± 15 VDC $\pm 5\%$

Input/Output: Range: 0.0 to 10.0 VDC

Sensor Overpressure limit: 35 psia

Factory Mutual Approvals: Explosion-proof: Class 1 Division 1&2, Group C & D

Calibration Interval: 1 year between calibrations

2.2.3 Project Specifications

The project safety specifications for the 12 torr sensor include the following:

Safety Classification: Safety Class (SC)

Performance Category: PC-3 (for pressure boundary only)

Environmental Qualification: Environmental Condition B (Certified to 105 °F)

NPH Design Requirements: Seismic Condition B for boundary only

Required Safety Functions: Pressure boundary integrity, input to SCIC for 12 torr trip and pressure rebound test results

2.2.4 Uncertainty Terms that Affect Set Point Determination

A. Assumptions

- i.) Turn Down Ratio = 1 (transmitter will have a full span of 100 Torr)
- ii.) Calibrations performed at ambient 72 ± 8 °F or 64 to 80 °F
- iii.) Min/max temperature range is 40 to 115 °F
- iv.) Drift: $\pm 1\%$ Calibrated Span (CS) per year
- v.) Calibrated Span (CS) = 100 Torr

Baratron Absolute Pressure Transmitter

B. Sensor Uncertainty

i.) Relative Accuracy (RA)

Given: RA = 0.15% Reading (Rdg)

ii.) Static Pressure (SP)

SP = 0% CS

Basis: Assumed zero for pressures <35 psi.

Sensor maintains RA = $\pm 0.15\%$ of Rdg up to 35 psi

iii.) Humidity Effect (HE)

HE = 0% Calibrated Span

Basis: Housed in NEMA 4 enclosure

iv.) Temperature Effect (TE)

Given: $TE_s = \pm 0.020\% \text{ Rdg}/^\circ\text{C}$ for Span (100 Torr)

$TE_z = \pm 0.007\% \text{ FS}/^\circ\text{C}$ for Zero (0 Torr)

Uncertainty below temp range of 15°C (60°F) = ± 0.05 torr

With TDR = 1, CS = Span = 100 Torr

Assume worst case Rdg = 100 $TE_s = 0.02\% \text{ CS}/^\circ\text{C}$

$TE_z = 0.007\% \text{ CS}/^\circ\text{C}$

Combining terms (+)

Temp Effect = $0.007\% \text{ FS}/^\circ\text{C} + 0.02\% \text{ Rdg}/^\circ\text{C} = 0.027\% \text{ CS}/^\circ\text{C}$

Temp Uncertainty = $0.027\% \text{ CS}/^\circ\text{C} + 0.05 * 100\%/100\text{torr}$ (converts to CS
since calibrated range is 100 torr)

= $0.027\% \text{ CS}/^\circ\text{C} + 0.05\% \text{ CS}$

Assume $T_{\text{max}} = 105^\circ\text{F}$, $T_{\text{norm}} (\text{lower}) = 72-8 = 64^\circ\text{F}$

Therefore $T_{\text{delta}} = 105^\circ\text{F} - 64^\circ\text{F} = 41^\circ\text{F} = 22.8^\circ\text{C}$

i.e., Temp Uncertainty = $(0.027 \cdot \text{FS} \cdot dT + 0.05 \cdot \text{FS})\%$

= $(0.027 \cdot 100 \cdot 22.8^\circ\text{C} + 0.05 \cdot 100)/100$

= $0.666\% \text{ CS}$

v.) Radiation Effect (RE)

Given: Dose Rate = 8.5mR/hr

Total Integrated Dose = $8.5 \text{ mR/hr} * 43800 \text{ hr} = 372,300 \text{ mR}$

No Radiation Effect Data, assumed zero because relatively small dose

Assume: RE = $\pm 0\% \text{ CS}$

vi.) Power Supply Effect (PSE)

Given: No PSE while supply voltage maintained at 15 VDC $\pm 5\%$

PSE = 0%

Baratron Absolute Pressure Transmitter

vii.) Seismic Effect (SE)

No credit for this device is taken during or after a seismic event

$$SE = 0\%$$

viii.) Sensor Measurement and Test Equipment Effect (SMTE)

Test Equipment1 : Fluke 743B, DC Volts, Damping is OFFCalibration Temperature Range with no TempEffect: >18 and <28°C
(~64 to 80°F)

Full Scale (FS) = 10V

Calibrated Span = 0 to 10V, Max Reading (Rdg) = 100 Torr = 10V

$$RA_{MTE1} = 0.025\% * R_{dg} + 3 * (0.005\% FS) \text{ (Given: times 3 with damping OFF)}$$

$$= 0.025\% * CS + 0.015\% FS * (CS/FS)$$

$$= \pm 0.040\% CS$$

$$RA_{STD1} = 0.01\% * R_{dg} + 3 * 0.005\% FS \text{ (Use given Source Accuracy,}$$

Assume also *3 with Damping OFF)

$$= 0.01\% * CS + 0.015\% FS * (CS/FS)$$

$$= \pm 0.025\% CS$$

$$RD1 = 0\% FS \text{ (digital readout)}$$

$$SA1 = 0.15\% R_{dg} + TE \text{ (relative accuracy and TempEffect)}$$

Assume calibrated at 72 and operated at 64 to 80

$$= 0.15\% R_{dg} + 0.027\% CS/^{\circ}C * \Delta T = 0.15\% CS + (0.027\% CS/^{\circ}C) * 8.89^{\circ}C/2$$

$$= 0.27\% CS$$

$$MTE1 = (RA_{MTE1}^2 + RA_{STD1}^2 + RD1^2 + SA1^2)^{1/2}$$

$$MTE1 = (0.04^2 + 0.025^2 + 0^2 + 0.27^2)^{1/2} = 0.274\% CS$$

$$MTE1 = 0.274\% FS$$

Test Equipment2, MKS Portable Pressure Transfer Standard Type PBTS1

Operating Temperature Range: 15 to 40°C

Full Scale (FS) = 100 Torr

Resolution = 0.0001 Torr

$$RA_{MTE2} = 0.05\% * R_{dg}$$

$$= 0.05\% * CS \text{ (100 Torr = CS is maximum Reading)}$$

$$= \pm 0.05\% CS$$

$$RA_{STD2} \leq 0.01\% CS \text{ (Assume Calibration Standard used was at least 4:1)}$$

$$RD2 = 0\% FS \text{ (digital readout)}$$

$$SA2 = 0 \text{ (already counted in MTE1)}$$

$$MTE2 = (RA_{MTE1}^2 + RA_{STD1}^2 + RD1^2 + SA1^2)^{1/2}$$

$$MTE2 = (0.05^2 + 0.01^2 + 0^2 + 0^2)^{1/2} = 0.051\% CS$$

$$MTE2 = 0.051\% FS$$

$$SMTE = MTE1 + MTE2 = 0.274 + 0.051 = 0.325\% CS$$

Baratron Absolute Pressure Transmitter

ix.) Total Sensor Uncertainties

The assumed drift term DR will be taken as a bias (conservative option).

$$\begin{aligned} e^+ &= [(RA+TE)^2 + SP^2 + HE^2 + RE^2 + PSE^2 + SE^2 + SMTE^2]^{1/2} + DR \\ &= [(0.15 + 0.666)^2 + 0 + 0 + 0 + 0 + 0 + (0.325)^2]^{1/2} + 1 = 1.9\%CS \end{aligned}$$

$$\begin{aligned} e^- &= -([(RA+TE)^2 + SP^2 + HE^2 + RE^2 + PSE^2 + SE^2 + SMTE^2]^{1/2} + DR) \\ &= -([(0.15 + 0.666)^2 + 0 + 0 + 0 + 0 + 0 + (0.325)^2]^{1/2} + 1) = -1.9\%CS \end{aligned}$$

The error with drift associated with the sensor (e_{sens}) is as follows:

$$e_{sens} = \pm 1.9\%CS$$

Framatome STAR System – Baratron channels

2.3 Framatome STAR System - Analog Voltage Isolation Module (AVIM)**2.3.1 Instrument Data**

Name: AVIM
 Manufacturer: Framatome Technologies
 Model Number:
 Type: Analog Voltage Isolation Module

2.3.2 Reference Specifications

Range: 0 to 10 VDC
 Resolution:
 Accuracy: input to output: $\pm 0.1\%$ of Full Range (for temperature range 40 to 140 °F)
 Drift: $\pm 0.05\%$ Full Range
 Analog Input/Output: Range: 0.0 VDC to 10.0 VDC
 Calibration Interval: 12 months (letter J. Secina FTI-99-1537)

2.3.3 Calibration**A. Assumptions**

- i.) Turn Down Ratio = 1
- ii.) Calibrations performed at ambient 72 ± 8 °F or 64 to 80 °F
- iii.) Min/max expected temperatures is 40 to 105 °F
- iv.) Calibrated Span (CS) = Full Scale = 10 VDC
- v.) Processor Module input error calculation multiplier factor = 1

B. Channel Uncertainty to MCS – General Service

- i.) Drift (DR)
 $DR = \pm 0.05\% \text{ CS}$
- ii.) Relative Accuracy (RA)
 Given: $RA = RA_{\text{avim}}$
 $= \pm 0.1\% \text{ Full Range}$
 $RA = \pm 0.1\% \text{ CS}$
- iii.) Static Pressure (SP)
 $SP = 0\% \text{ CS}$
 Basis: Not a pressure sensor, not subject to the pressure effects of the process
- iv.) Humidity Effect (HE)
 $HE = 0\% \text{ CS}$
 Basis: Housed in NEMA 4 enclosure

Framatome STAR System – Baratron channels

- v.) Temperature Effect (TE)
 Given: Reference accuracy is certified for range 40 to 140 °F
 And expected range 40 to 105 °F
 TE = 0%CS
- vi.) Radiation Effect (RE)
 Given: Dose Rate = 8.5mR/hr
 Total Integrated Dose = 8.5 mR/hr * 43800 hr = 372,300 mR
 Radiation Effect Data says there is no effect to 10,000,000 mR TID
 Because relatively small dose (based on HNF-SD-SNF-DRD-002, Rev.1)
 Assume: RE = ±0%CS
- vii.) Power Supply Effect (PSE)
 Given: No PSE while supply voltage maintained at 15 VDC ±10%
 PSE = 0%
- viii.) Seismic Effect (SE)
 Device is qualified per IEEE 344-1987 to withstand 17 g seismic event
 Design Basis event is postulated as 0.26 g
 SE = 0%
- ix.) Sensor Measurement and Test Equipment Effect (SMTE)
Test Equipment1: Fluke 743B, DC Volts, Damping is OFF
 Calibration Temperature Range with no TempEffect: >18 and <28°C
 (~64 to 80°F)
 Full Scale (FS) = 10V
 Calibrated Span = 0 to 10V, Max Reading (Rdg) = 100 Torr = 10V
 $RA_{MTE1} = 0.025\% * R_{dg} + 3 * (0.005\% FS)$ (Given: times 3 with damping OFF)
 $= 0.025\% * CS + 0.015\% FS * (CS/FS)$
 $= \pm 0.04\% CS$
 $RA_{STD1} = 0.01\% * R_{dg} + 3 * 0.005\% FS$ (Use given Source Accuracy,
 Assume also *3 with Damping OFF)
 $= 0.01\% * CS + 0.015\% FS * (CS/FS)$
 $= \pm 0.025\% CS$
 RD1 = 0%FS (digital readout)
 SA1 = 0.2% FS (Assume twice Relative accuracy of AVIM - in/out))
 $MTE1 = (RA_{MTE1}^2 + RA_{STD1}^2 + RD1^2 + SA1^2)^{1/2}$
 $MTE1 = (0.04^2 + 0.025^2 + 0^2 + 0.2^2)^{1/2} = 0.206\% CS$
 MTE1 = 0.206 %FS (used for both the input and output of the AVIM.)
 $SMTE = (0.206^2 + 0.206^2)^{1/2} = 0.291$
- x.) STAR AVIM Uncertainties – MCS monitoring
- $$e^+ = [DR^2 + RA^2 + SP^2 + HE^2 + TE^2 + RE^2 + PSE^2 + SE^2 + SMTE_{AVIM-in/out}^2]^{1/2}$$
- $$= [0.05^2 + 0.1^2 + 0 + 0 + 0 + 0 + 0 + 0 + 0.291^2]^{1/2} = 0.312\% CS$$
- $$e_{proc} = \pm 0.312\% CS$$

MCS Modicon– Baratron channels

2.4 MCS Analog to Digital Module (A/D)**2.4.1 Instrument Data**

Name: Analog In Module
 Manufacturer: Modicon
 Model Number: AVI 030 00
 Type: 16 bit

2.4.2 Reference Specifications

Range: 0 to 10 VDC
 Resolution: 16 bit
 Accuracy: input to output: $\pm 0.05\%$ of Full Range
 Drift: $\pm 0.0025\%FS/^\circ C$
 Calibration Interval: 12 months between calibrations (assume)

2.4.3 Calibration**A. Assumptions**

- i.) Calibrations performed at ambient $72 \pm 8^\circ F$ or 64 to $80^\circ F$
- ii.) Min/max expected temperatures is 40 to $105^\circ F$
- iii.) Calibrated Span (CS) = Full Scale = 10 VDC

B. Channel Uncertainty

- i.) Assume Drift (DR1)
 $DR1 = \pm 0.05\% CS$
- ii.) Relative Accuracy (RA)
 Given: $RA = \pm 0.05\% FS$
 $RA = \pm 0.05\% CS$
- iii.) Static Pressure (SP)
 $SP = 0\% CS$
 Basis: Not a pressure sensor, not subject to the pressure effects of the process
- iv.) Humidity Effect (HE)
 $HE = 0\% CS$ Basis: Housed in NEMA 4 enclosure
- v.) Temperature Effect (TE)
 Given: $0.005\%FS/^\circ C$
 Assume $T_{max} = 105^\circ F = 40.6^\circ C$
 $T_{norm(lower)} = 72 - 8 = 64^\circ F = 17.8^\circ C$ Lower calibration temperature
 Therefore $T_{delta} = 41\Delta^\circ F = 22.8\Delta^\circ C$
 $TE = 0.005\%CS/^\circ C * 22.8\Delta^\circ C = 0.114\%CS$

MCS Modicon-- Baratron channels

vi.) Radiation Effect (RE)

Given: Dose Rate = 8.5mR/hr

Total Integrated Dose = 8.5 mR/hr * 43800 hr = 372,300 mR

Radiation Effect Data says there is no effect to 10,000,000 mR TID

Because relatively small dose (based on HNF-SD-SNF-DRD-002, Rev.1)

Assume: RE = $\pm 0\%$ CS

vii.) Power Supply Effect (PSE)

Given: External power not required

PSE = 0%

viii.) Seismic Effect (SE)

No credit for this device is taken during or after a seismic event.

SE = 0%

ix.) Sensor Measurement and Test Equipment Effect (SMTE)

Test Equipment1: Fluke 743B, DC Volts, 5 digit display

See Section 2.3.3 B.ix.)

SMTE = MTE1 = 0.206 %CS

x.) Total MCS A/D Uncertainties

$$e^+ = [DR^2 + RA^2 + SP^2 + HE^2 + TE^2 + RE^2 + PSE^2 + SE^2 + SMTE^2]^{1/2}$$

$$= [0.05^2 + 0.05^2 + 0 + 0 + 0.114^2 + 0 + 0 + 0 + 0.206^2]^{1/2} = 0.246\%CS$$

$$e_{a/d} = \pm 0.246\%CS$$

OCRWM Loop Uncertainty– Baratron channels

2.5 Total Loop Uncertainty - General Service MCS Loop

$$CU^+ = [e^2_{\text{sens-dr}} + e^2_{\text{proc}} + e^2_{\text{a/d}}]^{1/2} + DR_{\text{sens}} + B_{\text{proc}}$$

$$CU^+_{\text{mcs}} = \pm \{ [0.9^2 + 0.312^2 + 0.25^2]^{1/2} + 1 + 0 \} = 1.985 \%CS$$

$$CU_{\text{mcs}} = \pm 1.985 \%CS$$

2.6 MCS Vacuum Loop Error Determination (OCRWM)

$$E_{\text{ocrwm}} = \pm 1.985 \%CS * 100 \text{ torr/CS} + 2 \text{ torr (system drop)} = \pm 3.99 \text{ torr}$$

Delta Pressure - Baratron channels

2.7 Delta Pressure Accuracy**2.7.1 Uncertainty Terms that Affect Accuracy**

Note: Since this is a Delta Pressure over a relatively short time, several terms are no longer necessary. However, since the accuracy test could be run on a different day than when the result may be required, temperature does affect the results.

A. Sensor Uncertainty**i.) Relative Accuracy (RA)**

Given: RA = 0.15% Reading (Rdg)

ii.) Drift (DR)

Assume DR = 0 for time interval of 1 hour

iii.) Temperature Effect (TE)

Given: $TE_s = \pm 0.020\% \text{ Rdg}/^\circ\text{C}$ for Span (100 Torr)

$TE_z = \pm 0.007\% \text{ FS}/^\circ\text{C}$ for Zero (0 Torr)

Uncertainty below temp range of 15°C (40 to 60°F) = ± 0.05 torr

With TDR = 1, CS = FS = Span = 100 Torr

Temp Effect = $0.02\% \cdot \text{Rdg}/^\circ\text{C} + (0.007\% \cdot \text{FS}/^\circ\text{C})$

Temp Uncertainty = $0.0002 \cdot \text{Rdg}/^\circ\text{C} + (0.007 \text{ torr}/^\circ\text{C} + 0.05 \text{ torr})$

Assume $T_{\text{max}} = 105^\circ\text{F}$, $T_{\text{norm}} (\text{lower}) = 72-8 = 64^\circ\text{F}$

Therefore $T_{\text{delta}} = 105 - 64 = 41^\circ\text{F} = 22.8^\circ\text{C}$

Temp Uncertainty = $0.0002 \cdot 22.8 \cdot \text{Rdg} + (0.007 \cdot 22.8 \text{ torr} + 0.05 \text{ torr})$

= $0.00456 \cdot \text{Rdg} + (0.21 \text{ torr})$

NOTE: Assume that the 0.21 torr (the Zero Drift and the uncertainty below temperature range) is a bias and can be ignored over the time interval

Temp Uncertainty = $0.00456 \cdot \text{Rdg}$ torr

iv.) Framatome Analog Voltage Isolation Module (AVIM) Input and Output Error

$RA_F = \pm 0.1\%$ of Full Range

Full Range = 10 VDC $\Leftrightarrow$ 100 torr

$RA_F = (0.1^2)^{1/2} = 0.1\% \text{CS} = 0.1\% \cdot 10\text{V}/100\% \cdot 100 \text{ torr}/10\text{V} = 0.1 \text{ torr}$

v.) MCS Input and Output Error

Processor Module input error calculation multiplier factor $\beta = 1.0$

MCS 16 bit Accuracy: $\pm 0.05\%$ of Full Range (Analog Input)

Full Range = 10 VDC $\Leftrightarrow$ 100 torr

$RA_{\text{mcs}} = (\beta \cdot RA_I^2)^{1/2}$

$RA_{\text{mcs}} = (0.05^2)^{1/2} = 0.05\% \text{CS} = 0.05\% \cdot 10\text{V}/100\% \cdot 100 \text{ torr}/10\text{V} = 0.05 \text{ torr}$

Delta Pressure - Baratron channels

vi.) Total Sensor Delta Pressure Uncertainties

Sensor and Readout Error on Span Measurements

Pressure rise from 0.5 to 2.9 torr

$$\begin{aligned}
 SE_1 &= \pm [RA_s^2 + TE_s^2 + RA_F^2 + RA_{mcs}^2]^{1/2} \\
 &= \pm [(0.0015*0.5)^2 + (0.00456*0.5)^2 + 0.1^2 + 0.05^2]^{1/2} \\
 &= \pm 0.112 \text{ torr} \\
 SE_2 &= \pm [RA_s^2 + TE_s^2 + RA_F^2 + RA_{mcs}^2]^{1/2} \\
 &= \pm [(0.0015*2.9)^2 + (0.00456*2.9)^2 + 0.1^2 + 0.05^2]^{1/2} \\
 &= \pm 0.113 \text{ torr}
 \end{aligned}$$

Pressure rise from 5 to 7.4 torr

$$\begin{aligned}
 SE_1 &= \pm [RA_s^2 + TE_s^2 + RA_F^2 + RA_{mcs}^2]^{1/2} \\
 &= \pm [(0.0015*5.0)^2 + (0.00456*5)^2 + 0.1^2 + 0.05^2]^{1/2} \\
 &= \pm 0.114 \text{ torr} \\
 SE_2 &= \pm [RA_s^2 + TE_s^2 + RA_F^2 + RA_{mcs}^2]^{1/2} \\
 &= \pm [(0.0015*7.4)^2 + (0.00456*7.4)^2 + 0.1^2 + 0.05^2]^{1/2} \\
 &= \pm 0.114 \text{ torr}
 \end{aligned}$$

2.7.2 MCS Delta Vacuum Loop Error Determination (OCRWM)

Without considering Temperature Effects:

For a pressure rise test from 0.5 torr to 2.9 torr or from 5.0 torr to 7.4 torr, the OCRWM loop error on each measurement is less than or equal to ± 0.114 torr. Since it is an $\pm$ error, the maximum error would be 0.228 torr.

i.e.) 0.5 ± 0.114 to 2.9 ± 0.114 becomes 0.386 to 3.014 or 0.614 to 2.786

$$\text{Span} = 2.9 (\pm 0.114) - 0.5 (\pm 0.114) = 2.4 \pm 0.228 \text{ torr}$$

Considering Temperature Effects:

When temperature variation (i.e., the potential difference between calibration temperature and test temperature) is included, the loop error on all measurements ≤ 8 torr (12 – 4 torr measurement error) is ≤ 0.118 torr. Since it is an $\pm$ error, the maximum error would be 0.236 torr.

The maximum resolution is 0.01 torr. Therefore, rounding up to two digit accuracy,

$$\text{DELTA } E_{\text{ocrwm}} = \pm 0.24 \text{ torr}$$

Calibration Requirements - Baratron channels

2.8 OCRWM Vacuum Pressure Calibration Requirements**2.8.1 Vacuum Pressure Sensor/Loop****2.8.1.1 MKS Baratron****A. Assumptions**

- i.) Turn Down Ratio = 1 (transmitter will have a full span of 100 Torr)
- ii.) Calibrations performed at ambient 72 ± 8 °F or 64 to 80 °F

B. Sensor Uncertainty

- i.) Relative Accuracy (RA)
Given: RA = 0.15% Reading (Rdg)

C. Tolerance Requirements

- i.) Proof Mode and Pressure Test (Range ≤ 10 Torr)
 $\pm 0.15\% \text{ Reading} * 10 \text{ Torr} = \pm 0.015 \text{ Torr}$
 Resolution = 0.01 Torr
 Therefore, rounding up
 Tolerance (Range ≤ 10 Torr) = ± 0.02
- ii.) Pressure Test (Range > 10 Torr)
 $\pm 0.15 \% \text{ CS} * 100 \text{ Torr/CS} = 0.15 \text{ Torr}$
 Tolerance (Range 10 to 100 Torr) = $\pm 0.15 \text{ Torr}$

D. OCRWM Sensor Calibration Tolerance

<u>RANGE</u>	<u>Sensor Tolerance</u>
0 to 10 Torr	$\pm 0.02 \text{ torr}$
10 to 100 Torr	$\pm 0.15 \text{ torr}$

Calibration Requirements - Baratron channels

2.8.1.2 Loop Components

2.8.1.2.1 Framatome STAR System - Analog Voltage Isolation Module (AVIM)

A. Assumptions

- i.) Calibrations performed at ambient 72 ± 8 °F or 64 to 80 °F
- ii.) Calibrated Span (CS) = Full Scale (FS) = 10 VDC

B. Channel Uncertainty to MCS – General Service

- i.) Relative Accuracy (RA)
Given: $RA = RA_{avim} = \pm 0.1\%$ Full Range
 $RA = \pm 0.1\%$ CS

2.8.1.2.2 Modicon Analog to Digital Module (A/D)

A. Assumptions

- i.) Calibrations performed at ambient 72 ± 8 °F or 64 to 80 °F
- ii.) Calibrated Span (CS) = Full Scale (FS) = 10 VDC

B. Channel Uncertainty

- i.) Relative Accuracy (RA)
Given: $RA = \pm 0.05\%$ FS

2.8.1.2.3 OCRWM Loop Calibration

A. Loop Tolerance (LT) Determination

Range ≤ 10 Torr, Max Reading = 10 Torr, FS = CS = 100 Torr

$$LT = \pm [RA_s^2 + RA_F^2 + RA_{mcs}^2]^{1/2} = \pm [(0.15\% \text{ Rdg})^2 + 0.1\%FS^2 + 0.05\%FS^2]^{1/2}$$

$$= \pm [(0.0015 \cdot 10)^2 + (0.1\% \cdot 100 \text{ Torr}/100\%)^2 + (0.05\% \cdot 100 \text{ Torr}/100\%)^2]^{1/2}$$

$$LT = \pm [(0.0015 \cdot 10)^2 + 0.1^2 + 0.05^2]^{1/2} \text{ Torr}$$

$$LT = \pm 0.11 \text{ Torr (Note Resolution is 0.01, Truncate to 0.1 Torr)}$$

$$LT = \pm 0.1 \text{ Torr}$$

Range 10 to 100 Torr, Max Reading = FS = CS = 100 Torr

$$LT = \pm [RA_s^2 + RA_F^2 + RA_{mcs}^2]^{1/2}$$

$$= \pm [0.15^2 + 0.1^2 + 0.05^2]^{1/2} \%CS = \pm 0.19\%CS$$

$$= \pm 0.19\%CS \cdot 100 \text{ Torr}/100\%CS = 0.19 \text{ Torr}$$

$$\text{Rounding } 0.19 \approx 0.2$$

B. OCRWM Loop Calibration Tolerance

<u>RANGE</u>	<u>Loop Tolerance</u>
≤ 10 Torr	± 0.1 torr
10 to 100 Torr	± 0.2 torr

Vacuum Pressure M&TE Requirements

2.8.2 Measurement and Test Equipment

i.) Test Equipment Error Maximum (TEM)

1. Test Equipment1: Volt Meter

Assume Fluke 743B, DC Volts with Damping OFF or equivalent
 Calibration Temperature Range with no TempEffect: >18 and <28°C
 (~64 to 80°F)

$$\begin{aligned} RA_{MTE1} &= 0.025\% * R_{dg} + 3 * (0.005\% FS) \text{ (Given: times 3 with damping OFF)} \\ &= 0.025\% * CS + 0.015\% FS * (CS/FS) \\ &= \pm 0.04\% CS \end{aligned}$$

$$\begin{aligned} RA_{STD1} &= 0.01\% * R_{dg} + 3 * 0.005\% FS \text{ (Use given Source Accuracy, Assume also *3 with Damping OFF)} \\ &= 0.01\% * CS + 0.015\% FS * (CS/FS) \\ &= \pm 0.025\% CS \end{aligned}$$

$$RD1 = 0\% FS \text{ (digital readout)}$$

TEM Contribution from Volt Meter

Note: Setting Accuracy (SA) is not considered.

$$TEM = \pm (0.04^2 + 0.025^2 + 0)^{1/2} = \pm 0.05\% CS$$

2. Test Equipment2, Vacuum Standard

Assume MKS Portable Pressure Transfer Standard Type PBTS1 or equivalent
 Operating Temperature Range: 15 to 40°C
 Full Scale (FS) = 100 Torr
 Resolution = 0.0001 Torr

$$\begin{aligned} RA_{MTE2} &= 0.05\% * R_{dg} \\ RA_{STD2} &\leq 0.01\% CS \text{ (Assume Calibration Standard used was at least 4:1)} \\ RD2 &= 0\% FS \text{ (digital readout)} \end{aligned}$$

TEM Contribution from Pressure Transfer Standard

$$TEM = \pm (0.05^2 + 0.01^2 + 0)^{1/2} = \pm 0.05\% CS$$

Rosemount Temperature Transmitter

3 MCO temperature transmitter to MCS

Figure 3.1 TW Temperature Simplified Block Diagram

3.1 Plant Operating Conditions

The tempered water (TW) water temperature, in combination with the MCO absolute pressure, provides an indication of water content in the MCO. This information on Proof of Drying is required for the Office of Civilian Radioactive Waste Management (OCRWM).

3.1.1 Drying Mode Operations

A period of time under vacuum (Proof Mode) is completed at the CVD Facility to assure free water has been sufficiently removed from the MCO. This operation will measure the MCO internal pressure above a specific temperature for a specified time.

- Proof Mode: the MCO must be $\geq 40^{\circ}\text{C}$, and the MCO pressure must be ≤ 12 torr for a total time of greater or equal to
 - (1) 8 hours for an MCO with no scrap baskets,
 - (2) 20 hours for an MCO with one scrap basket,
 - (3) 28 hours for an MCO with two scrap baskets.
- The final pressure rebound test: the MCO must be $\geq 40^{\circ}\text{C}$, and the MCO evacuated to ≤ 10 torr. MCO pressure rise shall be ≤ 2.4 torr per hour for a duration of ≥ 1 hour.

This information, and the analysis that documents the correlation of temperature, pressure, and time to water content in the MCO, will be used to document the fuel in the MCO has met the “no free liquid” criteria.

Rosemount Temperature Transmitter

3.2 Temperature Transmitter (TIT-3*05, TIT-3*12)**3.2.1 Instrument Data**

Name: Smart Temperature Transmitters
 Manufacturer: Rosemount Instruments
 Model Number: 3244MV 1 NA M5 C2 Q4
 Type: Model 3244 MV Smart Temperature Transmitter

3.2.2 Reference Specifications**3.2.2.1 Transmitter Reference Specifications**

Temperature Range:	0 to 100 °C span
Ambient Temp Effect:	Digital: 0.0015°C per 1°C change in ambient D/A: 0.001% span per 1°C change in ambient When the location has range between -40 to 85 °C
Stability:	± 0.1 % Rdg or 0.1 °C whichever is greater
Accuracy:	digital: ± 0.14 °C, D/A: ± 0.02 % of span
Repeatability:	± 0.05 °C
Calibration Interval:	2 years between calibrations

3.2.2.2 RTD Reference Specifications

Input Temp Range:	0 to 100 °C
Stability:	± 0.08% ice point resistance shift
Repeatability:	± 0.05 %
Calibration Interval:	2 years between calibrations

3.2.3 Calibration**A. Assumptions**

- i.) Transmitter calibrations performed at ambient 72 ± 8 °F or 64 to 80 °F
- ii.) Min/max expected normal ambient temperature range is 40 to 105 °F
- iii.) Calibration Interval = 1 year

B. Sensor Uncertainty

- i.) Relative Accuracy (RA)

Given: transmitter RA = $0.14 \text{ °C} \cdot (100\% \text{CS} / 100 \text{ °C}) + 0.02\% \text{CS} = 0.16\% \text{CS}$

Given: sensor Repeatability = 0.05% Span

$$RA = (0.16^2 + 0.05^2)^{1/2} = 0.17 \% \text{CS}$$

Rosemount Temperature Transmitter

- ii.) Drift
Assume RTD Drift is the ice point resistance shift (zero) 0.08%CS
Treat as bias. i.e., additive
 $DR = \pm (0.1 \% CS + 0.08\% CS) = \pm 0.18\%CS$
- iii.) Temperature Effect (TE)
Given: Transmitter TE = $0.0015\ ^\circ C / (1^\circ C \text{ change in ambient}) * T_{\Delta}$
 $+ 0.001\%CS / (1^\circ C \text{ change in ambient}) * T_{\Delta}$
Assume $T_{max} = 105\ ^\circ F = 40.6\ ^\circ C$
 $T_{norm(lower)} = 72 - 8 = 64^\circ F = 17.8\ ^\circ C$ Lower calibration temperature
Therefore $T_{\Delta} = 105 - 64 = 41\Delta^\circ F = 22.8\ \Delta^\circ C$
Transmitter Temperature Effect
 $TE = 0.0015\ ^\circ C / 1^\circ C * 22.8^\circ C * (100\%CS / 100^\circ C) + 0.001\%CS / 1^\circ C * 22.8^\circ C$
 $TE = 0.057\ \%CS$
- iv.) Static Pressure (SP)
 $SP = 0\%$
Basis: Assumed zero for low pressures.
- v.) Humidity Effect (HE)
 $HE = 0\%$
Basis: Active portions are sealed i.e. not exposed to outside environment.
NEMA-4X Enclosure. Listed range 0 to 100% relative humidity
- vi.) Radiation Effect (RE)
Given: Dose Rate = 8.5mR/hr
 $Total\ Integrated\ Dose = 8.5\ mR/hr * 43800\ hr = 372,300\ mR\ TID$
No Radiation Effect Data, RE is assumed zero because of the very low dose
Assume: $RE = \pm 0\%$
- vii.) Power Supply Effect (PSE)
Given: $PSE = \pm 0.005\%$ of span/volt
Assume power supply variance $15\ VDC \pm 10\% = 1.5V$
 $PSE = \pm 0.005\%$ of span/V * 1.5V = 0.0075%CS
- viii.) Seismic Effect (SE)
No credit for this device is taken during or after a seismic event, unit will have to be re-qualified and recalibrated if seismic level exceeds TBD g.
 $SE = 0\%$

Rosemount Temperature Transmitter

ix.) Sensor Measurement and Test Equipment Effect (SMTE)

Test Equipment 1: Fluke 87, DC voltage mode with a 4 digit display

$$RA_{MTE1} = 0.05\%Rdg + 1 \text{ digit}$$

$$\text{Max Reading} = 15V = CS$$

$$RA_{MTE1} = \pm 0.05\% * 15V / (15V/CS) + 0.01V / (15V/CS) * 100\% \\ = \pm 0.12\%CS$$

$$RA_{STD1} = 0.04\% \text{ (assume 4 times more accurate)}$$

$$RD1 = 0\% \text{ (digital read out)}$$

$$SA1 = 0.25\% \text{ (assume setting accuracy equal to twice the relative accuracy)}$$

$$MTE1 = (RA_{MTE1}^2 + RA_{STD1}^2 + RD1^2 + SA1^2)^{1/2} \\ = (0.12^2 + 0.04^2 + 0^2 + 0.25^2)^{1/2}$$

$$MTE1 = 0.28 \%CS$$

Test Equipment2: NIST traceable Temperature Standard AMETEK 140SE JOFRA dry block

$$\text{Accuracy} = \pm 0.3 \text{ }^{\circ}C$$

$$\text{Stability} = \pm 0.05 \text{ }^{\circ}C$$

$$RA_{MTE1} = \text{Accuracy} + \text{Stability}$$

$$RA_{MTE1} = 0.3 + 0.05 = 0.35 \text{ }^{\circ}C = 0.35/1.0 CS = 0.35\% CS$$

$$RA_{MTE1} = \pm 0.35\% CS$$

$$RA_{STD1} = \pm 0.1 \text{ }^{\circ}C \text{ (NIST standard (RTD used for calibration))}$$

$$RA_{STD1} = 0.1 \text{ }^{\circ}C (100/100) = 0.1\% CS$$

$$RD1 = 0\%CS \text{ (digital readout)}$$

$$SA1 = 0.1\%CS$$

(Assume standard temperature setpoint accuracy equal to relative accuracy)

$$MTE1 = (RA_{MTE1}^2 + RA_{STD1}^2 + RD1^2 + SA1^2)^{1/2}$$

$$MTE1 = (0.35^2 + 0.1^2 + 0 + 0.1^2)^{1/2} = 0.4\%CS$$

$$SMTE = (MTE1^2 + MTE2^2)^{1/2} = (0.28^2 + 0.4^2)^{1/2} \%CS = 0.49 \%CS$$

x.) Total Uncertainties

$$e^+ = [RA^2 + DR^2 + TE^2 + SP^2 + HE^2 + RE^2 + PSE^2 + SE^2 + SMTE^2]^{1/2} + \text{bias} \\ = [0.17^2 + 0.1^2 + 0.057^2 + 0 + 0 + 0 + 0.0075^2 + 0 + 0.49^2]^{1/2} + 0.08 \\ = (0.53 + 0.08) = 0.61\%CS$$

$$e^- = -\{[RA^2 + DR^2 + TE^2 + SP^2 + HE^2 + RE^2 + PSE^2 + SE^2 + SMTE^2]^{1/2} + \text{bias}\} \\ = -\{[0.17^2 + 0.1^2 + 0.057^2 + 0 + 0 + 0 + 0.0075^2 + 0 + 0.49^2]^{1/2} + 0.08\} \\ = -0.61\%CS$$

$$e_{\text{sens}} = \pm 0.61\%CS$$

MCS Modicon - Rosemount Temperature Channels

3.3 MCS Analog to Digital Module (A/D)**3.3.1 Instrument Data**

Name: Analog In Module
 Manufacturer: MODICON
 Model Number: ACI 030 00
 Type: 12 bit

3.3.2 Reference Specifications

Range: 4 to 20 mA
 Resolution: 12 bit
 Accuracy: input to output: $\pm 0.1\%$ of Full Range
 Drift: $\pm 0.0025\%FS/^\circ C$
 Calibration Interval: 12 months between calibrations (assume)

3.3.3 Calibration**A. Assumptions**

- i.) Calibrations performed at ambient $72 \pm 8^\circ F$ or 64 to 80 $^\circ F$
- ii.) Min/max expected temperatures is 40 to 95 $^\circ F$
- iii.) Calibrated Span (CS) = Full Scale = 10 VDC

B. Channel Uncertainty

- i.) Assume Drift (DR1)
 $DR1 = \pm 0.05\% CS$
- ii.) Relative Accuracy (RA)
 Given: $RA = \pm 0.1\% FS$ (worst case)
 $RA = \pm 0.1\% CS$
- iii.) Static Pressure (SP)
 $SP = 0\% CS$
 Basis: Not a pressure sensor, not subject to the pressure effects of the process
- iv.) Humidity Effect (HE)
 $HE = 0\% CS$
 Basis: Housed in NEMA 4 enclosure
- v.) Temperature Effect (TE)
 Given: $0.005\%FS/^\circ C$
 Assume $T_{max} = 105^\circ F = 40.6^\circ C$
 $T_{norm(lower)} = 72 - 8 = 64^\circ F = 17.8^\circ C$ Lower calibration temperature
 Therefore $T_{delta} = 105 - 64 = 41\Delta^\circ F = 22.8\Delta^\circ C$
 $TE = 0.005\%CS/^\circ C * 22.8\Delta^\circ C = 0.114\%CS$

Calibration Requirements- Rosemount Temperature Channels

- vi.) Radiation Effect (RE)
 Given: Dose Rate = 8.5mR/hr
 Total Integrated Dose = 8.5 mR/hr * 43800 hr = 372,300 mR
 Radiation Effect Data says there is no effect to 10,000,000 mR TID
 Because relatively small dose (based on HNF-SD-SNF-DRD-002, Rev.1)
 Assume: RE = $\pm 0\%$ CS
- vii.) Power Supply Effect (PSE)
 Given: External power not required
 PSE = 0%
- viii.) Seismic Effect (SE)
 No credit for this device is taken during or after a seismic event.
 SE = 0%
- ix.) Sensor Measurement and Test Equipment Effect (SMTE)
Test Equipment 1: Fluke 87, DC voltage mode with a 4 digit display
 See Section 3.2.3 B. ix)
 MTE1 = 0.28 %CS

 SMTE = MTE1 = 0.28 %CS
- x.) Total MCS A/D Uncertainties

$$e^+ = [DR^2 + RA^2 + SP^2 + HE^2 + TE^2 + RE^2 + PSE^2 + SE^2 + SMTE^2]^{1/2}$$

$$= [0.05^2 + 0.1^2 + 0 + 0 + 0.114^2 + 0 + 0 + 0 + 0.28^2]^{1/2} = 0.322 \%CS$$

$$e_{a/d} = \pm 0.322 \%CS$$

3.4 Total Loop Uncertainty - General Service MCS Loop

$$CU^+ = [e_{sens-dr}^2 + e_{a/d}^2]^{1/2} + B_{sens} + B_{proc}$$

$$CU_{mcs} = \pm \{ [0.53^2 + 0.322^2]^{1/2} + 0.08 + 0 \} = 0.62 + 0.08 = 0.70 \%CS$$

$$CU_{mcs} = \pm 0.70 \%CS$$

3.5 MCS TW Temperature Loop Error Determination (OCRWM)

$$E_{ocrwm} = \pm 0.70 \%CS * 100 ^\circ C/CS = \pm 0.70 ^\circ C$$

Calibration Requirements- Rosemount Temperature Channels

3.6 Calibration Requirements**3.6.1 Annulus Temperature Sensor/Loop****3.6.1.1 Rosemount Temperature Transmitter****A. Assumptions**

- i.) Transmitter calibrations performed at ambient 72 ± 8 °F or 64 to 80 °F
- ii.) Calibration Interval = 1 year

B. Sensor Uncertainty

- i.) Relative Accuracy (RA)

Given: transmitter RA = 0.14 °C $\cdot$ (100%CS/100°C) + 0.02%CS = 0.16%CS

Given: sensor Repeatability = 0.05% Span

$$RA = (0.16^2 + 0.05^2)^{1/2} = 0.17 \% \text{ CS} = 0.17\% \cdot 100 \text{ °C} / 100 = \pm 0.17 \text{ °C}$$

C. OCRWM Sensor Calibration Tolerance

<u>RANGE</u>	<u>Sensor Tolerance</u>
0 to 100 °C	± 0.17 °C

3.6.1.2 Loop Components**3.6.1.2.1 Framatome STAR System - Analog Voltage Isolation Module (AVIM)****A. Assumptions**

- i.) Calibrations performed at ambient 72 ± 8 °F or 64 to 80 °F
- ii.) Calibrated Span (CS) = Full Scale = 10 VDC

B. Channel Uncertainty to MCS – General Service

- i.) Relative Accuracy (RA)

Given: RA = RA_{avim} = $\pm 0.1\%$ Full Range

RA = $\pm 0.1\%$ CS

3.6.1.2.2 Modicon Analog to Digital Module (A/D)**A. Assumptions**

- i.) Calibrations performed at ambient 72 ± 8 °F or 64 to 80 °F
- ii.) Calibrated Span (CS) = Full Scale = 10 VDC

B. Channel Uncertainty

- i.) Relative Accuracy (RA)

Given: RA = $\pm 0.05\%$ FS

RA = $\pm 0.05\%$ CS

Calibration Requirements- Rosemount Temperature Channels

3.6.1.2.3 OCRWM Loop Calibration

A. Loop Tolerance (LT) Determination

$$\begin{aligned}
 LT &= \pm [RA_s^2 + RA_F^2 + RA_{mcs}^2]^{1/2} \\
 &= \pm [0.17^2 + 0.1^2 + 0.05^2]^{1/2} \%CS = \pm 0.2\% CS \\
 &= \pm 0.2 * 100 \text{ }^\circ\text{C} / 100 = \pm 0.2 \text{ }^\circ\text{C}
 \end{aligned}$$

B. OCRWM Loop Calibration Tolerance

<u>RANGE</u>	<u>Loop Tolerance</u>
0 to 100 °C	± 0.2 °C

3.6.2 Measurement and Test Equipment

i.) Test Equipment Error Maximum (TEM)

1. **Test Equipment1:** Volt Meter

See Section 2.8.2 i., #1

2. **Test Equipment2:** AMETEK 140SE JOFRA dry block

Accuracy = ±0.3 °C, Stability= ±0.05 °C

 $RA_{MTE1} = \text{Accuracy} + \text{Stability} = 0.3 + 0.05 = 0.35 \text{ }^\circ\text{C} = 0.35\% \text{ CS}$ $RA_{MTE1} = \pm 0.35\% \text{ CS}$ $RA_{STD1} = \pm 0.1 \text{ }^\circ\text{C} = 0.1 \text{ }^\circ\text{C} (100\%/100 \text{ }^\circ\text{C}) = 0.1\% \text{ CS}$

RD1 = 0%CS (digital readout)

TEM Contribution from Temperature Standard

$$TEM = (0.35^2 + 0.1^2 + 0 + 0.1^2)^{1/2} = 0.4\% \text{ CS}$$

References

4 References

4.1 Standards

1. ISA-S67.04, Part I, *Setpoints for Nuclear Safety-Related Instrumentation*, Instrument Society of America, 1994

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