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NRW-FPGA-Based PRM System Qualification Project

Document Title :Availability/Reliability Analysis Report

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0	Apr 9, 2008	First Issue	N.Oda	Y.Goto	T.Miyazaki

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1 Purpose

The purpose of this document is to document the Availability/Reliability Analysis of the Non-Rewritable Field Programmable Gate Array (NRW-FPGA) based PRM system to be qualified by Toshiba during the NRW-FPGA-Based PRM System Qualification Project. The availability/reliability study was performed to meet the requirements of EPRI TR 107330, Section 4.2.3.

2 Reference Documents

(1) EPRI Report TR-107330, "Generic Requirements Specification for Qualifying a Commercially Available PLC for Safety-Related Applications in Nuclear Power Plants," December 1996.

(2) ANSI/IEEE Std 352-1987, "IEEE Guidelines for General Principles of Reliability Analysis of Nuclear Power Generating Station Safety Systems."

(3) MIL-HDBK-217F, "Military Handbook, Reliability Prediction of Electronic Equipment," 2 December 1991.

(4) Draft 12 of ISA SP.84.02.

(5) FPG-RQS-C51-0001, "Equipment Requirement Specification of FPGA based Units ,".

(6) FPG-VDN-C51-0124, "MTBF Report"

3 Results

The NRW-FPGA based PRM system Test Specimen was analyzed for reliability and availability using MIL-HDBK-217F (Reference (3)). The reliability values are calculated by summing failure rates of whole devices.

The system analyzed contained LPRM, LPRM/APRM, and FLOW units configured in the arrangement shown in ERS (Reference (5)) for the PRM Test Specimen to be qualified in Toshiba's NRW-FPGA-based PRM System Qualification Project. Results of this analysis are as follows:

3.1 Test Specimen

MTBF of the test specimen is calculated based on MIL 217F. The results are listed in Table-2.1. Figure A-1 shows a representation of the test specimen.

Table-2.1 Availability Reliability Analysis Results

	MTBF	MTTR	Availability
Test Specimen Fig A-1	[ ]a,c year ([ ]a,c H)	[ ]a,c H	[ ]a,c
	using MIL-std-217F	using TR-107330 Section4.2.3.3 C.	using TR-107330 Section4.2.3.3 C.

3.2 Full PRM System

MTBF of the test specimen is calculated based on MIL 217F. The results are listed in Table-2.2. Figure A-2 shows a representation of the test specimen.

Table-2.2 Availability Reliability Analysis Results

	MTBF	MTTR	Availability
Full System Fig A-2	[ ]a,c year ([ ]a,c H)	[ ]a,c H	[ ]a,c
	using MIL-std-217F	using TR-107330 Section4.2.3.3 C.	using TR-107330 Section4.2.3.3 C.

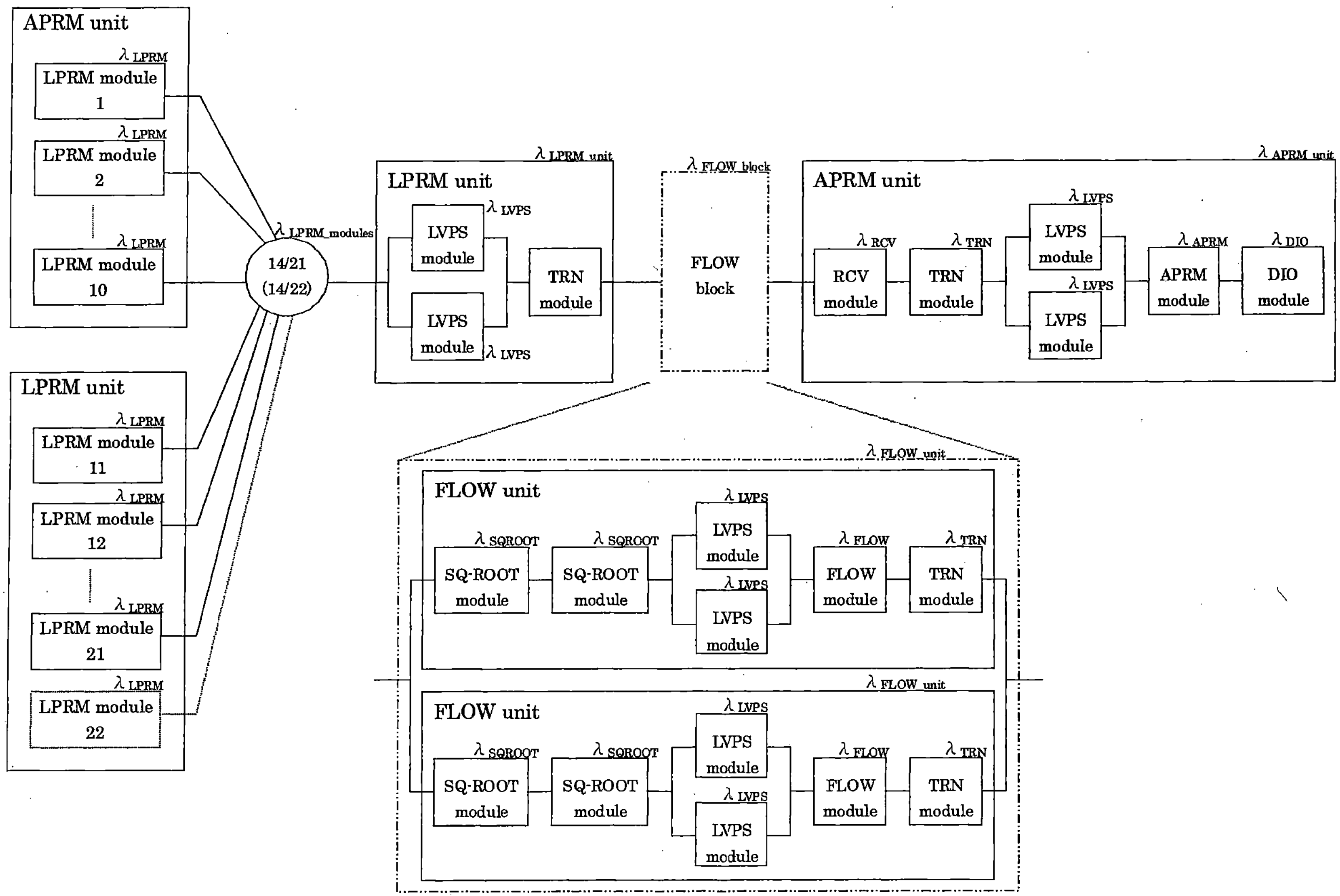
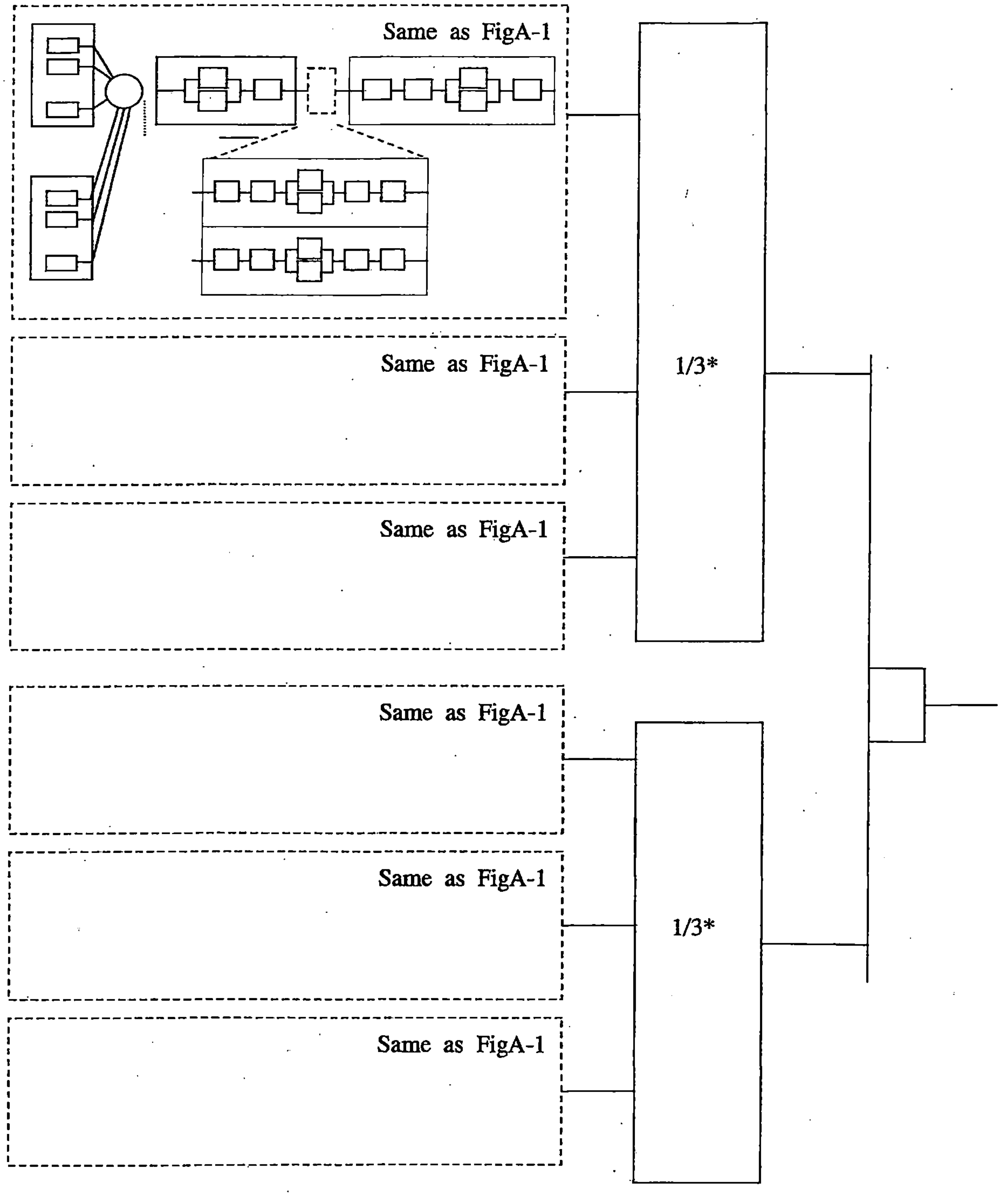


Fig.A-1 PRM Trip Function Block Diagram in one channel PRM



* One channel of the three can be bypassed.

Fig.A-2 PRM Trip Function Block Diagram in Full PRM System

3.3 Detailed MTBF Calculation for PRM

This section is summary of the MTBF Report (Reference (6)).
PRM trip function to be evaluated is defined by the diagram in Fig A-1.

A-PRM FAILURE RATE			
	MODULE NAME	MODULE FAILURE RATE ($1/10^9$H)	
1	APRM MODULE	λ_{APRM}	[ ]^{a,c}
2	LPRM MODULE	λ_{LPRM}	[ ]^{a,c}
3	STS MODULE	λ_{STS}	[ ]^{a,c}
4	AO MODULE	λ_{AO}	[ ]^{a,c}
5	DIO MODULE	λ_{DIO}	[ ]^{a,c}
6	TRN MODULE	λ_{TRN}	[ ]^{a,c}
7	RCV MODULE	λ_{RCV}	[ ]^{a,c}
8	FLOW MODULE	λ_{FLOW}	[ ]^{a,c}
9	SQ-ROOT MODULE	λ_{SQROOT}	[ ]^{a,c}
10	LVPS MODULE	λ_{LVPS}	[ ]^{a,c}

*:Each failure rate is calculated by the reliability of components given in MIL-STD-217F

(1) FAILURE RATE for more than 8 LPRM modules failed in 24 hours

$\lambda_{LPRM\_modules}$ =[ ]^{a,c}

=[ ]^{a,c}

(2) FAILURE RATE for LPRM unit

a) FAILURE RATE for LVPS modules failed in 24 hours

λ_{LVPS_24H} =[ ]^{a,c}

=[ ]^{a,c}

b) FAILURE RATE for LPRM unit

$$\lambda_{LPRM\_unit} = (1-(1-\lambda_{LVPS\_24H})*(1-\lambda_{LVPS\_24H})) + \lambda_{TRN}$$
$$=[\quad]^{a,c}$$

(3) FAILURE RATE for FLOW unit

$$\lambda_{FLOW\_unit} = \lambda_{SQROOT} + \lambda_{SQROOT} + (1-(1-\lambda_{LVPS\_24H})*(1-\lambda_{LVPS\_24H})) + \lambda_{FLOW} + \lambda_{TRN}$$
$$=[\quad]^{a,c}$$

(4) FAILURE RATE for FLOW block

$$\lambda_{FLOW\_block} = 1-(1-\lambda_{FLOW\_unit})*(1-\lambda_{LFLOW\_unit})$$
$$=[\quad]^{a,c}$$

(5) FAILURE RATE for APRM unit

$$\lambda_{APRM\_unit} = \lambda_{RCV} + \lambda_{TRN} + (1-(1-\lambda_{LVPS\_24H})*(1-\lambda_{LVPS\_24H})) + \lambda_{APRM} + \lambda_{DIO}$$
$$=[\quad]^{a,c}$$

(6) FAILURE RATE for PRM (per One Channel)

$$\lambda_{PRM} = \lambda_{LPRM\_modules} + \lambda_{LPRM\_unit} + \lambda_{FLOW\_block} + \lambda_{APRM\_unit}$$
$$=[\quad]^{a,c}(\text{FAILURE}/10^9\text{H})$$

(7) MTBF for PRM (per One Channel)

$$\text{MTBF} = 10^9/\lambda_{PRM}$$
$$=[\quad]^{a,c}(\text{H})$$
$$=[\quad]^{a,c}(\text{year})$$

(8)Availability for PRM (per One Channel)

$$\text{Availability} = \text{MTBF}/(\text{MTBF} + \text{MTTR})$$
$$=[\quad]^{a,c}/([\quad]^{a,c}+[\quad]^{a,c})$$
$$=[\quad]^{a,c}(> 0.99)$$

(9)FAILURE RATE for PRM(Full System)

$$\lambda_{system} = 1-(1-3\lambda_{PRM})*(1-3\lambda_{PRM})$$
$$=[\quad]^{a,c}$$

(10) MTBF for PRM (Full System)

$$\text{MTBF}_{system} = 10^9/\lambda_{system}$$
$$=[\quad]^{a,c}(\text{H})$$
$$=[\quad]^{a,c}(\text{year})$$

(11)Availability for PRM (Full System)

$$Availability_{system} = MTBF_{system}/(MTBF_{system} + MTTR)$$

$$=[\quad]^{a,c}/([\quad]^{a,c}+[\quad]^{a,c})$$

$$=[\quad]^{a,c}\ (> 0.99)$$

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NRW-FPGA-Based PRM System Qualification Project

Document Title

Setpoint Support Analysis Report

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Apr. 9, 2008	Monitoring System Engineering Group	M. [illegible] Apr. 9, 2008	Y. Goto Apr. 8, 2008	T. Miyazaki Apr. 7, 2008	RS- 5130439

TOSHIBA CORPORATION Nuclear Energy Systems & Services Division

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0	Apr. 9, 2008	First issue	N.Oda	Y.Goto	T.Miyazaki

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Acronyms

APRM	Average Power Range Monitor
CSA	Channel Statistical Allowance
EA	Environmental Allowance
FPGA	Field Programmable Gate Array
LPRM	Local Power Range Monitor
NRW	Non Re-writable
PMA	Process Measurement Accuracy
PRM	Power Range Monitor (or Power Range Neutron Monitor)
RCA	Rack Calibration Accuracy
RD	Rack Drift
RMTE	Rack Measurement & Test Equipment Accuracy
RRA	Rack Reference Accuracy
RTE	Rack Temperature Effects
SCA	Sensor Calibration Accuracy
SD	Sensor Drift
SMTE	Sensor Measurement & Test Equipment Accuracy
SPE	Sensor Pressure Accuracy
SRA	Sensor Reference Accuracy
SRSS	Square-Root-Sum-of-Square
STE	Sensor Temperature Effects

1. Introduction

1.1. Purpose

The purpose of this report is to document uncertainty calculations for the setpoint of safety related trip signal of Non Re-writable (NRW)-Field Programmable Gate Array (FPGA)-based Power Range Monitor (PRM) system. The information provided in this report is typically used by nuclear industry users for establishing safety related setpoints.

1.2. Scope

Allowances are considered to be categorized in 3 categories. These are sensor allowances, rack allowances, and process allowances. The scope of the NRW-FPGA-Based PRM System qualification includes units performing the functions of the Local Power Range Monitor (LPRM), Average Power Range Monitor (APRM) and flow measurement. The scope does not include external interfacing components such as the in-core detectors and differential pressure transmitters. So the scope does not include any evaluation of sensor allowances or process allowances for non-instrument related effects (e.g. neutron flux) or measurement and test equipment used for calibration and functional testing of the transmitter and racks. Therefore, only allowances for rack are provided in this analysis.

2. Methodology

EPRI TR-107330 (Reference (5)) requires that information be provided to support an application specific setpoint analysis per ISA-RP67.04.02-2000 (Reference (4)). The latest version of Regulatory Guide 1.105 (Revision 3) (Reference (1)) endorses the 1994 version of ISA-S67.04, Part I (Reference (2)). The latest version is of ISA-S67.04, Part I is ANSI/ISA-67.04.01-2006 (Reference XX). Toshiba has evaluated and determined that the uncertainty calculations in this report consistent with ISA 67.04.01-2006 and ISA-RP67.04.02-2000 are also consistent with Regulatory Guide 1.105 Revision 3.

The methodology used to combine the uncertainty components for a channel is an appropriate combination of those groups which are statistically and functionally independent. Those uncertainties which are not independent are conservatively treated by arithmetic summation and then systematically combined with the independent terms. The basic methodology used is Square-Root-Sum-of-Square (SRSS) method. The generalized relationship between the uncertainty components and calculated uncertainty for a channel is noted in Eq.2.1:

$$CSA = \{(PMA)^2 + (PEA)^2 + (SRA)^2 + (SMTE + SD)^2 + (SMTE + SCA)^2 + (SPE)^2 + (STE)^2 + (RRA)^2 + (RMTE + RD)^2 + (RMTE + RCA)^2 + (RTE)^2\}^{1/2} + EA + BIAS \qquad \text{Eq.2.1}$$

where:

CSA	=	Channel Statistical Allowance
PMA	=	Process Measurement Accuracy
SRA	=	Sensor Reference Accuracy
SMTE	=	Sensor Measurement & Test Equipment Accuracy
SD	=	Sensor Drift
SCA	=	Sensor Calibration Accuracy
SPE	=	Sensor Pressure Accuracy
STE	=	Sensor Temperature Effects
RRA	=	Rack Reference Accuracy
RMTE	=	Rack Measurement & Test Equipment Accuracy
RD	=	Rack Drift
RCA	=	Rack Calibration Accuracy
RTE	=	Rack Temperature Effects
EA	=	Environmental Allowance
BIAS	=	One directional, known magnitude allowance

Eq.2.1 is based on the followings: 1) The sensor and rack measurement and test equipment uncertainties are treated as dependent parameters with their respective drift and calibration accuracy allowances. 2) While the environmental allowances are not considered statistically dependent with all other parameters, the equipment qualification testing generally results in large magnitude, non-random terms that are conservatively treated as limits of error which are added to the statistical summation. Toshiba generally considers a term to be a limit of error if the term is a bias with an unknown sign. The term is added to the SRSS in the direction of conservatism. 3) Bias terms are one directional with known magnitudes (which may result from several sources, e.g., drift or calibration data evaluations) and are also added to the statistical summation. 4) The calibration terms are treated in the same radical with the other terms based on the assumption that general tending, i.e., drift and calibration data are evaluated on a periodic and timely basis. This evaluation should confirm that the distribution function characteristics assumed as part of treatment of the terms are still applicable. This approach results in a net reduction of the CSA magnitude (over that which would be determined if trending was not performed).

These parameters are categorized in following 3 categories:

- Sensor Allowances: SRA, SCA, SMTE, SD, STE, SPE and EA
- Rack Allowances: RRA, RCA, RMTE, RTE, and RD
- Process Allowances: PMA and PEA

As described in Section 1.2 of this report, only allowances for rack are provided in this analysis.

In the rack allowances, there are Rack Reference Accuracy (RRA), Rack Calibration Accuracy (RCA), Rack Temperature Effect (RTE), Rack Measurement & Test Equipment Accuracy (RMTE), and Rack Drift (RD).

RRA is the manufacture's reference accuracy that is achievable by rack. Because the scope of NRW-FPGA-based PRM system qualification includes qualification of units, RRA is applicable allowance in this analysis.

RCA is the total calibration uncertainty for the rack. RMTE is the accuracy of the test equipment used to calibration. APRM value is adjusted to consist with required APRM value provided from plant computer. Plant computer calculates the required APRM value using reactor thermal power. The allowance of reactor thermal power is not scope of this analysis. RCA and RMTE is not applicable allowance in this analysis.

RTE is change in input-output relationship for the rack due to a change in the ambient environmental conditions (temperature, humidity). Because the scope of NRW-FPGA-based PRM system qualification includes qualification of units, RTE is applicable allowance in this analysis.

RD is the change in input-output relationship over a period of time for rack. Because the scope of NRW-FPGA-based PRM system qualification includes qualification of units, RD is applicable allowance in this analysis.

3. Result

As described in section 2, RRA, RTE, and RD are applicable for the scope of NRW-FPGA-based qualification.

There are following safety related trip signal in NRW-FPGA-based PRM system:

- APRM Upscale (High-High) Trip
- Simulated Thermal Power Upscale Trip
- APRM Inoperable Trip

In NRW-FPGA-based PRM system qualification, RRA, RTE, and RD were not evaluated separately for above safety related trip signals collectively. It has been verified that Channel Statistical Allowance (CSA) for APRM Upscale (High-High) Trip signal and Simulated Thermal Power Upscale Trip signal is less than 2.0%FS, and CSA for APRM Inoperable Trip signal is 0%FS through the qualification tests including environmental test. The result of environmental test are reported in Qualification Test Summary Report (Reference (6))

$$\text{Total Allowance} = \{(RRA)^2 + (RTE)^2 + (RD)^2\}^{1/2} \qquad \text{Eq.3.1}$$

References

(1) RG 1.105
"Setpoints for Safety-Related Instrumentataion", Rev.3, 1999

(2) ISA S67.04 Part I, 1994
"Setpoints for Nuclear Safety-Related Instrumentation."

(3) ANSI/ISA 67.04.01-2006
"Setpoints for Nuclear Safety-Related Instrumentation."

(4) ANSI/ISA 67.04.02-2000
"Methodologies for the Determination of Setpoints for Nuclear Safety Related Instrumentation"

(5) EPRI TR-107330
"Generic Requirements Specification for Qualifying a Commercially Available PLC for Safety-Related Applications in Nuclear Power Plants," December 1996.

(6) Toshiba FPG-TRT-C51-1001 Rev.0
"Qualification Test Summary Report"