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Topical Report

Licensing Topical Report for Toshiba NRW-FPGA-based Instrumentation and Control System for Safety-Related Application

Part III
Qualification Results of the BWR-5 PRM and the ABWR OPRM

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Note for Acronyms and References

All acronyms and references are listed in the separate Acronym and Reference Part, which is part of this LTR.

III-1 Introduction

This Part III of the Licensing Topical Report (LTR) for the Toshiba Non-Rewritable Field Programmable Gate Array-based (NRW-FPGA-based) Instrumentation and Control (I&C) Systems for Safety-Related Applications. This part addresses qualification results of the Power Range Neutron Monitor (PRM) for Boiling Water Reactor (BWR)-5 and Oscillation Power Range Monitor (OPRM) for Advanced Boiling Water Reactor (ABWR).

III-1.1 Background

Toshiba has extensive experience in supplying nuclear safety-grade Instrumentation and Control (I&C) systems in Japan. This experience ranges from supplying digital I&C systems, such as power range neutron monitors for individual plants, up to designing and manufacturing the world's first fully integrated digital CPU-based I&C systems for ABWRs. These systems were first installed at Kashiwazaki-Kariwa Unit 6, and are in use at Kashiwazaki-Kariwa Unit 6 and Hamaoka Unit 5.

Following the installation of the CPU-based BWR digital system, Toshiba started development of I&C technology based on Non-Rewritable (NRW) Field Programmable Gate Arrays (FPGAs) and supplied the NRW-FPGA-based I&C products to Japanese Nuclear Power Plants under Toshiba's ISO 9001 program. NRW-FPGA-based products have been installed in 11 nuclear power plants including 254 NRW-FPGA-based units for non-safety-related systems, 91 units for safety-related process radiation monitors, and 60 units for safety-related neutron monitoring systems.

Toshiba also established a 10 CFR 50 Appendix B (Reference (a2)) Quality Assurance (QA) process to permit the use of Toshiba FPGA-based system in the US for safety-related applications in nuclear power plants. Toshiba implemented Appendix B QA processes in a phased approach as follows to ensure a smooth transition of the processes at the affected organizations.

- Original Process:
  Initial establishment of the Appendix B QA process in the system engineering organization. This process was applied to the development and the qualification of the Power Range Monitor (PRM) for a Boiling Water Reactor (BWR)-5. This process is referred to as the "Original Process" in this topical report.

- Current Process:
  Toshiba improved the Original Process by extending the Appendix B QA process into the design organization and closer to the manufacturing organization where other Toshiba

NRW-FPGA-based I&C products are developed. This process is referred to as the "Current Process" in this LTR. All future work will be under this process, including modifications to equipment produced under the original process.

Toshiba has used the Original Process to develop and qualify a NRW-FPGA-based PRM for a BWR-5. Toshiba used the Current Process to develop and qualify the OPRM for ABWR.

This LTR uses the term "PRM," to mean PRM for BWR-5 and uses the term "OPRM," to mean OPRM for ABWR.

This LTR consists of the following six parts.

Part I describes software lifecycle and development processes.

Part II provides the design descriptions for the PRM and the OPRM and includes an application guide.

Part III describes the qualification results for the PRM and the OPRM.

Part IV provides the compliance tables for Toshiba processes to important Codes and Standards.

Part V provides the BWR-5 PRM V&V report.

Par VI provides the ABWR OPRM V&V report.

The Acronym and Reference Part lists all the acronyms and references used in the all Parts except Part V and VI of the LTR. Part V and Part VI have their own acronym and reference lists because they are the existing actual V&V reports for the PRM and the OPRM.

This is Part III of the LTR.

III-1.2 Purpose

The purpose of Part III of the LTR is to describe the qualification of Toshiba NRW-FPGA-based PRM and OPRM.

The PRM was developed by the Original process, and the qualification activities of the PRM, including EQ and EMC testing were completed using this process. Comparison between the Current process and the Original process is provided in Appendix I-A. One exception was a V&V iteration performed to resolve a problem found in the FPGA dynamic testing of PRM. The relating activities including V&V were performed using the Current process.

The OPRM was developed by the Current process, and the qualification activities of the OPRM including EQ and EMC testing were completed using current process.

III-1.3 Scope

This Part III of the report includes the following information:

- Section III-1 provides introductory material like the report purpose and scope,
- Section III-2 introduces the qualification testing and describes how Toshiba implements this qualification testing for qualification of PRM.
- Section III-3 introduces the qualification analysis and describes how Toshiba implements this qualification analysis for qualification of PRM.
- Section III-4 introduces the system V&V process and results of the PRM.
- Section III-5 introduces the qualification testing and describes how Toshiba implements this qualification testing for qualification of OPRM.
- Section III-6 introduces the qualification analysis and describes how Toshiba implements this qualification analysis for qualification of OPRM.
- Section III-7 introduces the system V&V process and results of the OPRM.

The model numbers of the qualified modules for PRM are listed in Table 4-1 of the Requirements Definition Phase V&V Report for the PRM, which is included in Part V.

The model numbers of the qualified modules for OPRM are listed in Table 9-1, 9-5, and 10-1 of the NICSD V&V Report for OPRM, which is included in Part VI.

III-2 Qualification Test of PRM

III-2.1 General Description

This section describes the qualification of the Toshiba FPGA-based PRM. Toshiba performed qualification test activities as required by EPRI TR-107330, (Reference (a46)), which describes the hardware qualification tests to demonstrate hardware acceptability for safety-related applications. The tests specified in EPRI TR-107330 are required in order to comply with the applicable regulatory requirements and industry standards. The qualification tests were performed using an assembled test system that is comprised of a test specimen and test equipment with validated final FPGA logic.

For equipment qualification, test plans were prepared that define the test activities and test sequence. The test plans specify the set of qualification tests to be performed on the test specimen, including defining a set of operability tests to be performed during qualification test. The tests include a pre-qualification test, qualification test, and performance proof test. The following describes the hardware testing required by EPRI TR-107330 as it relates to the FPGA-based systems. Test limits have been adjusted by more current NRC guidance, including USNRC RG 1.180, Revision 1.

III-2.1.1 Pre-Qualification Tests

The Pre-Qualification Test was performed prior to the Qualification Test. This test was performed to demonstrate that the Test Specimen operates as intended and to provide a performance baseline for the Qualification Tests. The Pre-Qualification test includes:

- System Set-up and Check-out Test. The purpose of this test is to verify proper assembly, integration, and operation of the assembled Test System for Pre-Qualification Test. This test confirms proper connection and operation of the Test System including monitoring instruments, variable power supplies, and signal simulators.
- Burn-in Test. The purpose of this test is to perform a minimum 352 hour burn-in of the assembled Test System. The objective of the test is to detect any failures in early life that might otherwise impact the subsequent Qualification Test activities. System Set-up and Check-out Test described above is repeated after the Burn-in Test.
- Operability Test. The purpose of this test is to verify the Test System functions correctly prior to the performance of Qualification Tests. This initial performance during Pre-Qualification Testing also established the baseline performance of the Test System, which are used for comparison to performance measured during Qualification

Tests.

- Prudency Test. The purpose of this test is to verify the Test System functions correctly while being exercised in various ways to simulate potential in-service stresses prior to the performance of Qualification Test. This initial performance of the prudency test also establishes baseline performance of the Test System for comparison to performance measured during Qualification Tests.

These tests were performed in accordance with Section 5 of EPRI TR-107330.

III-2.1.2 Qualification Tests

These tests were conducted to demonstrate compliance with requirement specifications and to demonstrate suitability of equipment while subject to stress conditions. Qualification tests were performed on the assembled Test System after the system passes the pre-qualification testing acceptance criteria. The Qualification Tests include:

- Environmental Test (Radiation). Since the PRM system is designed to be installed in a mild environment, radiation exposure was not necessary. However, Toshiba decided to demonstrate that the PRM system, the first NRW-FPGA-based I&C system for the US market, would not be affected by radiation exposure.
- Environmental Test. The Environmental Test is performed to ensure that the system provides the performance required under the temperature and humidity conditions shown in Section 6.3.3 of EPRI TR-107330 (Reference (a46)). After the Environmental Test, the Operability Test is performed with the limited scope of the Operability Test performed in the Pre-Qualification Test.
- Seismic Test. The Seismic Test is performed to ensure that the system continues to operate correctly during the seismic conditions shown in Section 6.3.4 of EPRI TR-107330 to the extent achievable at the test facility. After the Seismic Test, the Operability Test is performed with the limited scope of the Operability Test performed in the Pre-Qualification Test.
- Electromagnetic Interference/Radio-Frequency Interference (EMI/RFI) Test. The EMI/RFI Test is performed to ensure that the system is not susceptible to and does not radiate more than the EMI/RFI levels shown in USNRC RG 1.180 Revision 1 (Reference (a19)).
- Surge Withstand Capability (SWC) Test. The SWC test is performed to ensure that the system withstands the surge limits shown in USNRC RG 1.180 Revision 1.

- Electrical Fast Transient / Burst (EFT/B) Test. The EFT/B Test is performed to ensure that the system withstands the EFT/B limits shown in USNRC RG 1.180 Revision 1.
- Electrostatic Discharge (ESD) Test. The ESD Test is performed to ensure that the system can continue to operate when exposed to the ESD levels shown in the Section 4.3.8 of EPRI TR-107330. The test was performed in accordance with EPRI TR-102323 Revision 2 (Reference (a44)) Appendix B Section 3.5.
- Class 1E to Non Class 1E Isolation Test. The Class 1E to Non Class 1E Isolation Test demonstrated that the system provides suitable electrical and functional isolation. This test is necessary where the tested FPGA-based system is a safety-related device credited with isolating itself from Non Class 1E equipment. The test levels are shown in Section 4.6.4 of EPRI TR-107330 and IEEE Std 384-1992 (Reference (a34)).
- After all Class 1E to Non Class 1E Isolation tests completed, the Operability Test and the Prudency Tests are performed as Post-Qualification Test, with the same scope of Pre-Qualification Test to compare to the baseline from by the Pre-Qualification Test.

The detailed scope and the timing of the Operability Test and the Prudency Test are shown in Table IV-4-3 through IV-4-7 in the Part IV of this topical report.

III-2.1.3 Performance Proof Tests

Performance Proof Tests were conducted to confirm satisfactory operation after being subjected to qualification test conditions. Performance Proof Tests were also performed after the test system was re-configured to evaluate the aging effect, mainly from temperature, humidity, and seismic tests. Performance Proof Tests were a repeat of selected Pre-Qualification baseline tests to identify any changes in equipment performance. Performance Proof Tests includes:

- System Set-up and Check-out Test
- Operability Test
- Prudency Test

The sequence of tests is shown in Figure III-2-1 and Table III-2-1.

Note: System Set-up and Check-out Tests was performed, as necessary, when the Test System is moved or re-configured as the part of qualification testing. These tests are not part of the qualification, but are performed to confirm the equipment is properly configured and operating correctly before starting subsequent testing credited qualification.

III-2.2 Qualification Tests for PRM System

Qualification Tests were conducted for the PRM system during the PRM Qualification Project using a test specimen that is comprised of an LPRM unit, an LPRM/APRM unit and a FLOW unit.

Qualification Test items with reference to the relevant test documents of the PRM Qualification Project are shown in Table III-2-1. The test sequence that was used for the PRM Qualification Project is shown in Figure III-2-1. Table III-2-1 and Figure III-2-1 do not show the Operability Tests and the Prudency Tests. See Table IV-4-3 through IV-4-7 in Part IV of this topical report for detailed scope and the timing of the Operability Test and the Prudency Test during the Qualification Test.

As shown in Table III-2-1, the test levels for EMI/RFI Test, SWC Test, and EFT/B Test are not the same as those specified in EPRI TR-107330 (Reference (a46)) requirements. Instead, the test levels used were obtained from RG 1.180, Revision 1 (Reference (a19)), which was issued in October 2003 after the EPRI report was completed. These Regulatory Guide values are considered to better reflect the current requirements of US utilities.

Results of these tests conducted for the PRM system during the PRM Qualification Project are summarized in the following subsections.

Table III-2-1 Qualification Test Overview (PRM Qualification Project)

Test		Applied Standard	Toshiba Test Procedure Number*	Section in Master Test Plan (Reference (d19))
1.Hardware Pre-Qualification Test	1.1 System Set-up and Check-out Test	TR-107330	FPG-TPRC-C51-1001 (Reference (d20))	App. 2 Hardware Pre-Qualification Test Plan
	1.2 Burn-in Test	TR-107330		
	1.3 System Set-up and Check-out Test	TR-107330	FPG-TPRC-C51-1001	
	1.4 Operability Test	TR-107330	FPG-TPRC-C51-1009 (Reference (d28))	
	1.5 Prudency Test	TR-107330	FPG-TPRC-C51-1010 (Reference (d29))	
2.Hardware Qualification Test	2.2 Environmental Test (Radiation Exposure)	TR-107330	FPG-TPRC-C51-1002 (Reference (d21))	App. 3 Environmental Test Plan
	2.4 Environmental Test (Temperature and Humidity)	TR-107330	FPG-TPRC-C51-1002	
	2.6 Seismic Test	TR-107330	FPG-TPRC-C51-1003 (Reference (d22))	App. 4 Seismic Test Plan
	2.8 EMI/RFI Test	RG 1.180	FPG-TPRC-C51-1004 (Reference (d23))	App. 5 EMI/RFI Test Plan
	2.9 Surge Withstand Capability Test	RG 1.180	FPG-TPRC- C51-1005 (Reference (d24))	App. 6 Surge Withstand Capability Test Plan
	2.10 EFT / B Test	RG 1.180	FPG-TPRC- C51-1006 (Reference (d25))	App. 7 EFT / B Test Plan
	2.11 ESD Test	TR-107330	FPG-TPRC- C51-1007 (Reference (d26))	App. 8 ESD Test Plan
	2.12 Class 1E to Non-1E Isolation Test	TR-107330	FPG-TPRC- C51-1008 (Reference (d27))	App. 9 Class 1E to Non-1E Test Plan
3.Hardware Performance-Proof Test	3.2 Operability Test	TR-107330	FPG-TPRC-C51-1009	App. 10 Hardware Performance-Proof Test Plan
	3.3 Prudency Test	TR-107330	FPG-TPRC- C51-1010	

* This column lists the test procedure numbers used for PRM Qualification Project.

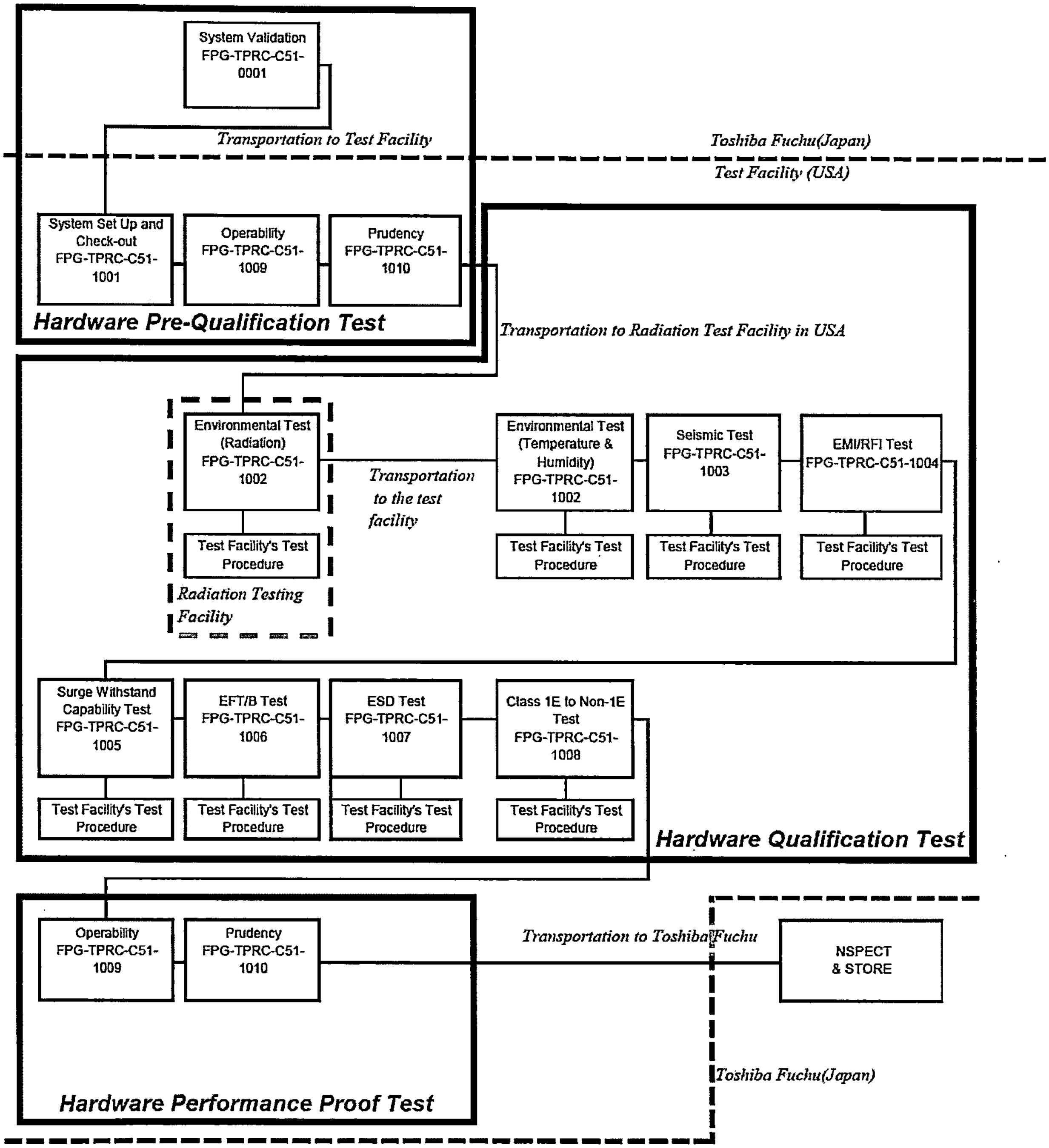

Figure III-2-1 Test Sequence (PRM Qualification Project)

III-2.2.1 Environmental Test

III-2.2.1.1 Environmental Test (Radiation)

The PRM System was exposed to radiation. Since all of the PRM equipment was installed only

in a mild environment, radiation exposure was not necessary. However, Toshiba decided to demonstrate that the PRM system, the first NRW-FPGA-based I&C system for the US market, would not be affected by radiation exposure.

The gamma irradiation on the Test Specimen was performed to 11 Gy to provide 10% margin above the requirement of 10 Gy. The 10 Gy exposure requirement is stated in Section 4.3.6.1 of EPRI TR-107330 (Reference (a46)). The test was performed in accordance with the guidance provided on IEEE Std 323-1983 (Reference (a31)). Radiation exposure was performed with the system powered down, which is the most conservative in terms of damage to the silicon, in that there is no heating to anneal radiation damage. Maximal damage is accumulated prior to powering the system.

The irradiation was performed at high level radiation effects test facility. For this irradiation, a [ ][a,c] curie (Ci) Co-60 source was used.

After the radiation exposure, a Performance Proof Test was performed. This test showed that all PRM safety functions were confirmed to be within the required tolerance, after subjecting the Test Specimen to this exposure. The evaluation concludes that exposure to these environmental stressors will not prevent the PRM System from performing its safety-related function. Details of the tests results and test data of Environmental Test are reported in the Qualification Test Summary Report (Reference (d16)). After the radiation exposure was finished, the PRM System was transported to another test facility for the environmental test.

III-2.2.1.2 Environmental Test Profiles for PRM System

The environmental test was performed to ensure that the Toshiba PRM system operates correctly when exposed to the environmental conditions shown TR-107330 (Reference (a46)) Section 6.3.3. Environmental qualification testing of the Test System was performed as described in the Environmental Test Procedure (Reference (d21)).

Requirements for environmental test are specified in EPRI TR-107330, Sections 4.3.6 and 6.3.3. The acceptance criteria are given in the Master Test Plan (Reference (d19)).

For the temperature and humidity exposure, specific test patterns were applied in repetition, and the output data was monitored through testing performed at specified times and conditions during the test.

After the test, the performance of the Test Specimen was compared to the baseline performance (measured during Pre-Qualification Test) to determine if the test impacted the performance and

operability of the Test Specimen Units.

Environmental Testing was performed at the test facilities from June 2006 through October 2006. In August 2006, the test was suspended due to problems with the environmental chamber. During this test, Toshiba observed that water condensation formed on the ceiling of the chamber. Water drops were observed on the top face of the Test Specimen Units. These water drops short-circuited the IC pins causing the failure of the Test Specimen. Because the test required a non-condensing environment, Toshiba concluded that the environmental condition deviated from the required conditions. Toshiba installed a condensation shield to prevent water condensate on the ceiling of the environmental chamber from falling directly onto the Test Specimen Units. In addition, Toshiba replaced the damaged modules with spare modules that had also been subjected to radiation exposure. The Environmental Testing was then re-performed satisfactorily.
The testing complied closely, but not identically, with the test curve in EPRI TR-107330, due to limitations on real world test equipment, and is considered to demonstrate satisfactory performance.

The value of relative humidity at the low temperature condition was not established due to test facility capability. Toshiba performed the low temperature test independently of the low humidity test. This is acceptable because EPRI TR-107330 states that if the specified relative humidity cannot be achieved for the specified temperature, then the test should be run for the specified time at the lowest relative humidity that can be achieved at the specified temperature followed by running the test at the lowest temperature that the specified relative humidity can be achieved.

The test achieved the objective of exposing the tested equipment to a wide range of humidity conditions. Also, review of the data collected during the test shows that the Test Specimen operated as intended.

Review of the post-test Operability and Prudency Test results shows that exposure to the environmental test conditions had no adverse effect on the Test Specimen.

Details of the tests results and test data of Environmental Test are reported in the Qualification Test Summary Report (Reference (d16)).

III-2.2.1.3 Power Quality Tolerance Test for PRM System

According to the requirement of Section 6.4.3 of TR-107330 (Reference (a46)), the Power Quality Tolerance Test was performed during acceptance test, at the end of the elevated

temperature test while still at high temperature, and following the Seismic Test. The test was performed in accordance with input voltage ranges and frequency ranges of power supplies for connection to an AC (and DC) source given in Section 4.6.1 of TR-107330, and the margin given in IEEE Std 323-1983 (Reference (a31)).

III-2.2.1.4 Summary of Environmental Test Results of PRM System

The test results are summarized as follows:

- The Test Specimen successfully completed the radiation exposure test with no signs of physical or functional degradation.
- The Test Specimen successfully completed the temperature and humidity test.
- The Test Specimen met all applicable performance requirements during and after application of the environmental test conditions.
- The test results show that the Test Specimen will not experience failures due to abnormal service conditions of temperature and humidity.

III-2.2.2 Seismic Test

III-2.2.2.1 Test Method and Process for PRM System

The Seismic Test was performed to assure that the PRM Test Specimen provides the performance and seismic withstand capability under Seismic Test conditions shown in Section 4.3.9 of TR-107330 (Reference (a46)) to the extent achievable at the test facility.

Requirements for seismic testing are specified in Sections 4.3.6 and 6.3.3 of EPRI TR-107330. These sections require that the system be seismically tested in accordance with IEEE Std 344 (Reference (a32)). The testing is required to include a resonance search followed by five simulated Operating Basis Earthquakes (OBEs) and one simulated Safe Shutdown Earthquake (SSE) at 9.75 g's and 14 g's respectively, based on 5% damping.

Due to the limitations of the Triaxial Seismic Simulator Table, the SSE tests were performed using a maximum acceleration level of 9.8g. For this reason, the PRM System testing did not fully meet EPRI TR-107330 for seismic requirements. Before using the PRM System in safety-related applications in nuclear power plants, licensees must determine that the plant-specific seismic requirements are enveloped by the existing test spectra of the PRM System.

Table III-2-2 shows seismic levels applied during this test.

Compliance of the Test Specimen seismic qualification testing with these requirements is described in the Seismic Test Procedure (Reference (d22)). The seismic test acceptance criteria are given in the Master Test Plan (Reference (d19)).

The Test Specimen was mounted to the seismic test table in accordance with mounting details provided on the Seismic Test Procedure. The Test Specimen Unit was mounted as follows.

- Two pieces of 6 inch by 3 inch by 3/8 inch steel tubing were welded to the test table with 3/16 inch fillet welds approximately 4 inches in length (two at each corner).
- The test fixture was constructed from 2 inch by 2 inch steel angle and was welded to the lower mounting tubes on each vertical 2 inch by 2 inch angle of the test fixture.
- The fixture was installed on the test facility's Triaxial Seismic Simulator Table such that its horizontal axes were collinear with the horizontal axis of the table.
- Accelerometers were provided on the test fixture to verify that actual triaxial seismic loads applied to the worst case locations on the frame.
- The Test Specimen Units were mounted in the test facility-provided test fixture using M5 mounting hardware located in the front of the chassis and M4 screws located in the rear of each unit.

Test Specimen Units were mounted on the seismic test table to comply with the following directional conditions:

- X-Direction: Parallel to the control panel of the test specimen units on the horizontal surface of the table,
- Y-Direction: Perpendicular to the control panel of the test specimen units on the horizontal surface of the table, and
- Z-Direction: Perpendicular to the surface of the table.

The units were fixed using four screws in the front side and eight screws in the back side. The specification of the torque to tighten the screws was 2.6 – 3.4 Nm in the front side and 1.3 – 1.7 Nm in the back side. The torque values were measured and confirmed that they were within the limits in the testing.

The simulated signals were input to the Test Specimen to establish the AO and DO status described in Sections 4.4 and 4.3 of the Seismic Test Procedure.

Table III-2-2 Seismic Levels

Seismic Event	Maximum Amplitude Requirement from EPRI TR-107330 Section 4.3.9
OBE	9.8 g
SSE	14 g (9.8 g was applied to type test for PRM Qualification Project due to the limitation of test facility)

The seismic tests were performed in accordance with the Seismic Test Procedure. The following tests were performed:

(1) Resonance Search

A low-level (approximately 0.2 g) single-axis sine sweep up to 100 Hz was performed in each of the three orthogonal axes to determine major resonance of the Test Specimen Units. There was no major resonance below 100Hz.

(2) Random Multifrequency Tests (5 OBEs and 1 SSE)

The Test Specimen was subjected to 30 second duration triaxial multi-frequency, random motion which was amplitude-controlled in one-sixth octave bandwidth spaced one-sixth octave apart over the frequency range of 1 to 100 Hz. The test response spectrum (TRS) obtained is shown in the Qualification Test Summary Report (Reference (d16)).

Details of the test results and test data of the Seismic Test are reported in the Qualification Test Summary Report. Data collected during and after each OBE and SSE test demonstrate that the Test Specimen operated as intended throughout the testing.

The Test Specimen was visually inspected for damage or degradation following each OBE and SSE test. Results of these inspections showed no physical damage or degradation of the Test Specimen.

III-2.2.2.2 Summary of Seismic Test Results of PRM System

The test results are summarized follows:

- The maximum level of acceleration in SSE was limited to 9.8g due to the limitation of

the test facility's seismic test table.

- The Test Specimen met all applicable performance requirements during and after application of the seismic test vibration levels.
- The Test Specimen units completed seismic testing with no signs of physical or functional degradation.

III-2.2.3 Electromagnetic Compatibility (EMC) Test

III-2.2.3.1 Test Method and Process for PRM System

The purpose of this test was to demonstrate the electromagnetic compatibility of the PRM Test Specimen. EMI/RFI, Surge Withstand Capability (SWC), EFT/B, ESD, and Class-1E to Non Class-1E Isolation Tests were performed.

The test levels specified for EMI/RFI, SWC, and EFT/B Tests were not the same as those specified in EPRI TR-107330 (Reference (a46)) requirements. Instead, the test levels used were obtained from RG 1.180, Revision 1 (Reference (a19)), which was issued in October 2003. These Regulatory Guide values are considered to better reflect the current requirements of US utilities. EPRI TR-107330 was published in December 1996, prior to issuance of Revision 1 of RG 1.180.

Table III-2-3 shows the results of EMC tests.

The EMC test (EMI/RFI, Surge, EFT/B, ESD, and Class 1E to Non Class 1E Isolation) was performed from October 18, 2007 to December 5, 2007.

Test Specimen Units were installed in the same free-standing instrument rack used in the Environmental Test. To permit confirmation of the Test Specimen Units capability, this rack was designed to not shield emission from the Test Specimen Units or to shield the equipment from external test signals. The Test Specimen Units were installed in test facility's anechoic chamber.

For the EMC Tests, specific test patterns were applied in repetition. The specific test patterns are described in Section 3.6 of the System Set-up and Check-out Test Procedure (Reference (d20)).

Details of the test results, required mitigations, and test data of EMC Test are reported in the Qualification Test Summary Report (Reference (d16)).

Table III-2-3 EMC Test Results

Test Item	Test Method	Test Level	Test Results
Conducted Emissions Low Frequency	MIL-STD-461E/CE101	60 Hz to 10 kHz	Comply with limited scope and/or condition (For CE101 test, choke coil should be added for mitigation.)
Conducted Emissions High Frequency	MIL-STD-461E/CE102	10 kHz to 2 MHz	Comply
Radiated Emissions Magnetic Field	MIL-STD-461E/RE101	30 Hz to 100 kHz	Comply
Radiated Emissions Electric Field	MIL-STD-461E/RE102	2 MHz to 1 GHz	Comply
Conducted Susceptibility Low Frequency	MIL-STD-461E/CS101	120 Hz to 150 kHz	Comply
Conducted Susceptibility High Frequency	MIL-STD-461E/CS114	10 kHz to 30 MHz	Comply
Conducted Susceptibility Bulk Cable Injection	MIL-STD-461E/CS115	2A	Comply
Conducted Susceptibility Damped Sinusoidal Transients	MIL-STD-461E/CS116	10 kHz to 100 MHz	Comply
Radiated Susceptibility Magnetic Field	MIL-STD-461E/RS101	30 Hz to 100 kHz	Comply
Radiated Susceptibility Electric Field	MIL-STD-461E/RS103	30 MHz to 1 GHz	Comply (Note 1)
Surge 100 kHz Ring Wave	IEC 61000-4-12/Ring Wave	2 kV	Comply (Note 2)
Surge Combination Wave	IEC 61000-4-5/ Combination Wave	2 kV	Comply
Electrical Fast Transient /Burst	IEC 61000-4-4/EFT/B	2 kV	Comply
Electrostatic Discharge	IEC 61000-4-2/ESD	15 kV (Air Discharge) 8 kV (Contact Discharge)	Comply (Note 3)
Class 1E to Non-1E Isolation	---	600VAC 250VDC	Comply

Note 1: Toshiba did not test for radiated susceptibility (RS103) above 1 GHz for the PRM test, and thus accepts that either a utility employing this equipment must preclude the use of cell phones and radios near this equipment or accept an open issue from the USNRC in the SER requiring an evaluation by the utility.
Note 2: The application of one repetition each second is described in IEC 61000-4-12. However, the Test Lab's equipment could not operate this rapidly. This is only an issue in the application period and has no adverse effect on the equipment qualification envelope. Toshiba and the Test Lab cannot find the record of the coupling impedance value used 12 Ω or 30 Ω for the ring wave test.
Note 3: Some test points in the back panel of the Test Specimen Units showed susceptibilities, but recovered without degradation. These results complied with the requirement of the ESD Test. The Application Guide is updated with the requirement that all contact with the back panel requires use of grounded ESD wrist straps.

Table III-2-4 [Deleted]

Table III-2-5 [Deleted]

III-2.2.3.2 EMI/RFI Test for PRM System

The purpose of this test is to demonstrate the suitability of the PRM System for qualification as a safety-related device with permissible EMI/RFI emissions and susceptibility.

EMI/RFI Test was performed to assure that the PRM System withstands the EMI/RFI levels given in RG 1.180 (Reference (a19)). Toshiba decided to use these test levels because they were issued more recently than the requirements specified in the EPRI TR-107330 (Reference (a46)) requirements. These Regulatory Guide values are considered to better reflect the current requirements of US utilities.

The EMI/RFI susceptibility and emissions withstand capability was tested using the following test methods from MIL-STD-461E (Reference (a25)).

Test Type	Test Method
(a) Low-Frequency Conducted Susceptibility (Power):	CS101
(b) High-Frequency Conducted Susceptibility (Power):	CS114
(c) High-Frequency Conducted Susceptibility (Signal):	CS114
	CS115
	CS116
(d) Radiated Susceptibility, Magnetic Field:	RS101
(e) Radiated Susceptibility, Electric Field:	RS103
(f) Low-Frequency Conducted Emissions:	CE101
(g) High-Frequency Conducted Emissions:	CE102
(h) Radiated Emissions, Magnetic Field:	RE101
(i) Radiated Emissions, Magnetic Field:	RE102

Tests were not performed in the above order. Prior to the first EMI/RFI Test, a System Set-up and Check-out Test was performed.

Environmental conditions were kept at "normal environmental basic conditions" in accordance with the requirements of Section 4.3.6.1 of EPRI TR-107330.

Compliance of the Test Specimen EMI/RFI qualification testing with these requirements is described in the EMI/RFI Test Procedure (Reference (d23)).

The acceptance criteria are given in the Master Test Plan (Reference (d19)).

Details of the test results and test data of EMI/RFI testing are reported in the Qualification Test Summary Report (Reference (d16)). The results of the susceptibility testing show that the Test Specimen continued to function correctly throughout all test exposure levels. The transfer of input and output data was not interrupted. There were no interruptions or inconsistencies in the operation of the system.

For the emissions tests, the Test Specimen was found to comply with the allowable equipment emissions levels for radiated magnetic field emissions from 30 Hz to 100 kHz (RE101). A specific exceedance was found during CE101 in the power leads. From approximately 100 Hz to 700 Hz, emissions exceed the limit shown in RG 1.180 Revision 1. This excess comes from the waveform distortion due to the AC/DC power supply (i.e. LVPS module) in the units in PRM system. To suppress this emission, Toshiba inserted a filter into the AC power line to the LVPS module, and confirmed that the test results met the requirement.

For the CE101 requirement, mitigation is needed for PRM system. Toshiba confirmed that Low Frequency Conducted Emission can be mitigated by inserting filters in the power line. Toshiba will supply the system with the coils on the power supply leads to ensure that these emissions are beneath the required levels.

III-2.2.3.3 Surge Withstand Capability Test for PRM System

The purpose of this test is to demonstrate the suitability of the PRM System for qualification as a safety-related device with Surge Withstand Capability (SWC), as stated in Section 5 of RG 1.180 (Reference (a19)), IEC 61000-4-5 (Reference (a28)), and IEC 61000-4-12 (Reference (a29)).

The SWC Test was performed to ensure that the PRM System withstands the surge limits given in Table 22 of RG 1.180. Surges were applied in accordance with IEC 61000-4-12 (for Ring Wave) and IEC 61000-4-5 (for Combination Wave). The Surge Withstand Capability Test Procedure (Reference (d24)) describes in detail the surge tests applied to the Test Specimen.

The surge withstand test acceptance criteria are defined in the Master Test Plan (Reference (d19)).

During this test, environmental conditions were kept at "normal environmental basic conditions" shown in Section 4.3.6.1 of TR-107330. The specific test patterns are described in Section 3.6

of the System Set-up and Check-out Test Procedure (Reference (d20)).

Details of the test results and test data of the SWC Test are reported in the Qualification Test Summary Report (Reference (d16)). The surges were applied to the test points, and the Test Specimen maintained normal operation during the surge application. Based on the results reported in the Qualification Test Summary Report, the Test Specimen continued to operate in accordance with the test acceptance criteria following application of the surge test voltages. However, the test results show that the repetition rate for the ring wave was not in accordance with the testing requirements, [ ][a,c] [ ][a,c] [ ][a,c] Since the period of the ring wave (30 μsec) is very short compared to the required 1-second repetition rate, the effect of the transient can be considered over and the longer [ ][a,c]-second rate will, therefore, not affect the conclusion of the test.

III-2.2.3.4 EFT/B Test for PRM System

The purpose of this test is to demonstrate the suitability of the PRM System for qualification as a safety-related device with EFT/B withstand capability, as stated in Section 5 of RG 1.180 (Reference (a19)), and IEC 61000-4-4 (Reference (a27)).

The EFT/B Test was performed to assure that the PRM Test Specimen withstands the EFT/B wave forms given in the Table 22 of RG 1.180. The EFT/B Test Procedure (Reference (d25)), describes in detail the tests applied to the Test Specimen. The EFT/B test acceptance criteria are defined in the Master Test Plan (Reference (d19)).

During this test, environmental conditions were kept at "normal environmental basic conditions" shown in Section 4.3.6.1 of TR-107330 (Reference (a46)). The specific test patterns are described in Section 3.6 of the System Set-up and Check-out Test Procedure (Reference (d20)).

Details of the test results and test data of EFT/B Test are reported in the Qualification Test Summary Report (Reference (d16)). The EFT/B wave forms were applied to the defined test points.

Results of the EFT/B testing show that the Test Specimen continued to operate in accordance with the test acceptance criteria.

III-2.2.3.5 ESD Test for PRM System

The purpose of this test is to demonstrate the suitability of the PRM System for qualification as a safety-related device with regard to Electro-Static Discharge (ESD) withstand capability, as stated in IEC 61000-4-2 (Reference (a26)).

The tests were performed according to Appendix B Section 3.5 of EPRI TR-102323 (Reference (a44)) as Section 4.3.8 of EPRI TR-107330 (Reference (a46)) requires. The test was performed at 58% (day 1 of the ESD testing) and 51% (day 2 of the ESD testing) relative humidity, which is within the required 30 to 60% relative humidity.

The ESD Test Procedure (Reference (d26)) describes in detail the tests applied to the Test Specimen.

The ESD test acceptance criteria are given defined in the Master Test Plan (Reference (d19)). Environmental conditions were kept at "normal environmental basic conditions" shown in Section 4.3.6.1 of EPRI TR-107330. The specific test locations and voltages are described in Section 3.6 of the System Set-up and Check-out Test Procedure (Reference (d20)).

Details of the test results and test data for the ESD test are reported in the Qualification Test Summary Report (Reference (d16)).

Results of the ESD testing show that the Test Specimen did not present any temporary degradation or loss of function or performance when the ESD noises were applied to front panels, components on the front panels, and side panels, which can all be touched during normal operation.

However, testing showed temporary degradation/loss of function when ESD was applied to back panels. System functionality was recoverable. These panels are not generally exposed to ESD during normal operation. For the PRM System, ESD can be mitigated by preventing access to the back panel during plant operation, or by requiring personnel to wear anti-ESD wristbands when accessing the equipment back panel during plant operation. The back panels in the units are accessible only when locked cabinet doors are opened. In normal use at a US plant, the cabinet doors are unlocked and opened only when work is to be done on the panels, such as maintenance or calibration, which is done with unit bypassed. The equipment behind the plane of the door on the back panels should not be touched unless the technician or engineer is wearing a grounded ESD wriststrap. Therefore, administrative controls (e.g., procedures requiring use of static discharge control devices such as grounding straps) will be required to prevent or reduce exposure to electrostatic discharges. This instruction is incorporated in Appendix II-A, Application

Guide.

III-2.2.3.6 Class 1E to Non-Class1E Isolation Test for PRM System

The purpose of this test is to demonstrate the suitability of the PRM System for qualification as a safety-related device with respect to providing electrical isolation capability of Class 1E to Non-Class 1E field connections. Section 4.6.4 of EPRI TR-107330 (Reference (a46)) requires that isolation test demonstrate that the isolation features conform to IEEE Std 384-1992 (Reference (a34)).

The communication data link provided in each PRM System has a one-way fiber optic communication link, providing fixed data sets from each safety-related PRM division individually to the non-safety-related Rod Block Monitor (RBM), providing Class 1E to non-Class 1E isolation, and offering no possibility of data transfer from the non-safety to the safety equipment. This design eliminates any potential for data from one division being supplied to another division. Based on this system design, only the devices installed in the main chassis are required to provide Class 1E to Non-1E electrical isolation capability (if these modules are used to interface to Non-1E equipment). Accordingly, the following devices that are used to provide analog output signals to Non-1E portion were tested for Class 1E isolation capability:

- HNS518 and HNS515 AO modules installed in LPRM Units
- HNS518, HNS516, and HNS515 AO modules installed in LPRM/APRM Units
- HNS518, HNS517, and HNS516 AO modules installed in Flow Unit

The detailed functional descriptions of these AO modules are shown in Table II-A-3-1.

The test levels used comply with the level shown in Section 4.6.4 of EPRI TR-107330 and IEEE Std 384-1992. IEEE Std 384 requires the following:

(1) The isolation device prevents shorts, grounds, and open circuits on the Non-Class 1E side from degrading the operation of the circuits on the Class 1E side.

(2) The isolation device prevents application of the maximum credible voltage on the Non-Class 1E side from degrading the operation of the circuits on the Class 1E side.

The Class 1E to Non-1E Isolation Test Procedure (Reference (d27)) describes in detail the tests applied to the Test Specimen.

Class 1E to Non-1E test acceptance criteria are defined in the Master Test Plan (Reference (d19)).

During this test, environmental conditions were kept at "normal environmental basic conditions" shown in Section 4.3.6.1 of EPRI TR-107330.

Details of the test results and test data of the Class 1E to Non-1E test are reported in the Qualification Test Summary Report (Reference (d16)). Test level voltages were applied to the test points and the safety-related portion of the Test Specimen operated normally during and after the application.

As expected, damage occurred to the non-1E portion of the AO module, which did not propagate to the Class 1E equipment. After this test, the damaged AO modules were replaced with spare modules. Post-replacement testing (System Set-up and Checkout Test, Operability Test, and Prudency Test) show that the system operated correctly with the replacement AO modules installed.

III-2.2.4 Performance Proof Test for PRM System

The Performance Proof Test was conducted at the completion of all qualification testing to demonstrate the continued acceptable performance of the Test Specimen after exposure to the various qualification test conditions.

The Performance Proof Test involved performing the Operability Test and the Prudency Test, (References (d28) and (d29), respectively) under the same environmental conditions as during Pre-Qualification Testing. These procedures were developed in accordance with Sections 5.3 and 5.4 of EPRI TR-107330 (Reference (a46)).

The conclusion from the performance proof testing was that the Test Specimen provided required operability and performance after completion of the series of qualification tests.

III-2.2.5 Conclusion of Qualification Tests for PRM System

As a result of Qualification Tests, the following limitations should be considered when the PRM System is applied to the actual plant:

(1) In the Seismic Test, due to the limitation of the test facility's seismic table, the peak amplitude of SSE was 9.8g. The maximum amplitude should be evaluated in actual plant installation; this is stipulated in the Application Guide, Appendix II-A-4.4.

(2) For the CE101 requirement, mitigation is needed for PRM System Unit. Toshiba confirmed that Low Frequency Conducted Emission can be mitigated by inserting filters in the power line. Toshiba will provide production PRM system equipment with appropriate

emission protection (e.g., a coil). This issue is discussed in the Application Guide, Appendix II-A-4.5.1.

(3) ESD test show temporary degradation/loss of function occurred when ESD was applied to back panels. System functionality can be recoverable. These panels are not generally exposed to ESD during normal operation. For this PRM system, ESD can be mitigated by preventing access to the back panel during plant operation or by requiring personnel to wear anti-ESD wristbands when accessing the equipment back panel during plant operation. This instruction is stated in the Application Guide, Appendix II-A-4.7.

With the above considerations, the PRM System Units achieved the required performance and are considered satisfactory for safety-related applications.

III-3 Qualification Analysis of PRM

III-3.1 General Description

Availability/Reliability Analysis, Failure Modes and Effects Analysis (FMEA), and Setpoint Support Analysis were performed for the PRM system. Toshiba does not perform a diversity and defense in depth analysis in this LTR, because this analysis is a plant wide evaluation based on overall considerations and general characteristics of devices rather than the specification of any device in the system. The qualification analysis of Toshiba FPGA-based I&C systems only provides assurance for a qualified device and logic.

An availability/reliability analysis was performed by NICSD to meet the requirements of Section 4.2.3 of EPRI TR-107330 (Reference (a46)). This section requires that analysis is performed to determine the availability and reliability of a Programmable Logic Controller in safety-related applications. Section 4.2.3 of EPRI TR-107330 defines the hypothetical system configuration and conditions under which these probabilities must be determined.

A Failure Modes and Effects Analysis (FMEA) was performed by NICSD to meet the requirements of Section 4.2.3.5 of EPRI TR-107330 and IEEE Std 352-1987 (Reference (a33)). The system analyzed by the FMEA is identical to the Test Specimen configuration that is used in the Qualification Test Program. The intent of the FMEA is to identify potential failure states of modules and units. Toshiba performs the FMEA at the module level.

A Setpoint Support Analysis was performed by NED to meet the requirements of EPRI TR-107330, Section 4.2.4 and RG 1.105 Revision 3 (Reference (a10)).

Section 6.3.1 of EPRI TR-107330 requires performing aging analysis. Toshiba did not perform aging analysis, since aging analysis is not necessary when equipment is qualified for use only in mild environments.

III-3.2 Qualification Analysis of PRM System

Qualification analysis was conducted for the PRM system during the PRM Qualification Project. Results of the analysis conducted for the PRM system are summarized in the following subsections.

III-3.2.1 Availability/Reliability Analysis of PRM System

The PRM system was conservatively analyzed for reliability and availability using MIL-HDBK-217F (Reference (a24)). The reliability and availability analysis for the test specimen is documented in the Availability/Reliability Analysis Report (Reference (d30)). This analysis complies with the applicable requirements of EPRI TR-107330 (Reference (a46)) for the standard to be used, 24 hour MTTR and the consideration for surveillance test period. The reliability values were calculated by summing failure rates of whole devices.

Table III-3.1 lists the reliability values for the single division Test Specimen. Table III-3.2 lists the reliability values for a full PRM System (for a BWR-5) for two cases, including redundant divisions; the system analyzed contains LPRM, LPRM/APRM, and Flow units qualified in the PRM Qualification Project.

Table III-3-1 Availability/Reliability Analysis Results (Test Specimen)

	MTBF	MTTR	Availability
Test Specimen	[ ]a,c year ([ ]a,c H)	24 H	[ ]a,c > 0.99
	using MIL-STD-217F	using TR-107330 Section 4.2.3.3 C.	using TR-107330 Section 4.2.3.3 C.

Note *): It is recommended to perform once a year surveillance work for linearity check which need 24 hours at most. Taking this surveillance work into account, the availability is 0.99672 which is also greater than 0.99.

Table III-3-2 Availability/Reliability Analysis Results (Full PRM System)

		MTBF	MTTR	Availability
PRM System	Case 1	[ ]a,c year ([ ]a,c H)	24 H	[ ]a,c > 0.99
	Case 2	[ ]a,c year ([ ]a,c H)	24 H	[ ]a,c > 0.99
Case 1: (2 out of 3) twice with repair Case 2: (1 out of 3) twice without repair		using MIL-STD-217F	using TR-107330 Section 4.2.3.3 C.	using TR-107330 Section 4.2.3.3 C.

Case 1: The PRM full system is evaluated for the condition that more than two of the three PRM channels are functional in both trip channels. One PRM channel in three PRM channel in both trip channels is allowed to be bypassed and to be repaired.

Case 2: The PRM full system is evaluated for the condition that at least one of the three PRM channels is functional in both trip channels. Repair is assumed not to be possible.

Note *): When once a year surveillance work with duration of 24 hours is taken into account, the availability is 0.99667, which is also greater than 0.99.

III-3.2.2 FMEA for PRM System

The FMEA was performed in the Preliminary Hazard Analysis in the Requirements Definition Phase and documented in an appendix of the Requirements Definition Phase Preliminary Hazard Analysis Report (Reference (d11)).

Failure modes that affect the safety-related functions and methods of detection for those failure modes were identified through the FMEA. The FMEA has been performed based on the design information from the module design specifications. The analysis focused on the input and output of each FPGA, determining possible deviations from normal operation and their effects.

The detailed results of the FMEA are documented in the Requirements Definition Phase Preliminary Hazard Analysis Report. The results showed that failure modes that can prevent the PRM System from performing its function were detected by the application-specific design, the built-in system diagnostics, or by periodic testing.

The Application Guide, Appendix II-A, includes recommendations for periodic surveillance. The general surveillance techniques should be similar to those used for existing PRM systems. The surveillance interval of once per month, similarly, is based on existing technology. The surveillance is used to detect failures to lower the risk of occurrence of any problem that could adversely affect plant operation or safety. It is strongly recommended that specific nuclear plant safety-related applications incorporate Toshiba's recommended methods and frequencies to maximize system reliability and operability. This result conforms to the failure state/FMEA requirements shown in Section 4.2.3.5 of EPRI TR-107330 (Reference (a46))).

III-3.2.3 Setpoint Support Analysis for PRM System

In accordance with the Setpoint Support Analysis, the Rack Reference Accuracy (RRA), Rack Temperature Effect (RTE), and Rack Drift (RD) are applicable allowances to the following safety-related trip signals in the PRM System:

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

In the PRM Qualification Project, RRA, RTE, and RD were evaluated collectively for the above safety-related trip signals. It has been verified that Channel Statistical Allowance (CSA) (the

relationship among CSA, RRA, RTE, and RD is noted in Eq. III-3-1) for APRM Upscale (High-High) Trip signal and Simulated Thermal Power Upscale Trip signal is less than 2.0% Full Scale (FS). CSA is not applicable to APRM Inoperable Trip, because the APRM Trip Inoperable Trip will be issued by self diagnosis of APRM.

$$CSA = \{(RRA)^2 + (RTE)^2 + (RD)^2\}^{1/2} \qquad \text{Eq. III-3-1}$$

The methodology and details of the results are reported in the Setpoint Support Analysis Report (Reference (d31)).

III-4 Verification and Validation of PRM

III-4.1 Power Range Neutron Monitor

Toshiba developed a PRM system, and conducted V&V for the PRM system through the development.

The Original process described in Section III-1.1 was used in the development and V&V. In the Original process, NED worked under the Appendix B QA program and procured the PRM from NICSD who worked under its ISO 9001 QA program those days, using NED's CGD process. ICDD had the overall responsibility for the V&V activities.

In 2011, a problem was found in the FPGA dynamic testing performed using the Original process, and necessary V&V activities were activated. In the activities, the Current process was used, because the Original process was no longer applicable. Section III-4.1.4 describes the V&V iteration.

III-4.1.1 V&V Organization and Process

ICDD organized an ICDD V&V Team independent of its design group. The ICDD V&V Team established an NED VVP defining the organizations, responsibilities, applicable standards, and the life cycle activities. The NED VVP was attached to the Job Order to NICSD.

NICSD organized their V&V Team. The NICSD V&V Team established a NICSD VVP based on the NED VVP defining the organizations, responsibilities, applicable standards, and the life cycle activities for their portions. The NICSD VVP was submitted to NED for review and approval.

The V&V activities were performed following the original process described in Section I-1.5.2, i.e., the following life cycle phases:

- Project Planning and Concept Definition Phase,
- Requirements Definition Phase,
- Design Phase,
- Implementation and Integration Phase,
- Unit/Module Validation Testing Phase, and

- System Validation Testing Phase.

Of these phases, NED performed the Project Planning and Concept Definition Phase, and the System Validation Testing Phase. The remaining phases were performed by NICSD in accordance with the Job Order, and under the oversight by the ICDD V&V Team.

III-4.1.2 Design Verification

The ICDD and NICSD V&V Team verified the design of the PRM by reviewing the design documents, and tracing the requirements for the PRM throughout the life cycle using RTM.

III-4.1.2.1 Document Reviews

The NED design engineers established an Equipment Requirements Specification (ERS), which specified all functional and design requirements for the PRM.

Based on the ERS, the NICSD design engineers established the following design documents:

- Unit Equipment Design Specifications for the LPRM, LPRM/APRM and FLOW units,
- Module Equipment Design Specifications for modules installed in those units, and
- FPGA Design Specifications for all FPGAs.

The ICDD V&V Team reviewed the ERS. The NICSD V&V Team reviewed the above NICSD design documents. The ICDD V&V Team made spots checks of the NICSD design documents. The ICDD V&V Team concluded that these design documents, and the manner of the NICSD reviews were satisfactory.

In addition to the design documents, the NICSD V&V Teams reviewed the following test procedures before the tests were performed:

- FPGA test procedures,
- Module test procedures, and
- Unit test procedures.

After the test, the NICSD V&V Teams reviewed the corresponding test reports.

The NICSD V&V Team concluded that these test procedures and reports were satisfactory. The

ICDD V&V Team accepted the results from the NICSD V&V Team, after spot checks of these test procedures and reports.

The ICDD V&V Team reviewed the System test procedure prepared by the ICDD design engineers, and the System test report after the system validation testing. The ICDD V&V Team concluded that the documents were satisfactory.

III-4.1.2.2 Requirements Traceability Efforts

NED prepared an RTM by collecting requirements from the ERS. The RTM was reviewed by the ICDD V&V Team, and sent to NICSD as the base requirments for the PRM.

The NICSD V&V team developed the RTM through the life cycle phases, tracing requirements or design specifications in the following documents:

- Unit Equipment Design Specifications for the LPRM, LPRM/APRM and FLOW units,
- Module Equipment Design Specifications for modules installed in those units,
- FPGA Design Specifications for all FPGAs,
- FPGA test procedures,
- Module test procedures, and
- Unit test procedures.

The NICSD V&V team verified that all the base requirements provided by NED were traced forward and traced back through the life cycle phases.

The ICDD V&V team made spot checks, and confirmed the NICSD V&V Team's conclusions.

The ICDD V&V team completed the RTM by filling in the test items from the System Validation Test Procedures.

III-4.1.2.3 FPGA Logic Implementation V&V

The NICSD design engineers established FPGA Design Specifications for all FPGAs. The Toshiba FPGA-based systems uses a Functional Element (FE) approach, as described in Section II-2.1.6. The FPGA Design Specifications represented the FPGA design in block diagrams and broken down to the level of FEs.

The NICSD design engineers developed the VHDL source code for each FPGA, converted the VHDL source code into a netlist, and into a fusemap using software tools. The fusemap was implemented in an FPGA for FPGA testing.

These design activities were performed in accordance with the FPGA design principles described in Section II-2.1.5.

The FPGA Logic Implementation V&V included:

(1) VHDL Source Code Review. See Section I-3.10.2.5.

(2) Software Tool Message Review. See Section I-3.10.2.5.

(3) Signal Timing Analysis Review. See Section I-3.10.2.5 and Section II-2.1.5.3.

(4) Netlist Review. See Section I-3.10.2.5.

(5) FPGA Testing, the NICSD design engineers performed validation testing of the FPGAs in a manner that achieved the 100% toggle coverage criteria. See Section I-3.10.2.5 and Section II-2.1.7.

(6) Software Tool Control Review. See Section I-3.10.2.5.

The NICSD V&V Team concluded that the results of the V&V activities were acceptable. The NED V&V Team concluded that the conclusion of the NICSD V&V Team was acceptable.

III-4.1.2.4 Validation Testing

NICSD performed the module validation tests for each module, and then performed unit validation tests for each unit installing the modules. Finally, NED performed the system validation testing of the assembled PRM system. As stated before, NED reviewed and accepted the work performed by NICSD, ensuring the Validation Testing activities completed were complete, correct, thorough, adequate, controlled, and that the resulting safety system would produce accurate, timely results, with the correct functionality, acceptable reliability, appropriate cyber security, and ability to operate (and identify) single faults and failures in a redundant installation.

For the validation testing, a set of test equipment was used. The test equipment entered test signals into the LPRM modules in the LPRM units or in the LPRM/APRM unit. The LPRM converted the signals into digital data, and applied a digital filter on the data. The data was sent to the APRM module in the LPRM/APRM unit through the fiber optic links or through the middle plane of the LPRM/APRM unit. The APRM module made trip determinations, and sent the trip signal to the discrete output module, from which the trip signals were sent to the test equipment.

One or more test PCs controlled the test equipment, and recorded the input and output signals. The records were compared with the desired values.

The NICSD V&V Team reviewed the results of the module and unit validation testing, and concluded that they were acceptable. The ICDD V&V Team reviewed the NICSD VVR and the result of the system validation testing, and concluded that the validation testing was acceptable.

III-4.1.3 Hazard Analyses

NED, as an Appendix B vendor, performed a hazard analysis for each phase of the life cycle, and completed the analysis at the System Validation Testing Phase.

In the Project Planning and Concept Definition Phase, a fault tree analysis (FTA) was performed as a top down analysis approach. The analysis concluded that it requires two concurrent occurrences of failures to affect plant operation.

However, the analysis pointed out that errors in the software tools and timing errors of FPGA should be addressed in the life cycle. The hazard analyses performed in subsequent phases addressed the two issues, and concluded that the PRM system-level risk was less than the existing plant equipment.

The NED V&V Team reviewed the hazard analysis reports at each phases, and concluded that they were acceptable.

III-4.1.4 V&V Iteration

In 2011, NICSD and the Power Platform Development Department (PPDD) of the Fuchu Complex found a problem in the FPGA testing that had been performed in the V&V for the PRM, and notified to the Instrumentation & Control Systems Design & Engineering Dept. (ICDD). The problem was that the FPGA dynamic timing simulation had not been performed appropriately. A Corrective Action Request (CAR)-11-176, which requested resolution of the problem was issued.

To resolve the problem, the NICSD and PPDD performed a correct dynamic timing simulation as FPGA retesting. The result of the retesting was satisfactory ensuring the correct operation of the FPGAs without any logic change.

NICSD issued a V&V report for the retesting in accordance with the V&V Plan. The ICDD IV&V Team updated the Verification and Validation Final Report for the PRM, which is Part V

of the LTR. The updated V&V Final Report concluded that the result of the V&V was acceptable.

III-4.1.5 V&V Conclusions

The ICDD V&V Team issued the Verification and Validation Final Report for the PRM system, concluding that all requirements for the PRM system were fulfilled in the final product, and that the PRM system is suitable for nuclear plant power monitoring. This conclusion was not changed after the V&V iteration described in Section III-4.1.4, and the V&V Final Report was issued. In the V&V for the PRM, all observed issues and concerns were resolved appropriately.

III-5 Qualification Test of OPRM

III-5.1 General Description

This section describes the qualification of the safety-related Oscillation Power Range Monitor (OPRM). Toshiba performed qualification test activities as required by EPRI TR-107330 (Reference (a46)) in the similar manner as the qualification test for PRM. Table III-5-1 shows the configuration of the test specimen of the OPRM for the qualification test.

Table III-5-1 Test Specimen Configuration during Environmental, Seismic, and EMC test of OPRM

(Slot ID) Module Name	Model Number	Functional Description
OPRM Unit (HNU1200B00000)		
(FSL01) Blank Panel	---	Blank Panel
(FSL02) Blank Panel	---	Blank Panel
(FSL03) Blank Panel	---	Blank Panel
(FSL04) Blank Panel	---	Blank Panel
(FSL05) to (FSL07) CELL Module	HNS0400B00000	LPRM Levels are converted to Normalized Oscillation Signal.
(FSL08) to (FSL09) AGRD Module	HNS0420B00000	Amplitude-Based Detection Algorithm judgment is performed. Growth Rate-Based Detection Algorithm judgment is performed.
(FSL10) to (FSL11) PBD Module	HNS0430B00000	Period-Based Detection Algorithm judgment is performed.
(FSL12) Blank Panel	---	Blank Panel
(FSL13) Blank Panel	---	Blank Panel
(FSL14) DAT/ST Module	HNS0410B00000	Power status is indicated on the front panel. Input status is indicated on the front panel. Data are multiplexed.
(PSSL01) LVPS Module	HNS0500B00000	+5V and ±15V power supply to each module.
(BSL01) Blank Panel	---	Blank Panel
(BSL02) Blank Panel	---	Blank Panel
(BSL03) Blank Panel	---	Blank Panel
(BSL04) DIO Module	HNS520B00000	Digital inputs are received from the Relay unit. Digital outputs are provided to the Relay unit.
(BSL05) RCV Module	HNS0541B00000	Optical data reception of the LPRM unit data from LPRM unit.
(BSL06) RCV Module	HNS0541B00000	Optical data reception of the APRM unit data from APRM unit.
(BSL07) TRN Module	HNS0531B00000	Optical data transmission of OPRM unit data to ELCS and PICS.
(BSL08) TRN Module	HNS0531B00000	Optical data transmission of OPRM unit data to TDR, SOE, and PC.
(PSSL02) LVPS Module	HNS500B00000	+5V and ±15V power supply to each module.
Power Factor Correction module (PFC)		
(External) Power Factor Correction module (PFC)	BPC-10	Input line filter for LVPS module.

III-5.1.1 Performance Proof Test

The performance proof test was performed prior to the qualification test as pre-qualification test, and it was also performed after the qualification test as post-qualification test. The performance proof test includes Set-up and Check-out Test, Operability Test, and Prudency Test, and these tests were conducted in the same manner as the PRM Qualification. Qualification Tests

Qualification tests were conducted to demonstrate compliance with requirement specifications and to demonstrate suitability of equipment while subject to stress conditions. Qualification tests were performed on the assembled Test System after the system passes the pre-qualification testing acceptance criteria.

The qualification tests include the Wear Aging Test, the Environmental Test, the Seismic Test, the Electromagnetic Interference/Radio-Frequency Interference (EMI/RFI) EMI/RFI Test, the Power Surge Test, the Electrical Fast Transient / Burst (EFT/B) Test, and Electrostatic Discharge (ESD) Test. The Environmental Test, the Seismic Test, the EMI/RFI Test, the Power Surge Test, the EFT/B Test, and ESD Test were performed in the similar manner as BWR-5 PRM Qualification.

The Radiation Test performed for the PRM was not performed for the OPRM, since the equipment is designed to be installed in a mild environment, radiation exposure was not necessary.

The Wear Aging Test which was not performed for PRM was performed for OPRM. As a result of design, since the attachment of connectors and switching of a key-switch may cause wear degradation, thus the wear aging testing for them was performed. Result of the Wear Aging Test is applicable to the same type of the connectors and the key-switch applied in BWR-5 PRM. The wear aging test is performed prior to the temperature and humidity test, in order to apply severe condition such as interface oxidation due to wear aging. The wear aging test for any screw used in the test specimen is not required since it is managed with a controlled torque. After the wear aging test was performed, an operability test was performed.

The Class 1E to Non-Class 1E Isolation Test was performed for PRM for reference. The test was not performed for the ABWR OPRM because fuses, analog isolators, optical couplers, and optic cables which support class 1E to Non-Class 1E isolation are out of scope of OPRM qualification.

The detailed scope and the timing of the Operability Test and the Prudency Test are shown in Table IV-4-8 through IV-4-10 in the Part IV of this topical report.

III-5.2 Qualification Tests for OPRM System

Qualification tests were conducted for the ABWR OPRM using a test specimen that is comprised of one OPRM unit with two Power Factor Correction modules (PFCs).

Qualification Test items with reference to the relevant test documents of OPRM Qualification are shown in Table III-5 2. The test sequence of environmental qualification test, seismic test, and EMC qualification test that were used for OPRM qualification are shown in Figure III-5-1 and Figure III-5-2. The EMC qualification test was conducted prior to the seismic test. Table III-5-2, Figure III-5-1 and Figure III-5-2 do not show the Operability Tests and the Prudency Tests. See Table IV-4-8 through IV-4-10 in Part IV of this topical report for detailed scope and the timing of the Operability Test and the Prudency Test during the Qualification Test.

As shown in Table III-5-2, the test levels for EMI/RFI Test, Power Surge Test, and EFT/B Test are not the same as those specified in EPRI TR-107330 (Reference (a46)) requirements. Instead, the test levels used were obtained from RG 1.180, Revision 1 (Reference (a19)), which was issued in October 2003 after the EPRI report was completed. These Regulatory Guide values are considered to better reflect the current requirements of US utilities.

Results of these tests conducted for the OPRM system are summarized in the following subsections.

Table III-5-2 Qualification Test Overview (OPRM Qualification)

Test		Applied Standard	Toshiba Test Procedure Number*	Section in EQ Test Plan (Reference (c10))/EMC Test Plan (Reference (c11))
1.Performance Proof Test	1.1 Set-up and Check-out Test	TR-107330	FC51-7021-1002 (Reference (c12))	Section 7.1 of EQ Test Plan/Section 7.1 of EMC Test Plan
	1.2 Operability Test	TR-107330	FC51-7021-1003 (Reference (c13))	
	1.3 Prudency Test	TR-107330	FC51-7021-1004 (Reference (c14))	
2.Qualification Test	2.1 Environmental (Wear Aging, Temperature and Humidity) Test	TR-107330	FC51-7021-1005 (Reference (c15))	Section 7.2 of EQ Test Plan
	2.2 Seismic Test	TR-107330	FC51-7012-1006 (Reference (c16))	Section 7.2.3 of EQ Test Plan
	2.3 EMI/RFI Test	RG 1.180	FC51-7012-1007 (Reference (c17))	Section 7.2.1.1 and 7.2.1.2 of EMC Test Plan
	2.4 Power Surge Test	RG 1.180	FC51-7012-1009 (Reference (c18))	Section 7.2.1.3 of EMC Test Plan
	2.5 EFT/B Test	RG 1.180	FC51-7012-1009 (Reference (c18))	Section 7.2.1.3 of EMC Test Plan
	2.6 ESD Test	TR-107330	FC51-7012-1010 (Reference (c19))	Section 7.2.1.4 of EMC Test Plan

* This column lists the test procedure numbers used for OPRM qualification.

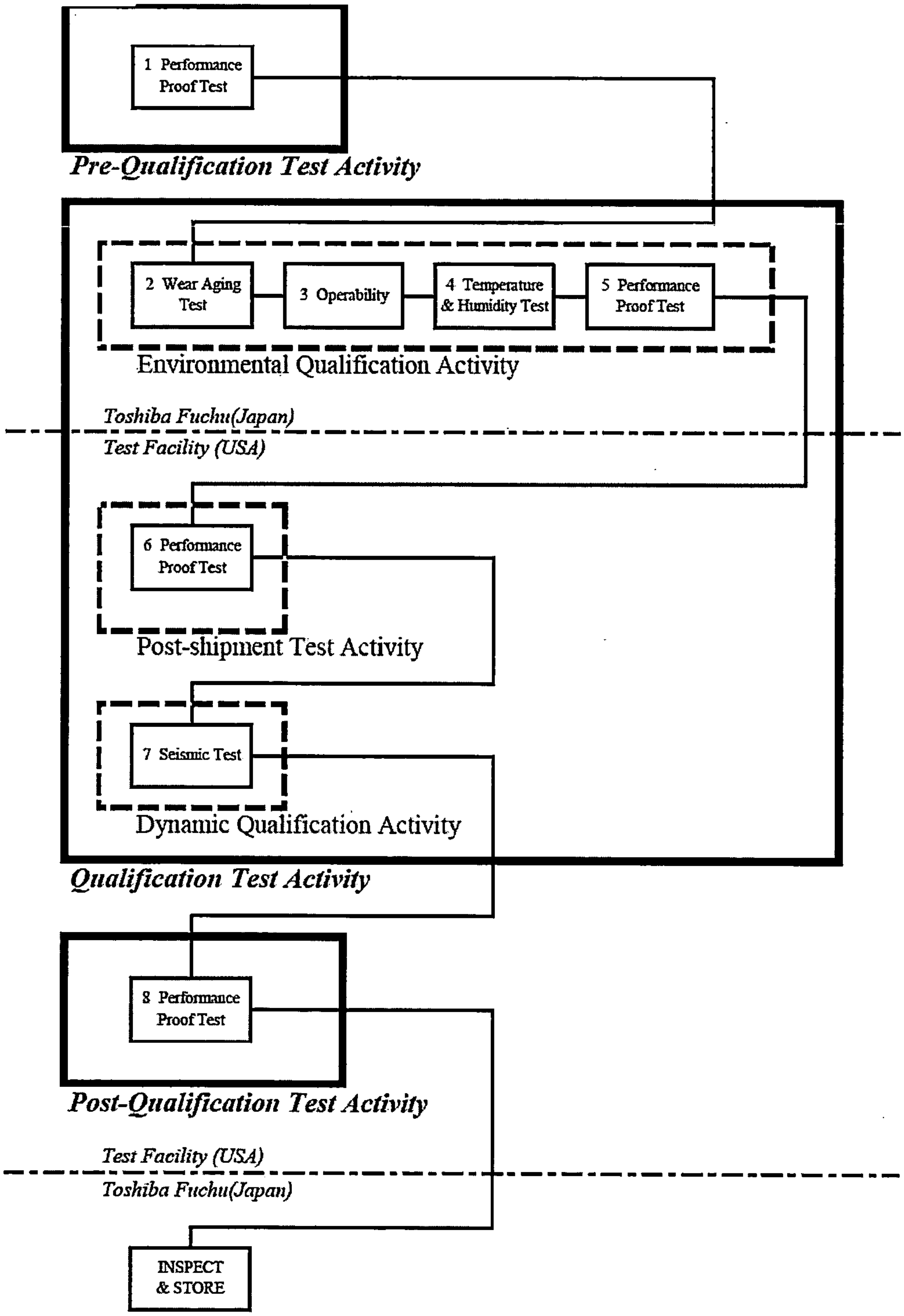

Figure III-5-1 Environmental and Seismic Qualification Test Sequence (OPRM Qualification)

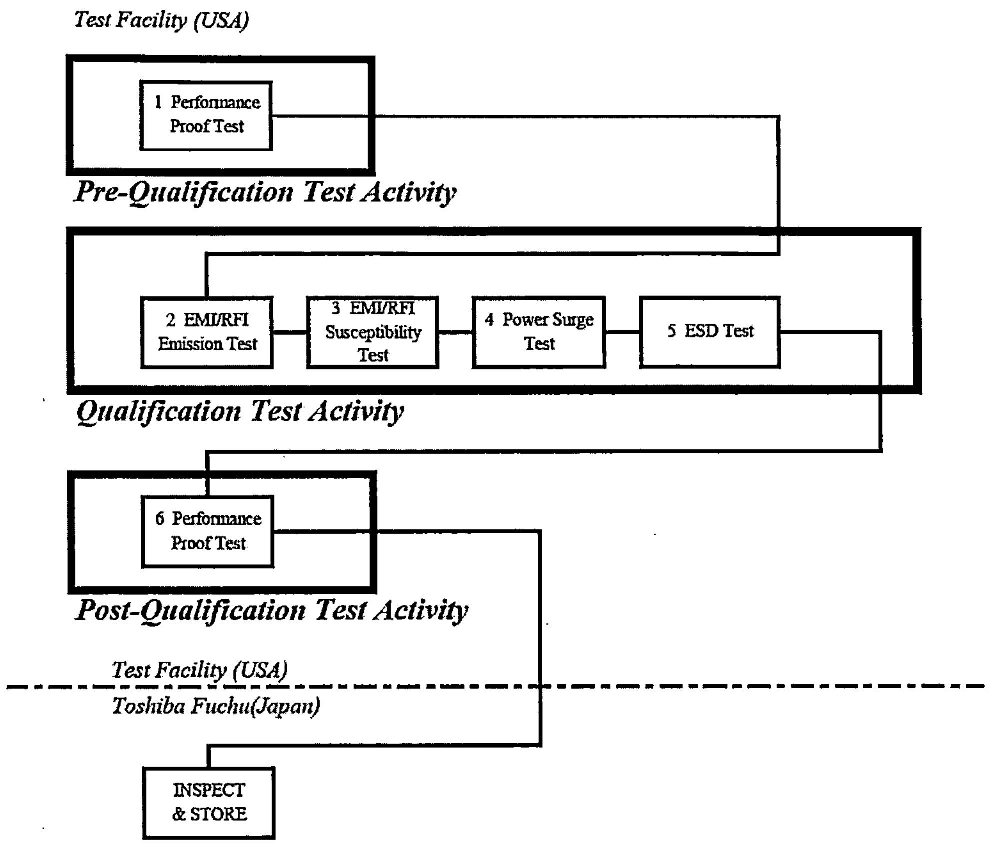

Figure III-5-2 EMC Qualification Test Sequence (OPRM Qualification)

III-5.2.1 Environmental Test

III-5.2.1.1 Wear Aging Test

The wear aging test was performed at the Toshiba Fuchu Complex. The test specimen was not energized during the wear aging test. In this test, the target connectors were subjected to 200 cycles of mechanical wear and the key switches were subjected to 550 cycles of mechanical wear. The operability test after the wear aging test was successfully performed. Thus, the test results showed that performance of the test specimen was not directly degraded by wear aging at that time and the test results were acceptable. Details of the wear aging test results are reported in the Environmental Qualification Report (Reference (c20)).

III-5.2.1.2 Temperature and Humidity Test Profiles for OPRM System

The temperature and humidity test was performed in the test facility in US to ensure that the Toshiba OPRM system operates correctly when exposed to the temperature and humidity conditions shown TR-107330 (Reference (a46)) Section 6.3.3.

Requirements and the acceptance criteria for environmental test are specified in the Equipment Qualification Test Plan (Reference (c10)).

A total of two cycles of the temperature and humidity test was performed as planned. The temperature and relative humidity in the test chamber satisfied the requirements based on the Equipment Qualification Test Plan (Reference (c10)) throughout the temperature and humidity test.

After the test, the performance of the Test Specimen was compared to the baseline performance (measured during Pre-Qualification Test) to determine if the test impacted the performance and operability of the Test Specimen.

III-5.2.1.3 Summary of Temperature and Humidity Test Results of OPRM System

The test results demonstrated that exposure to the temperature and humidity test conditions had no adverse effect on the OPRM performance. Details of the tests results of the temperature and humidity test are reported in the Environmental Qualification Report (Reference (c20)).

III-5.2.2 Seismic Test

III-5.2.2.1 Seismic Test Method and Process for OPRM System

The seismic test was performed to assure that the OPRM Test Specimen provides the performance and seismic withstand capability under seismic test conditions shown in Section 4.3.9 of EPRI TR-107330 (Reference (a46)) in accordance with IEEE Std 344 (Reference (a32)).

Requirements and the acceptance criteria for the seismic test are specified in the Equipment Qualification Test Plan (Reference (c10)).

Table III-5-3 shows the seismic level applied during this test.

The OPRM unit was mounted on a rigid seismic test fixture using mounting brackets. The direction of OPRM unit was as follows:

- X-Direction: Side-to-side of OPRM
- Y-Direction: Front-back
- Z-Direction: Vertical

The OPRM unit was fixed in the brackets with four M5-12mm truss head screws with fiber washers, and eight M4-14 mm hexagon socket bolts with flat and lock washers for the rear side. The PFCs were mounted on a steel plate in the rigid seismic test fixture. Each PFC was fixed on the steel plate with four M4 bolts with hexagon socket, with 14 mm threaded portion. The specification of the torque to tighten the screws was 2.6 – 3.4 Nm in the front side and 1.3 – 1.7 Nm in the back side. The torque values were measured and confirmed that they were within the limits in the testing.

Table III-5-3 Seismic Levels

Seismic Event	Maximum Amplitude Requirement from EPRI TR-107330 Section 4.3.9
OBE	10.8 g
SSE	15.4g

The seismic tests were performed in accordance with the Seismic Test Procedure (Reference ((c16)). The following tests were performed:

(1) Resonance Search

The resonance search was conducted in each of the three principal orthogonal directions (front-to-back (Y), side-to-side (X), and vertical (Z)) with a 0.2g input peak sinusoidal acceleration from 1 to 100 Hz at a one octave/minute sweep rate. Following the 1–100 Hz sweep, a 100–1 Hz sweep was also conducted for each principal direction.

(2) Random Multifrequency Tests (5 OBEs and 1 SSE)

The seismic test was performed on the triaxial vibration table, using random, multi-frequency acceleration time-history inputs to the vibration table at the seismic test area in the test facility in US. The vibration table drive signal was a multi-frequency, random input, and 30 seconds in duration with a minimum of 20 seconds of strong motion.

III-5.2.2.2 Summary of Seismic Test Results of OPRM System

(1) Resonance Search

Results from all the run cases show that the natural frequencies at three locations (OPRM Rack, OPRM Chassis, and PFC Plate) were substantially the same, and also the natural frequencies of sweep up from 1 to 100 Hz and sweep down from 100 to 1 Hz were substantially the same. Thus it indicates that these natural frequencies were not caused by OPRM and/or PFC but by the fixture itself.

The response magnification factor with respect to the input acceleration at each location was less than 3.1 at a maximum at 41 through 45 Hz, and less than 3.8 at a maximum at 65 Hz or more. This indicates that the fixture on which the test specimen was mounted was adequately rigid.

The results stated above demonstrate that the fixture was appropriately designed and fabricated for testing, the mounting of the test specimen was successful, and the test specimen had no resonance point from 1 to 100 Hz.

Details of the tests results of the resonance search are reported in the Dynamic Qualification Report (Reference (c22)).

(2) Random Multifrequency Tests (5 OBEs and 1 SSE)

(a) OBE Test Result

The OPRM unit and PFCs were subjected to five acceptable OBE test runs. Each OBE test run was 30 seconds in duration, with multiple frequency independent triaxial random motion over the frequency range of 1 through 100 Hz.

The test specimen maintained structural integrity, all the OPRM safety-related functions correctly operated, and no error was detected by the test system during and after each OBE test.

(b) SSE Test Result

An acceptable SSE test run to the SSE RRS was performed at the completion of the OBE test. The SSE test run was 30 seconds in duration, with multiple frequency independent triaxial random motion over the frequency range of 1 through 100 Hz.

The Test Response Spectra (TRS) did not envelop the Test Required Response Spectra (TRRS) below 2 Hz in the Side to Side and Vertical directions. The dips are acceptable per clause 7.6.3.1 of IEEE Std. 344-1987 (Reference (a32)) because it was shown that the test specimen and test fixture had no natural frequencies below 5 Hz as described in (1) of this section.

The test specimen maintained structural integrity, all the OPRM safety-related functions correctly operated, and no error was detected by the test system during and after the SSE test.

Details of the tests results of the random multifrequency tests are reported in the Dynamic Qualification Report (Reference (c22)).

III-5.2.3 Electromagnetic Compatibility (EMC) Test

III-5.2.3.1 Test Method and Process for OPRM System

The purpose of this test was to demonstrate the electromagnetic compatibility of the OPRM Test Specimen. EMI/RFI, Power Surge, EFT/B, and ESD tests were performed.

The test levels specified for EMI/RFI, Power Surge, and EFT/B Tests were not the same as those specified in EPRI TR-107330 (Reference (a46)) requirements. Instead, the test levels used were obtained from RG 1.180, Revision 1 (Reference (a19)), which was issued in October 2003. These Regulatory Guide values are considered to better reflect the current requirements of US utilities. EPRI TR-107330 was published in December 1996, prior to issuance of Revision 1 of RG 1.180.

Table III-5-4 shows the results of EMC tests.

The EMC tests were performed from December 3 2012 through January 7, 2013.

Test Specimens were installed in the free-standing instrument rack. To permit confirmation of the Test Specimen's capability, this rack was designed to not shield emissions from the Test Specimen or to shield the equipment from external test signals. The Test Specimen rack was placed in the test facility's EMC chamber. During the EMC qualification test, the OPRM unit was operated with a specific test pattern in the normal and abnormal modes for monitoring the OPRM performance in order to demonstrate the soundness of the test specimen throughout the test period. The specific test patterns are described in Section 8.4.1 of the EMC Qualification Report (Reference (c21)).

Details of the test results are reported in the EMC Qualification Report (Reference (c21)).

Table III-5-4 EMC Test Results

Test Item	Test Method	Test Level	Test Results
Conducted Emissions Low Frequency	MIL-STD-461E/CE101	60 Hz to 10 kHz	Comply
Conducted Emissions High Frequency	MIL-STD-461E/CE102	10 kHz to 2 MHz	Comply
Radiated Emissions Magnetic Field	MIL-STD-461E/RE101	30 Hz to 100 kHz	Comply
Radiated Emissions Electric Field	MIL-STD-461E/RE102	2 MHz to 10 GHz	Comply
Conducted Susceptibility Low Frequency	MIL-STD-461E/CS101	120 Hz to 150 kHz	Comply
Conducted Susceptibility High Frequency	MIL-STD-461E/CS114	10 kHz to 30 MHz	Comply
Conducted Susceptibility Bulk Cable Injection	MIL-STD-461E/CS115	2A	Comply
Conducted Susceptibility Damped Sinusoidal Transients	MIL-STD-461E/CS116	10 kHz to 100 MHz	Comply
Radiated Susceptibility Magnetic Field	MIL-STD-461E/RS101	30 Hz to 100 kHz	Comply
Radiated Susceptibility Electric Field	MIL-STD-461E/RS103	30 MHz to 10 GHz	Comply
Surge 100 kHz Ring Wave	IEC 61000-4-12/Ring Wave	2 kV	Comply
Surge Combination Wave	IEC 61000-4-5/Combination Wave	2 kV	Comply
Electrical Fast Transient /Burst	IEC 61000-4-4/EFT/B	2 kV	Comply
Electrostatic Discharge	IEC 61000-4-2/ESD	15 kV (Air Discharge) 8 kV (Contact Discharge)	Comply

III-5.2.3.2 EMI/RFI Test for OPRM System

The purpose of this test is to demonstrate the suitability of the OPRM System for qualification as a safety-related device with permissible EMI/RFI emissions and susceptibility.

EMI/RFI Test was performed to assure that the OPRM System withstands the EMI/RFI levels given in RG 1.180 (Reference (a19)). Toshiba decided to use these test levels because they were issued more recently than the requirements specified in the EPRI TR-107330 (Reference (a46)) requirements. These Regulatory Guide values are considered to better reflect the current requirements of US utilities.
The EMI/RFI susceptibility and emissions withstand capability was tested using the following test methods from MIL-STD-461E (Reference (a25)).

	Test Type	Test Method
(a)	Conducted Emissions, Low-frequency	CE101
(b)	Conducted Emissions, High-frequency	CE102
(c)	Radiated Emissions, Magnetic Field	RE101
(d)	Radiated Emissions, Magnetic Field	RE102
(e)	Conducted Susceptibility, Low-Frequency	CS101
(f)	Conducted Susceptibility, High-frequency	CS114
(g)	Conducted Susceptibility, Bulk Cable Injection	CS115
(h)	Conducted Susceptibility, Damped Sinusoidal Transients	CS116
(i)	Radiated Susceptibility, Magnetic Field:	RS101
(j)	Radiated Susceptibility, Electric Field:	RS103

Requirements and the acceptance criteria for EMI/RFI tests are specified in the EMC Qualification Test Plan (Reference (c11)).

Details of the test results are reported in the EMC Qualification Report (Reference (c21)).

The EMI/RFI emission test was performed. All the test items of the EMI/RFI emission test were successfully completed. During the EMI/RFI emission test, the performance of the OPRM unit was supplied with the test pattern, and checked whether the OPRM unit normally operated. The history of test progress and performance check result shown that the OPRM normally operated as expected performing its intended safety functions.

The EMI/RFI susceptibility test was performed. All the test items of the EMI/RFI susceptibility

test were successfully completed. During the EMI/RFI susceptibility test, the performance of the OPRM unit was continuously monitored inputting the test pattern. The performance of the test specimen was checked to confirm whether the test specimen met the criteria specified in the EMC Qualification Test Plan (Reference (c11)) without showing any susceptibility to applied test level. The history of test progress and performance check result shown that the OPRM normally operated as expected performing its intended safety functions.

III-5.2.3.3 Power Surge Test for OPRM System

The purpose of this test is to demonstrate the suitability of the OPRM System for qualification as a safety-related device with Power Surge, as stated in Section 5 of RG 1.180 (Reference (a19)), IEC 61000-4-5 (Reference (a28)), and IEC 61000-4-12 (Reference (a29)).

The Power Surge Test was performed to ensure that the OPRM System withstands the surge limits given in Table 22 of RG 1.180. Surges were applied in accordance with IEC 61000-4-12 (for Ring Wave) and IEC 61000-4-5 (for Combination Wave).

Requirements and the acceptance criteria for EMI/RFI tests are specified in the EMC Qualification Test Plan (Reference (c11)).

Details of the test results are reported in the EMC Qualification Report (Reference (c21)).

The power surge test was performed. All the test items of the power surge test were successfully completed. During the power surge test, the performance of the OPRM unit was continuously monitored inputting the test pattern. The performance of the test specimen was checked to confirm whether the test specimen met the criteria specified in the EMC Qualification Test Plan (Reference (c11)) without showing any susceptibility to applied test level. The history of test progress and performance check result shown that the OPRM normally operated as expected performing its intended safety functions.

III-5.2.3.4 EFT/B Test for OPRM System

The purpose of this test is to demonstrate the suitability of the OPRM System for qualification as a safety-related device with EFT/B withstand capability, as stated in Section 5 of RG 1.180 (Reference (a19)), and IEC 61000-4-4 (Reference (a27)).

The EFT/B Test was performed to assure that the OPRM Test Specimen withstands the surge EFT/B wave form given in the Table 22 of RG 1.180.

Requirements and the acceptance criteria for EFT/B tests are specified in the EMC Qualification Test Plan (Reference (c11)).

Details of the test results are reported in the EMC Qualification Report (Reference (c21)).

The EFT/B tests were performed by applying the disturbances of ±2 kV categorized as "Category B locations" and "Low Exposure levels" in Regulatory Position 5 and Table 22 of RG 1.180, Revision 1 (Reference (a19)). The test specimen did not exhibit susceptibility to the required interference conditions for all levels and applications. The test specimen met the criteria specified in the EMC Qualification Test Plan (Reference (c11)). Thus, the test specimen was demonstrated the surge withstand capability required in Regulatory Position 5.3 of RG 1.180, Revision 1.

III-5.2.3.5 ESD Test for OPRM System

The purpose of this test is to demonstrate the suitability of the OPRM System for qualification as safety-related device with regard to Electro-Static Discharge (ESD) withstand capability, as stated in IEC 61000-4-2 (Reference (a26)).

The ESD Test was performed to assure that the Test Specimen withstands the ESD levels given in Section 4.3.8 of EPRI TR-107330 (Reference (a46)). The test was performed at 40 % (day 1) and 41 % (day 2) relative humidity, which is within the required range of 30 to 60 % relative humidity.

Requirements and the acceptance criteria for ESD tests are specified in the EMC Qualification Test Plan (Reference (c11)).

Details of the test results are reported in the EMC Qualification Report (Reference (c21)).

ESD test was performed. During the ESD test, the performance of the OPRM unit was continuously monitored inputting the test pattern. The performance of the test specimen was checked by to confirm whether the test specimen met the criteria specified in the EMC Qualification Test Plan (Reference (c11)) without showing any susceptibility to applied test level. The history of test progress and performance check result shown that the OPRM normally operated as expected performing its intended safety functions.

The ESD test in accordance with IEC 61000-4-2 (Reference (a26)) was performed by applying the Level 4 shown in Table 1 of IEC 61000-4-2. The test specimen met the criteria specified in the EMC Qualification Test Plan (Reference (c11)). Thus, the test specimen was demonstrated

the ESD withstand capability required in Section 4.3.8 of EPRI TR-107730 (Reference (a46)).

III-5.3 Similarity Evaluation for New Module Design

The test specimen listed in Table III-5-1 was qualified through the environmental test, seismic test, and EMC qualification test. The design changes of the TRN module, the RCV module, and related FPGAs used in those modules were made to add Cyclic Redundancy Check (CRC) functionality. Supplemental software safety analysis activities and Verification & Validation (V&V) activities were performed on the changes of module and FPGA designs in a same manner applied to the test specimen listed in Table III-5-1.

Table III-5-5 shows the relationship between the module types of the TRN modules and the FPGA code names applied to each module type before and after the design change. The design change is implemented on the FPGA logic change made on [ ][a,c] to enhance the integrity of data transmission between the RCV module and the TRN module used within the PRNM system, and data transmission between the PRNM system and an external system implementing the CRC functionality. No change is made to the printed circuit board wiring, parts, hardware structure, and manufacturing process of the modules. Thus hardware design change is not included in this design change. The HNS0531B00001 has the same hardware configuration as that of the HNS0531B00000.

Table III-5-5 Applicable Module Type and FPGA Code Name for TRN Modules

Before design change		After design change		
Module Type	FPGA Code Name	Module Type	FPGA Code Name	Modified in this deign change?
HNS0531 B00000	[ ][a,c]	HNS0531 B00001	[ ][a,c]	**Modified**
				Use as is
				Use as is

Table III-5-6 shows the relationship between the module types of the RCV modules and the FPGA code names applied to each module type before and after the design change. The design change is implemented on the FPGA logic change made on [ ][a,c] and [ ][a,c] to enhance the integrity of data transmission between the RCV module and the TRN module used within the PRNM system, and data transmission between the PRNM system and external

system. No change is made to the printed circuit board wiring, parts, hardware structure, and manufacturing process of the module. Thus hardware design change is not included in this design change. The HNS0541B00001 has the same hardware configuration as that of the HNS0541B00000.

Table III-5-6 Applicable Module Type and FPGA Code Name for RCV Modules

Before design change		After design change		
Module Type	FPGA Code Name	Module Type	FPGA Code Name	Modified in this deign change?
HNS0541 B00000	[ ]a,c	HNS0541 B00001	[ ]a,c	**Modified**
				Modified

As discussed above, it was evaluated those new module designs had no effect on the results of the environmental qualification test, seismic test, and EMC qualification test reported in Section III-5.2, and the qualification test results obtained for the test specimen listed in Table III-5-1 were extended to the new module designs.

III-5.4 Conclusion of Qualification Tests for OPRM System

From the results of the qualification tests for ABWR OPRM, Toshiba concludes:

- The EMI/RFI emission test results show that the electromagnetic emissions from the test specimen satisfied the limit level specified in Regulatory Position 3 of RG 1.180, Revision 1 (Reference (a19)).
- The EMI/RFI susceptibility test results show that the test specimen did not exhibit any malfunction, degradation of performance, or deviation from specified limits when subjected to an immunity test signal specified in Regulatory Position 4 of RG 1.180, Revision 1.
- The power surge including EFT/B test results show that the test specimen did not exhibit any malfunction, degradation of performance, or deviation from specified limits, when subjected to an immunity test signal in Regulatory Position 5 of RG 1.180, Revision 1.
- Results of the ESD testing of OPRM show that the Test Specimen did not present any temporary degradation or loss of function or performance. Thus, the test specimen was

demonstrated the ESD withstand capability required in Section 4.3.8 of EPRI TR-107730 (Reference (a46)).

- As a result of the similarity evaluation described in Section III-5.3, it was determined that the Environmental, Seismic, and EMC qualification test result is applicable to the PRM when new TRN module and RCV module with the Cyclic Redundancy Check (CRC) function are used in the PRM.

III-6 Qualification Analysis of OPRM

III-6.1 General Description

Availability/Reliability Analysis, Failure Modes and Effects Analysis (FMEA), and Setpoint Support Analysis are performed for OPRM in the similar manner as PRM.

III-6.2 Qualification Analysis of OPRM System

Qualification analysis was conducted for the ABWR OPRM. Results of the analysis conducted for the OPRM are summarized in the following subsections.

III-6.2.1 Availability/Reliability Analysis of OPRM System

The availability and reliability analysis was performed for one OPRM unit and two Power Factor Correction modules (PFCs). In this analysis, analysis for the PRNM system was not performed because the scope of this project is limited to the qualification of the OPRM equipment. Module failure rates were calculated in accordance with MIL-HDBK217F (Reference (a24)). Each of those module failure rates is the rate of the worst case condition, which is calculated by summing up the failure rate of respective components that makes up each module. The OPRM unit adopts modular design, which supports module replacement and 24 hour MTTR using spare replacement parts stored at plant site. Failures of non-safety-related functions, which do not affect safety-related functions and plant availability, are excluded from the analysis. Table III-6-1 lists the reliability values for the OPRM equipment (OPRM unit and PFC). Details of the availability and reliability analysis of OPRM are documented in the Availability/Reliability Analysis Report for Safety-Related Oscillation Power Range Monitor (OPRM) (Reference (c23)).

Table III-6-1 Availability/Reliability Analysis Results (OPRM equipment)

OPRM	MTBF	MTTR	Availability
OPRM Equipment	[ ][a,c] year ([ ][a,c] H)	24 H	[ ][a,c] >0.99
	using MIL-STD-217F	using TR-107330 Section 4.2.3.3 C.	using TR-107330 Section 4.2.3.3 C.

Note *): In case that once a year surveillance period with 24 hour work duration is taken into account, the availability is 0.99664, which is also greater than 0.99.

III-6.2.2 FMEA for OPRM System

The FMEA was performed in the Software Safety Analysis in the Design Phase and documented in the NICSD Software Safety Analysis Report for Safety-Related Oscillation Power Range Monitor (OPRM) (Design Phase) (Reference (c24)).

Failure modes that affect the safety-related functions and methods of detection for those failure modes were identified through the FMEA. The FMEA has been performed based on the design information from the module design specifications.

The detailed results of the FMEA are documented in the NICSD Software Safety Analysis Report for the Safety-Related Oscillation Power Range Monitor (OPRM) (Design Phase). The results showed that failure modes that can prevent the OPRM from performing its function can be detected by the application-specific design, the built-in system diagnostics, or by periodic testing.

The Application Guide, Appendix II-A in the Part II of this Topical Report, includes recommendations for periodic surveillance. The general surveillance techniques should be similar to those used for existing systems. The surveillance interval of once per month, similarly, is based on existing technology. The surveillance is used to detect failures to lower the risk of occurrence of any problem that could adversely affect plant operation or safety. It is strongly recommended that specific nuclear plant safety-related applications incorporate Toshiba's recommended methods and frequencies to maximize system reliability and operability. This result conforms to the failure state/FMEA requirements shown in Section 4.2.3.5 of EPRI TR-107330 (Reference (a46)).

III-6.2.3 Setpoint Support Analysis for OPRM System

The function of the OPRM setpoint is to trip the reactor during a core instability event before the critical power ratio drops below the fuel safety analysis limit anywhere in the core. To determine core instability, the OPRM is comprised of multiple cells which receive input from Local Power Range Monitors (LPRMs). Each LPRM signal is processed through a conditioning filter followed by an averaging filter in order to generate a normalized signal to the OPRM cells. Because of the filtering process and generation of the normalized signal, the LPRM sensor and process uncertainties that are used in other Neutron Monitoring functions (e.g. APRM) are indiscernible for the OPRM system. The normalized signal is then sent to three detection algorithms (the Amplitude Based Detection Algorithm (ABA), Growth Rate-Based Algorithm (GRA) and Period Based Detection Algorithm (PBDA)). Of the three detection algorithms used by the OPRM system, only the PBDA is applied in the protection of the safety limit. Since the OPRM PBDA

algorithm uses the normalized signal for trip determination and a digital rack contact for the trip, the uncertainties are effectively zero for this trip function. Applying the methodology to the OPRM PBDA value will still result in a same value as a setpoint for the OPRM PDBA trip.

The methodology and details of the results are reported in the Setpoint Support Analysis Report for Safety-Related Oscillation Power Range Monitor (OPRM) (Reference (c25)).

III-7 Verification and Validation of OPRM

III-7.1 Oscillation Power Range Neutron Monitor

Toshiba developed an OPRM, and conducted V&V for the OPRM through the development.

The Current process described in Section III-1.1 was used in the development and V&V. In the Current process, NED and NICSD worked under their Appendix B QA program. ICDD of NED ordered the OPRM system from NICSD. NICSD procured the modules of OPRM from PPDD who worked under its ISO 9001 QA program, using NICSD's CGD process. ICDD had the overall responsibility for the V&V activities.

III-7.1.1 V&V Organization and Process

Engineers from ICDD and NICSD organized IV&V Teams, the ICDD IV&V Team and the NICSD IV&V Team, independent of the design group. The two IV&V Teams communicate with each other as one IV&V Team as needed for quality of the products.

The ICDD IV&V Team established an NED VVP defining the organizations, responsibilities, applicable standards, and the life cycle activities.

The NICSD IV&V Team established an NICSD VVP based on the NED VVP defining the organizations, responsibilities, applicable standards, and the life cycle activities for their portions. The NICSD VVP was submitted to ICDD for review and approval; and ICDD approved the NICSD VVP.

The V&V activities were performed following the current process described in Section I-1.5.2 in the Part I of this Topical Report, i.e., the following life cycle phases:

- Project Planning and Concept Definition Phase,
- Requirements Definition Phase,
- Design Phase,
- Implementation and Integration Phase,
- Unit/Module Validation Testing Phase, and

- System Validation Testing Phase.

Of these phases, the ICDD IV&V Team performed V&V activities for the upstream part in the Project Planning and Concept Definition Phase; the NICSD IV&V Team performed their V&V activities for the remaining part through the life cycle. The ICDD IV&V Team reviewed the NICSD V&V activities through the life cycle and completed the V&V at the end of the System Validation Phase.

III-7.1.2 Design Verification

The ICDD and NICSD IV&V Teams verified the design of OPRM by reviewing the design documents, and tracing the requirements for OPRM throughout the life cycle using RTM.

III-7.1.2.1 Document Reviews

The ICDD IV&V Team reviewed the following upstream design documents prepared by the ICDD design engineers:

- System Design Description (SDD),
- Interlock Block Diagrams (IBDs), and
- Instrumentation Electrical Diagrams (IEDs).

The NICSD IV&V Team reviewed the following design documents prepared by NICSD:

- Equipment Design Specification (EDS) specifying equipment design for the Power Range Neutron Monitor (PRNM) including OPRM, and
- OPRM Unit Detailed Design Specification (Unit DDS) specifying the functional requirements for the OPRM unit and defining the configuration of the OPRM unit.

The NICSD IV&V Team reviewed the following design documents prepared by PPDD:

- Module Design Specifications for modules installed in the OPRM unit, and
- FPGA Design Specifications for all FPGAs mounted on each module.

In addition to the design documents, the NICSD IV&V Teams reviewed the following test procedures before the tests were performed:

- FPGA test procedures, and
- Module test procedures.

After each test, the NICSD IV&V Team reviewed the corresponding test reports.

The NICSD IV&V Team concluded that these test procedures and reports were satisfactory.

For the System Validation Test, the NICSD IV&V Team prepared the System Validation Test Procedure and System Validation Test Report.

III-7.1.2.2 Requirements Traceability Efforts

The ICDD design engineers prepared an upstream Requirement Traceability Matrix (RTM) by collecting base requirements from the SDD, and tracing the base requirements forward to and back from the IBDs and IEDs. The RTM was reviewed by the ICDD IV&V Team, and sent to NICSD as the base requirements for the OPRM.

NICSD developed and extended the RTM to the EDS and the OPRM Unit DDS. PPDD developed and extended the RTM further to the Module Design Specifications and FPGA Design Specifications. The NICSD IV&V Team verified that all requirements were traced forward and traced back through these design documents from the base requirements.

In addition, NICSD and PPDD developed and extended the RTM from design documents to corresponding test procedures, e.g., from each FPGA Design Specification to the corresponding FPGA test procedure. At the System Validation Testing Phase, the NICSD IV&V Team confirmed that all the OPRM unit requirements specified in the EDS and the OPRM Unit DDS were traced to the System Test Specification and the System Validation Test Plan.

III-7.1.2.3 FPGA Logic Implementation V&V

PPDD established FPGA Design Specifications for all FPGAs mounted on each module, and developed the VHDL source code for each FPGA, converted the VHDL source codes into netlists, and into fusemaps using software tools. The fusemaps were implemented into each FPGA for FPGA testing.

These design activities were performed in accordance with the FPGA design principles described in Section II-2.1.5.

The FPGA Logic Implementation V&V included:

(1) VHDL Source Code Review. See Section I-3.10.2.5 in the Part I of this Topical Report.

(2) Software Tool Message Review. See Section I-3.10.2.5 in the Part I of this Topical Report.

(3) Signal Timing Analysis Review. See Section I-3.10.2.5 in the Part I of this Topical Report and Section II-2.1.5.3 in the Part II of this Topical Report.

(4) Netlist Review. See Section I-3.10.2.5 in the Part I of this Topical Report

(5) FPGA Testing, the NICSD design engineers performed validation testing of the FPGAs in a manner that achieved the 100% toggle coverage criteria. See Section I-3.10.2.5 in the Part I of this Topical Report and Section II-2.1.7 in the Part II of this Topical Report.

(6) Software Tool Control Review. See Section I-3.10.2.5 in the Part I of this Topical Report.

The NICSD IV&V Team concluded that the NICSD V&V activities were completed in an acceptable manner.

III-7.1.2.4 Validation Testing

PPDD performed the Module Validation Testing for each module. NICSD assembled these modules into an OPRM unit. The NICSD IV&V Team performed the System Validation Testing. Since the OPRM includes only one unit, the OPRM unit, NICSD did not perform unit validation testing separate from the System Validation Testing.

A similar set of test equipment used for the PRM testing was used in the OPRM testing, except no analog signal is entered into or received from OPRM. In the System Validation Testing, the test equipment connected with the OPRM unit through fiber optic links and discrete I/O cables. One or more test PCs controlled the test equipment, and recorded the input and output signals. The output signals were compared with the desired values.

For the Module Validation Testing, the NICSD IV&V Team reviewed the Module Test Reports, and concluded that the test reports were acceptable.

For the System Validation Testing, the NICSD IV&V Team performed the testing, and concluded that each test result was satisfactory.

III-7.1.3 Safety Analyses

ICDD performed a safety analysis for the upstream design of the OPRM in the Project Planning and Concept Definition Phase. The analysis checked whether all software safety requirements of the OPRM safety functions described in the ABWR Design Control Documents were included in

the SDD, and concluded the OPRM design included all the requirements.

NICSD performed a safety analysis for each phase of the life cycle using fault tree, or FMEA. The analyses found some concerns. These concerns were resolved through the life cycle as reported in Part VI of this LTR.

ICDD reviewed all NICSD SSARs, and prepared ICDD SSARs based on the NICSD SSARs. ICDD finalized the safety analyses at the end of the System Validation Testing Phase.

III-7.1.4 V&V Iteration

The ICDD and NICSD IV&V Teams iterated necessary V&V activities when design documents were changed. In particular, the requirements for the CRC function of the TRN and RCV modules were added to the design documents in the middle of the project. The ICDD and NICSD IV&V Team reviewed all design documents affected by this change, and performed necessary RTM efforts. The NICSD IV&V Team performed the module validation tests for the modified TRN and RCV modules.

III-7.1.5 V&V Conclusions

The NICSD IV&V Team documented their V&V activities in the NICSD VVR. The NICSD VVR concluded that all NICSD V&V activities for OPRM had completed.

The ICDD IV&V Team issued the NED VVR for OPRM, which documents the ICDD portion of the V&V activities including review of the NICSD VVR.

The NED VVR concluded, confirming the conclusions of the NICSD VVR and NED SSAR, that the OPRM developed in this project is appropriate for safety-related use for ABWR plants as long as the recommendations in the NICSD VVR and the NED SSAR are implemented.

Part VI of this LTR is the NED VVR for OPRM attached with NICSD VVR for the OPRM.