FAILURE MODES AND EFFECTS ANALYSIS (FMEA) FOR THE TRICON VERSION 10.2 PROGRAMMABLE LOGIC CONTROLLER

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1.0 PURPOSE

EPRI TR-107330 "Generic Requirements Specification for Qualifying a Commercially Available PLC for Safety-Related Applications in Nuclear Power Plants" (Reference 5.1) defines the requirements for qualifying commercially available programmable logic controllers (PLCs) for safety-related nuclear power plant applications. The Reference 5.1 guidelines require the performance of a Failure Modes and Effects Analysis (FMEA) to evaluate the effects of failures of components in the PLC modules on PLC performance.

The Triconex Corporation is qualifying the commercial grade TRICON VERSION 10.2 Triple Modular Redundant (TMR) Programmable Logic Controller for safety-related nuclear power plant applications. This report documents the methodology and results of the FMEA performed for the generic qualification of the TRICON VERSION 10.2 TMR PLC.

2.0 OBJECTIVE

The objective of this report is to document the methodology and results of the generic FMEA for the TRICON VERSION 10.2 TMR PLC. The FMEA is performed in accordance with the applicable guidelines of Reference 5.1, Section 6.4.1, "FMEA".

3.0 SCOPE

This analysis is prepared as a part of the TRICON Nuclear Qualification Program as defined in Reference 5.2.

The system analyzed by the FMEA is identical to the Test Specimen configuration that was used in the Qualification Test Program. The Test Specimen includes one TRICON Main Chassis, two RXM Chassis and one Expansion Chassis. The Test Specimen configuration was established to simulate a single channel/train of a typical nuclear power plant safety-related protection system installation. Specific hardware configurations, application programs, supporting drawings and documents are identified in the Master Configuration List (Reference 5.3).

The intent of the FMEA is to identify potential failure states of a typical TRICON PLC in a single train system and to provide data for use in the application-specific FMEA for a particular system. This analysis does not address failure modes associated with application of multiple PLC systems in redundant safety trains. Although application-specific mitigating design features are described for certain failures, this analysis should not be considered as a bounding analysis applicable to actual safety-related applications and installations.

The Model 8107 Seismic Balance Module used in the qualification test specimen is passive in nature and provides no operational functionality. This module is therefore not included in the scope of the FMEA.

4.0 METHOD OF ANALYSIS

The subject FMEA is performed in accordance with the applicable requirements of EPRI TR-107330 Section 6.4.1, "FMEA" (Reference 5.1). In general, the techniques of Appendix A and Sections 4.1, 4.4, and 4.5 of ANSI/IEEE Std. 352-1987 (Reference 5.4), have been used in this analysis. These techniques included definition of functional areas of PLC operation, as described later in this section. The effect of both single failures and common mode failures on each functional area were then analyzed, as summarized in Section 8.0.

This FMEA is performed using a macroscopic approach, addressing failures on a major component and module level. This approach is appropriate because sub-components in the TRICON modules are triple redundant, and no single failure of an individual sub-component would impact the ability of the PLC to perform its safety related functions. In this analysis, a safety related function is defined as the ability of the safety system to perform a safety shut down function. In addition, the TRICON self-diagnostic features, described in References 5.5 and 5.6 and summarized in Section 6.0 of this report, have been specifically designed to detect and alarm failures of sub-components within each module. Extensive testing has been performed on each module to validate that the diagnostics detect all possible single failures within each module.

Because all single, internal failures are detected and alarmed, this FMEA focuses on credible failure modes of major components and modules in a typical TRICON PLC system. The components considered include the following:

a) Power Supplies (including chassis power supplies and I/O loop power supplies)
b) PLC Chassis (including internal power and communication buses)
c) Main Processors and Communications Modules

d) PLC Cables
e) PLC I/O Modules
f) Termination Panels

Figure 1 is a simplified block diagram of a typical TRICON chassis showing the arrangement of these major components. The approach used in this FMEA is to postulate credible failures of these components, identify the mechanisms that could cause these failure modes, and evaluate the consequences of these failures on the operation of the TRICON system. Because of the architecture of the TRICON, failure mechanisms that affect a single leg of the triple redundant system generally have no effect on system operation. Therefore, this FMEA considers (1) failure mechanisms that are recognized as being highly unlikely but that could affect multiple components, and (2) the coincident occurrence of otherwise single failures (i.e., multiple failures).

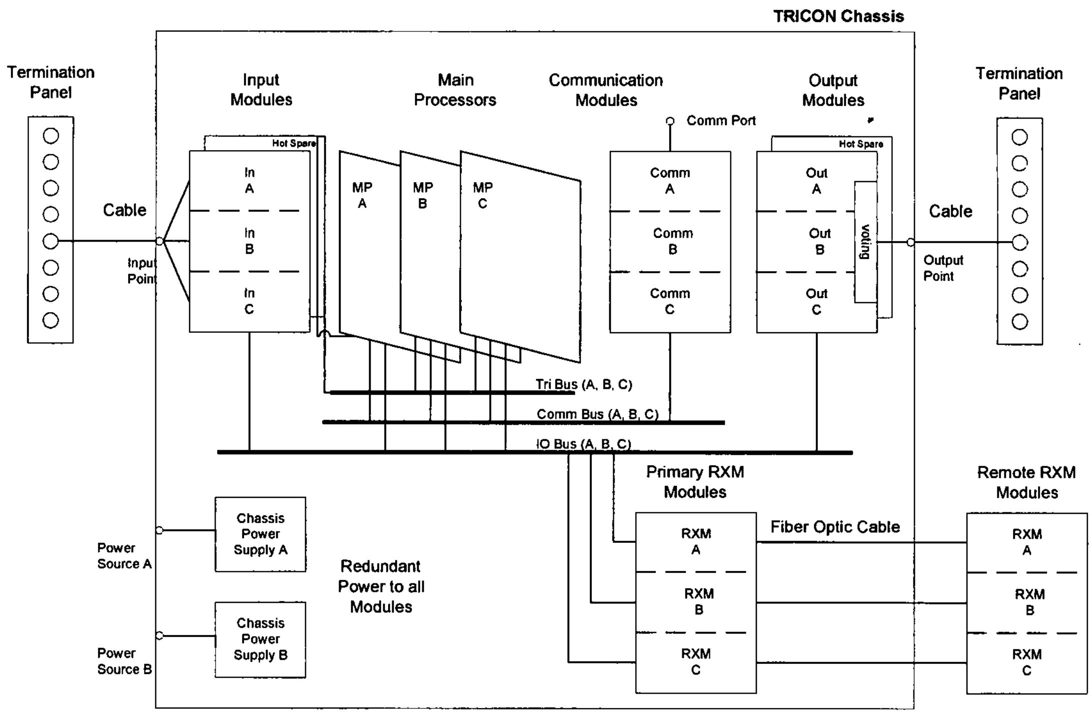

Figure 1 - Simplified Block Diagram of Typical TRICON System

In order to identify the effect of failures on system operation (i.e., to prioritize types of failures), Section 4.2.3.5.C of Reference 5.1 recommends the following categories of failure states be identified as a part of the FMEA for redundant PLCs:

C1. States that result from one or more failures where the PLC remains operable as well as states where it is not operable.
C2. States where undetected failures have occurred.
C3. States where a failure in a single element has caused the PLC to fail.
C4. States where failures reduce the effectiveness of self-diagnostics.

Reference 5.1 also recommends identification of failures detected by the system diagnostics, and those that will only be detected by surveillance testing. For this FMEA, the failure categories specified by Reference 5.1 are modified to be more applicable to the TRICON system. The categories used in this FMEA are as follows: a

a

a

For this FMEA, multiple failures are considered to include scenarios such as failure of all three main processors due to software common mode failure, loss of all power, fire, floods, or missiles. These types of multiple failure scenarios are recognized as being very unlikely but are included to describe system behavior in the presence of severe failures and to provide guidance for application design.

The FMEA tabulation in Section 8.0 of this report includes a column that documents the appropriate failure category assignment for each postulated PLC failure mode. The tabulation in Section 8.0 provides the following data for each type of failure, as required by the guidance of Reference 5.1:

a) Affected Components
b) Failure Mode
c) Failure Mechanism
d) Failure Category
e) Effect on PLC Inputs and Outputs
f) Effect on PLC Operability

Section 6.0 of this report provides a description of the PLC diagnostics that aid in detection of postulated failures.

5.0 REFERENCES

5.1 EPRI Report TR-107330, "Generic Requirements Specification for Qualifying a Commercially Available PLC for Safety-Related Applications in Nuclear Power Plants", Final Report dated December 1996

5.2 Triconex Document 9600164-500, Master Test Plan

5.3 Triconex Document 9600164-540, Master Configuration List

5.4 ANSI/IEEE Std. 352-1987, "IEEE Guide for General Principles of Reliability Analysis of Nuclear Power Generating Station Safety Systems"

5.5 Triconex Part No. 9720077-007, TRICON Planning and Installation Guide, August 2006.

5.6 Triconex Part No. 9791007-013, TRICON Technical Products Guide, Version 10.2, August 2006.

5.7 Triconex Part No. 9100069-001, TRICON V9 ETP Design Specification, Revision 1.2, January 2006.

5.8 Triconex Part No. 9600164-532, Reliability/ Availability Study for the TRICON VERSION 10.2 PLC, March 2, 2007.

5.9 Triconex Part No. 9600164-732, Reliability/ Availability Spreadsheet for TRICON VERSION 10.2 PLC Operating Under Normal Conditions, March 2, 2007.

5.10 Triconex Part No. 9600460-001, Tricon I/O Accuracy Including Drift Over Time For V10 Nuclear-Qualified Products, December 12, 2011

6.0 PLC MODULE DIAGNOSTIC DESCRIPTION

This section provides a basic description of the TRICON processor, communications and input/output module operation and diagnostic functions. This description of the diagnostic operations is provided to augment the FMEA tabulation provided in Section 8.0. A more detailed description of this information is presented in References 5.5 and 5.6.

6.1 INPUT MODULES

All triple modular redundant (TMR) input modules contain three separate, independent processing systems, referred to as legs, for signal processing (Input Legs A, B, and C). The legs receive signals from common field input termination points. The microprocessor in each leg continually polls the input points, and constantly updates a private input data table in each leg's local memory. Any signal conditioning, isolation, or processing required for each leg is also performed independently. The input modules possess sufficient leg-to-leg isolation and independence so that a component failure in one leg will not affect the signal processing in the other two legs.

6.1.1 DIGITAL INPUT MODULES

This discussion is applicable to the following digital input (DI) modules:

Model 3501T; 115 Vac/Vdc Opto-isolated, non-commoned (32 points)
Model 3502E; 48 Vac/Vdc Commoned in groups of 8, Self Test (32 points)
Model 3503E; 24 Vac/Vdc Commoned in groups of 8, Self Test (32 points)

Each DI module contains the circuitry for three identical legs. The three legs are completely isolated from each other and operate independently, so a fault on one leg cannot pass to another. There is an 8-bit microprocessor, called the I/O communication processor on each Main Processor Module to control communication with all I/O modules on a specific leg.

The three input legs independently measure each input signal, determine the respective state of each input signal, and place the values into input tables A, B, and C. Each input table is regularly interrogated over the leg-specific I/O busses by the I/O communication processor located on the corresponding main processor module. For TMR digital modules, all critical signal paths are triplicated. Each leg conditions signals independently and provides optical isolation between the field and the TRICON.

Each DI module sustains complete ongoing diagnostics for each leg. Failure of any diagnostic on any leg activates the module Fault Indicator, which in turn activates the chassis alarm signal. The module is designed to operate correctly in the presence of a single fault and may continue to operate properly with some multiple faults.

The diagnostic routine for the Model 3501T DI Module compares the input table data for the three legs. Any data discrepancies are reported to the respective Main Processor Modules, which maintain diagnostic information in local memory. The Main Processor Module fault analyzer routines determine whether a fault exists on a particular module at the end of each scan. One-time or short term differences that result from sample timing variations are distinguished from a pattern of differing data. Should a Main Processor Module diagnose a faulty leg, a fault indicator will be illuminated on that particular input module.

Failed optical isolation or signal processing/conditioning components could inhibit the ability of a module to communicate field input state transitions to the Main Processor Modules. Therefore, when a DI module is used to monitor field inputs signals that remain in one state for long periods of time, the field points should be toggled from the normal operational state to the opposite state within twenty-four months. Input signal toggling will test the module's ability to transition to the opposite state in order to diagnose problems such as "Stuck On" / "Stuck Off" signals due to failed or faulted leg components. Since normal opto-isolator failures are random and detectable due to the TMR sampling of inputs, only a single failure per input is likely. Even with stuck on faults on a single input leg, the other two input legs would vote out the failed opto-isolator.

The Model 3502E and 3503E DI modules extend fault coverage by self-diagnosing "Stuck On" leg signals. The DI modules are designed to monitor field signals that remain in the "On" state for long periods of time. The extended diagnostics verify the leg can process a transition to the "Off" commanded state.

The DI modules contain loopback circuitry in each leg that momentarily drive the input signal for the leg under test to the "logical zero" or "low" state. This test, which is continually rotated among the three legs, verifies proper operation of leg optical isolation and/or signal processing/conditioning circuitry. Should a leg fail the test, the module fault indicator will be illuminated. However, if these modules monitor normally off points, the field point must be toggled from the "Off" state to the "On" state.

The DI module diagnostics are specified to operate as follows, as defined in Reference 5.5:

Module	Minimum Input Toggle Rate	Maximum Input Toggle Rate
Model 3501T	Every 24 months	Every 100 msec
Model 3502E	On-state: Not required Off-state: Every 24 months	Every 100 msec
Model 3503E	On-state: Not required Off-state: Every 24 months	Every 100 msec

6.1.2 PULSE INPUT MODULE

This discussion is applicable to the following pulse input (PI) module:

Model 3511; Pulse Input, AC Coupled, fast update (8 points)

For the PI module, the extent of the diagnostic routine is the comparison across the three legs of the respective signal values.

Any leg signal value outside a set tolerance with the signal values in neighboring legs is reported to its respective Main Processor Module. The Main Processor Module fault analyzer routines determine whether a fault exists on a particular module at the end of each scan. One-time differences that result from sample timing variations are distinguished from a pattern of differing data. Should a Main Processor Module diagnose a faulty leg on a particular module, it will signal the pulse input module to illuminate its fault LED.

The PI module diagnostics are specified to operate as follows, as defined in Reference 5.5:

Module	Minimum Input Change	Input Change Sample Period	Minimum Period of Mis-compares
Model 3511	0.5% of full scale	1 scan or 210 msec, whichever is greater	10 samples

For a single input reading, a leg-to-leg deviation may result if the measured values of the three legs differ by the minimum input change specified. If the deviations continue for the specified minimum period, an input fault may be declared.

6.1.2 ANALOG INPUT MODULES

This discussion is applicable to the following analog input (AI) modules:

Model 3701; 0-10 Vdc Differential, DC Coupled (32 points)
Model 3703E; 0-5/0-10 Vdc Differential, Isolated (16 points)
Model 3721; 0-5/-5 to +5 Vdc Differential, DC Coupled (32 points)

Each of the three AI legs asynchronously measure the input signal and place the results into an input table of values, which is passed to its associated main processor module using the corresponding I/O bus. The input table in each main processor module is transferred to its neighbor across the TRIBUS. The median value is selected by each main processor (in a duplex mode, the average value is used), and the input table in each main processor is corrected accordingly. Signals outside an internally specified error band in this median signal selection process will be alarmed by the Main Processor on the input module. Each AI module leg is automatically calibrated using multiple reference voltages read through the multiplexer, which determine the gain and bias required to adjust the readings of the A/D converter. Several drift over time components can affect the automatically calibrated level and cannot themselves be calibrated out (Reference: 5.10).

Each AI module sustains complete ongoing diagnostics for each leg. Failure of any diagnostic on any leg activates the module Fault Indicator, which in turn activates the chassis alarm signal. The module is designed to operate correctly in the presence of a single fault, and may continue to operate properly with some multiple faults.

The extent of the diagnostic routine for the Model 3701 and Model 3721 AI modules includes automatic or self-calibration of the A/D converters in each of the three legs. The microprocessors on each leg test for known or expected signal values within a certain tolerance. If the signals reaching the leg microprocessors are within the allowed tolerance, the leg will self-calibrate its A/D converter to null out any undesirable offsets or gains. A leg in violation of the allowed tolerance will be flagged by illumination of a module Fault LED.

The Model 3703E AI module built on the diagnostic routine of the 3701 input modules by cross comparison of input table data across the three legs, within the module. The microprocessors in each leg compare the respective input table data with the neighbor legs, with out-of-tolerance data reported to respective Main Processor Modules. The Main Processor Module fault analyzer routines diagnose faulty input module legs at the end of each scan. One-time and short-term differences that result from sample timing variations are distinguished from a pattern of differing data. Should a Main Processor

Module diagnose a faulty leg on a particular module, it will signal the input module to illuminate its Fault LED.

The AI module diagnostics are specified to operate as follows, as defined in Reference 5.5:

Module	Minimum Input Change	Input Change Sample Period	Minimum Period of Mis-compares
Model 3701	2% of full scale	1 scan or 200 msec, whichever is greater	40 samples
Model 3703E	0.5% of full scale	1 scan or 50 msec, whichever is greater	256 samples
Model 3721	2% of full scale	10 ms	25 samples

For a single input reading, a leg-to-leg deviation may result if the measured values of the three legs differ by the minimum input change specified. If the deviations continue for the specified minimum period, an input fault may be declared.

6.1.3 THERMOCOUPLE INPUT MODULE

Sensing of each thermocouple input is performed in a manner that prevents a single failure on one channel from affecting another channel. Each module performs complete ongoing diagnostics on each channel.

The diagnostic routine for the Thermocouple Input (TC) modules consists of the automatic or self-calibration of each leg using internal-precision reference voltages. The microprocessors on each leg test for known or expected signal values within a certain tolerance. If the leg microprocessors receive signals within the allowed tolerance, the leg will self-calibrate its A/D converter to null out any undesirable offsets or gains. The module will flag any out of tolerance signal received. Several drift over time components can affect the automatically calibrated level and cannot themselves be calibrated out (Reference: 5.10).

The thermocouple input modules also perform automatic cold or reference junction temperature compensation. Solid-state temperature sensors on the termination panel produce a current for each leg that is proportional to the temperature at the field contact terminals. Each leg in turn adds the reference or cold junction temperature from the measured temperature signal.

The input diagnostic fault coverage is as follows:

Module	Minimum Input Change	Input Change Sample Period	Minimum Period of Miss-compares
Model 3708E	0.5% of full scale	50 ms	256 samples

6.2 OUTPUT MODULES

6.2.1 DIGITAL OUTPUT MODULES

This discussion is applicable to the following digital output (DO) modules:

Model 3601T; 115 Vac Opto-isolated, Non-commoned (16 points)
Model 3603T; 120 Vdc Opto-isolated, Commoned (16 points)
Model 3607E; 48 Vdc Opto-isolated, Non-commoned (16 points)
Model 3625; 24 Vdc Commoned (32 points)

Every DO module contains three identical and isolated legs. Each leg includes an I/O microprocessor that receives its output table from the Main Processor's I/O communication processor associated with that leg. All of the DO modules use special quadruplicated output circuitry that votes on the individual output signals. This voter circuitry is based on parallel-series paths that pass power if the driver for legs A and B, or legs B and C, or legs A and C command them to close (i.e. 2-out-of-3 vote).

A single switch failure will not affect the logic, which is optimized for de-energize-to-trip applications. The switches are opened and closed on command by the Output Switch Drive circuitry. Power will be passed to the load if the commanded state of Channels A and B, or Channels A and C, or Channels B and C feeding the Switch Drive Circuitry are "On" or energized, completing the path between the voltage source and the load. Any single leg failure, any single switch failure, or corrupted signal from a Main Processor Module will be compensated for or filtered out by the Voter Logic at the output module level.

All DO modules contain diagnostic routines called "Output Voter Diagnostics" (OVD) designed to detect failures in the four switches managing the field load terminal state. The routine consists of three basic steps.

In Step One, the "Commanded State" of each leg is compared to the "Actual State" of the field load terminal, to identify problems such as blown fuses and/or bad loopback detectors. The next two steps will not occur unless the module passes the first test.

In Step Two, the "Commanded State" of one of the three legs feeding the Output Switch Drive Circuitry is momentarily reversed, resulting in an indication of a switch failure. For this test, no output change will occur unless a switch has failed. If the leg was toggled from the "On" state to the "Off" state, a state change or "glitch" at the load is an indication of a switch stuck in the "Off" state. If the leg was toggled from the "Off" state to the "On" state, a glitch at the load is an indication of a switch stuck in the "On" state. The test is continuously rotated among the three legs.

In Step Three, the "Commanded States" of two of the three legs feeding the Output Switch Drive Circuitry are simultaneously toggled. A glitch at the field load is an indication of healthy circuitry. No glitch at the output is an indication of internal switch failure. The glitch at the field load during diagnostic routine execution is guaranteed to be less than 2.0 milliseconds and is transparent to most electromechanical field devices. If the "Commanded States" of the two legs are toggled from the "On" state to the "Off" state, the absence of a glitch at the load is an indication of a switch stuck in the "On" state.

If the "Commanded States" of the two legs are toggled from the "Off" state to the "On" state, the absence of a glitch at the load is an indication of a switch stuck in the "Off" state. The test is continually rotated for the three possible leg combinations.

The Models 3603T and 3607E DO modules execute the three phases of the OVD routine described above. Voltage loop-back circuits allow the modules to self-diagnose latent faults within the output voter circuitry.

Failure of any test within the three steps will result in the illumination of the fault LED on the output module. The modules additionally compare output table data across the three legs, with any discrepancies reported back to respective Main Processor Modules. The Main Processor Module fault analyzer routine diagnoses failed legs on output modules at the end of each scan, with a faulty output module annunciated by the system. The modules are specifically designed for applications that hold points in one state for long periods of time. The routine guarantees full fault coverage even if the commanded state at the field terminals never change.

The Model 3601T DO modules execute Steps 1 and 2 of the OVD routine. The modules do not attempt Step 3 due to the use of triacs instead of transistors for the series-parallel switch configuration driving the load. The triacs would cause a glitch duration of approximately 8.33 milliseconds for a 60 Hz load, which would not be transparent to most electromechanical field devices. A faulty switch will cause the output to transition to the opposite state for a maximum of one half an AC cycle during Step Two of the OVD routine. However, the module cannot self-diagnose "Stuck On" switches if the

"Commanded State" of a leg is "On" or "Stuck Off" switches if the "Commanded State" of a leg is "Off". Therefore, to ensure 100% fault coverage, the field points should be toggled from the normal state to the opposite state and leg output tested accordingly once every three to six months to guarantee the health of the circuitry.

The Model 3625 DO module OVD has two parts. For the normal routine, OVD collects 4 samples with no FET switches modified followed by 4 samples with a single FET switch modified followed by 4 samples with the FET switch returned to its commanded state. . If no change in the data samples is detected as a result of the single FET switch modification software will resort to the Glitch diagnostic to determine proper operation of the FET switch. During a Glitch cycle the first 8 samples are collected the same as a Normal cycle. The next three samples are collected with the analog feedback is set to low gain voltage, the ninth sample is taken to establish a pre Glitch data point after which the state of the appropriate FET switches are modified to cause the output to change state.

The DO module diagnostics are specified to operate as follows, as defined in Reference 5.5:

Module	Minimum Output Toggle Rate	Maximum Output Toggle Rate
Model 3601T	Every 24 months	Every 100 msec plus one scan
Model 3603T	Not applicable	Every 100 msec plus one scan
Model 3607E	Not applicable	Every 100 msec plus one scan
Model 3625	Not applicable	Every 30 msec

The maximum output toggle rate enables proper operation of I/O diagnostics and detection of all normally detectable faults. The minimum toggle rate provides fault coverage of normally undetectable faults within 5 % of the calculated Mean Time Between Failure (MTBF) of one of the switches on the digital output module.

6.2.2 SUPERVISED DIGITAL OUTPUT MODULES

This discussion is applicable to the following supervised digital output (SDO) modules:

Model 3623T; 120 Vac Opto-isolated, Commoned, Supervised (16 points)
Model 3625; 24 Vdc Commoned, Supervised (32 points)

The Model 3623T SDO module performs all three steps of the OVD routine, as discussed in the previous Section 6.2.1. However, these modules extend Step One of the routine to include fault coverage of the field load device. In addition to voltage loopback circuitry, the SDO modules contain additional current loopback circuitry allowing each leg to measure the current flowing to the load.

The current loopback circuitry allows the SDO modules to self-diagnose possible open or short circuit conditions at the field load terminals. The modules perform continuous continuity checks of the field load by verifying that when energized, current is actually flowing and the current is below a certain threshold value. The module annunciates any faulty switch or loss of field load. The modules are designed to provide complete fault coverage for both energize-to-trip and de-energize-to-trip applications.

The Model 3625 has a Supervisory portion of the OVD. During a Supervisory cycle if the point is not commanded ON the FET switches are turned ON and the appropriate gain is set. The data stored for the first eight samples represent the field point current. Measurement mode the mode is switched to low gain voltage and the 9^{th} sample is stored then the FET switches are set to back to the commanded state.

The SDO module diagnostics are specified to operate as follows, as defined in Reference 5.5:

Module	Minimum Output Toggle Rate	Maximum Output Toggle Rate
Model 3623T	Not applicable	Every 100 msec
Model 3625	Not applicable	Every 30 msec

6.2.3 RELAY OUTPUT MODULE

This discussion is applicable to the following relay output (RO) module:

Model 3636T; Relay Output, Non-triplicated, Normally Open, 32 points

This module may be used in both nuclear safety-related and non-safety related systems and is qualified as a 1E to non-1E isolator.

The RO modules have three legs that receive signals from respective Main Processor Modules. The three leg signal sets are voted, and the voted signals are used to drive the 32 individual output relays. Each output contains loopback circuits that verifies the operation of each relay independent of the load. Ongoing diagnostics test the operational status of the module. Failure of any diagnostic activates a Fault indicator on the module, which in turn activates the chassis alarm.

6.2.4 ANALOG OUTPUT MODULE

This discussion is applicable to the following Analog Output (AO) module:

Model 3805E; 4-20ma Current Loop, DC Coupled (8 points)

AO modules contain three separate and isolated legs, with each leg equipped with a D/A converter. One of the legs is selected to drive the analog output, and the output is continuously checked for correctness by loopback inputs on each point which are read by all three microprocessors. Each module in the system receives three tables of output values from the Main Processor Modules. All three legs drive current to leg-specific switches. Two of the switches are normally positioned to shunt the leg's output current to ground. Only one output leg switch will be set to drive current to the load.
Each analog output module sustains complete ongoing diagnostics for each leg. Failure of any diagnostic on any leg activates the module Fault Indicator, which in turn activates the chassis alarm signal. The module is designed to operate correctly in the presence of a single fault and may continue to operate properly with some multiple faults.

The health of each leg is verified by monitoring output current via a voltage loopback circuit. Each leg monitors the health of neighboring legs, by comparing output current signal values, and ensuring the leg driving the load is supplying the correct signal value. Each AO voltage loopback is automatically calibrated using multiple reference voltages read through the multiplexer, which determine the gain and bias required to adjust the readings of the A/D converter. Several drift over time components can affect the automatically calibrated level and cannot themselves be calibrated out (Reference: 5.10). Two out of three legs must vote a leg healthy before it is allowed to drive the load. The leg driving the load is rotated every 10 seconds between the healthy legs in a predetermined direction. Each leg tracks which leg is currently driving the load and which leg is next in the rotation, to allow each leg to vote on the health of the next leg up in the rotation. A leg must diagnose itself as healthy or it will be skipped in the rotation, and will also be unable to vote on the health of neighboring legs.

If a faulted leg is not currently selected to drive the load when the process outputs are updated, then any single leg failure or corrupted signal from a Main Processor Module will be compensated for or filtered out by the Voter Logic at the output module level.

If a faulted leg is currently driving the load, then the output modules receive updated process outputs as soon as the faulted signal reaches the field load. However, at the same time the AO module will go through the process of voting on the health of the faulted leg. The module will diagnose the faulty signal and select a healthy leg to drive the load. The

AO module is guaranteed to correct the faulted output signal within 20 ms, which is transparent to most electromechanical devices due to the capacitance of the system.

6.3 MAIN PROCESSOR MODULE

6.3.1 3008 MP

This discussion is applicable to the following Main Processor Module:

Model 3008; Enhanced TRICON Main Processor, 16 Mbytes DRAM

A TRICON system utilizes three Main Processor Modules to control three separate legs of the system. Each Main Processor Module operates independently with no shared clocks, power regulators, or circuitry. In Model 3008, each module owns and controls one of the three signal processing legs in the system, and each contains two 32-bit processors. One of the 32-bit processors is (1) a dedicated, leg-specific I/O communication (IOC) microprocessor that processes all I/O with the system I/O modules, and (2) a dedicated, leg-specific processor manages interfaces with all Communication Modules in the system.

For Model 3008, the 32-bit primary processor manages execution of the control program and all system diagnostics at the Main Processor Module level. Between both 32-bit processors is a dedicated dual port RAM allowing for direct memory access data exchanges.

The IOC processors constantly poll respective legs for all the input and output modules in the system. They continually update an input data table in shared memory on the Main Processor module with data downloaded from the leg-specific input data tables from each input module. Communication of data between the Main Processor Modules and the input and output modules is accomplished over the triplicated I/O data bus using a master-slave communication protocol. The system uses cyclic redundancy code (CRC) to ensure the health of data transmitted between modules. Should a Main Processor Module lose communication with its respective leg on any of the input modules in the system or the CRC reveals that the data has been corrupted, the system will retry the data transmission up to three times. If unsuccessful, input tables at the Main Processor Module level will be constructed with data in the de-energized state. Errors such as an open circuited data bus, short circuited data bus, or data corrupted while in transit will force the input table entries to the de-energized state.

At the beginning of each scan, each primary processor takes a snapshot of the input data table in shared memory, and transmits the snap shots to the other Main Processor

Modules over the TRIBUS. Each Module independently forms a voted input table based on respective input data points across the three snapshot data tables. If a Main Processor Module receives corrupted data or loses communication with a neighbor, the local table representing that respective leg data will default to the de-energized state.

For digital inputs, the voted input table is formed by a 2 out of 3 majority vote on respective inputs across the three data tables. The Voting scheme is designed for de-energize to trip applications, always defaulting to the de-energized state unless voted otherwise. Any single leg failure or corrupted signal feeding a Main Processor Module will be corrected or compensated for at the Main Processor Module level when the voted data table is formed.

A mid-value selection algorithm chooses an analog input signal representation in the voted input table. The algorithm selects the median of the three signal values representing a particular input point for representation in the voted input tables. Any single leg failure or corrupted signal feeding a Main Processor Module will be compensated for at the Main Processor Module level when the voted data table is formed. If an analog input value on one leg has a significant deviation from the other leg inputs, the point will be alarmed and the Main Processors will use the average value of the two analog inputs on the other two legs.

The primary processors on the Main Processor Modules execute the application program in parallel on the voted input table data and produce an output table of values in shared memory. The voting schemes explained above for analog and digital data ensure the process control programs are executed on the same or equal input data value representations. The IOC processors generate smaller output tables, each corresponding to an individual output module in the system. Each small table is transmitted to the appropriate leg to the corresponding output module over the I/O data bus.

The transmission of data between the Main Processor Modules and the output modules is performed over the I/O data bus using a master-slave communication protocol. The system uses cyclic redundancy code (CRC) to ensure the health of data transmitted between modules. If the CRC reveals that the data has been corrupted, the system will retry the data transmission up to three times. If unsuccessful, that respective leg data table at the output module level will default to the de-energized state. Watchdog timers on each output module leg ensure communication has been maintained with its respective Main Processor Module with a certain timeout period. If communication has not been established or has been lost, the respective leg data table will default to the de-energized state to protect against open or short-circuited data bus connection between modules.

Diagnostics at the Main Processor Module level validate the health of its circuitry as well as make decisions about the health of each I/O module and communication module in the system. The modules compare memory, basic processor instructions and operating modes, verify communication between shared memory and the IOC processor, verify communication between the IOC and the I/O modules, and verify the TriClock/TriTime and TRIBUS interfaces.

At the beginning of each scan, the Main Processor Modules transmit/receive copies of the previous scan Output Tables to/from neighbors over the TRIBUS. At the end of the scan, the modules vote on the previous scan output data to diagnose any faults. Extensive diagnostics validate the health of each Main Processor as well as each I/O module and communication channel. Transient faults are recorded and masked by the hardware majority-voting circuit. Persistent faults are diagnosed, and the faulted module can be replaced or operated in a fault-tolerant manner until replacement. The Main Processor Modules also process diagnostic data recorded locally and data received from the input module level diagnostics in order to make decisions about the health of the input modules in the system. All discrepancies are flagged and used by the built in fault analyzer routine to diagnose latent faults. The Main Processor diagnostics perform the following:

- Verification of fixed-program memory
- Verification of the static portion of RAM
- Testing of all basic floating-point processor instructions
- Verification of the shared memory interface with each I/O communication processor and communication channel
- Verification of handshake signals and interrupt signals between the CPU, each I/O communication processor and communication channel
- Checking of each I/O communication processor and communication channel microprocessor, ROM, shared memory access and loopback of RS-485 transceivers
- Verification of the TriClock/TriTime interface
- Verification of the TRIBUS interface

6.4 COMMUNICATIONS MODULE

6.4.1 TCM MODULE

This discussion is applicable to the following Communications Module:

Model 4352A; TRICON Communication Module (TCM), Fiber

TCM Model 4352A is compatible with only TRICON V10.1 systems and later. Each TCM contains two fiber-optic network ports (MTRJ connectors with 62.5/125 um fiber cables) – NET 1 and NET 2. It has a communication speed of 100 Mbps. Serial ports have speeds of up to 115.2 Kbps per port, aggregate data rate of 460.8 Kbps for all four ports. A single TRICON system supports a maximum of four TCMs, which must reside in two logical slots. Each TRICON system supports a total of sixteen Modbus masters or slaves – this total includes network and serial ports. The hot-spare feature is not available for the TCM, though you can replace a faulty TCM while the controller is online. TCM communication protocols include: TriStation, Modbus, Modbus TCP, TCP/IP, SNTP, TSAA, Trimble GPS, Peer-to-Peer, Triconex Time Synchronization, and Jet Direct.

The TCM communicates with all three Main Processors over three separate communication busses, one to each Main Processor. The TCM module has a dedicated communication port for each communication buss. Hence the TCM will continue to communicate with the Main Processors upon the failure of a Main Processor or a communication port.
The TCM can be used to transmit safety relevant data, provided the receiving Main Processors check for proper validity of the message and check to make sure the messages are being received at the require update rate. If the received data is not valid, delayed or not received then the data should be set to the Fail Safe state.

Two TCMs can be placed in one logical slot of the TRICON controller chassis, but they function independently, not as hot-spare modules. A faulty TCM module can be replaced while the controller is online. In TMR mode, the presence of any fault on a MP will not affect the operation of the TCM, except the normal TMR to Dual mode transition (i.e. correctly receive and process the data from the remaining good MPs. In Dual mode, the presence of any fault on a MP should not affect the operation on the TCM, except the normal Dual to Single mode transition. If data integrity cannot be assured, the TCM should enter the fail-safe state for all communication ports. The fail-safe state is defined as follows: Disable all process communications except debug information. In Single mode, the presence of any single critical fault on a MP will cause the system to enter a fail-safe state. In Zero mode, the TCM terminates all except diagnostic / debug communications.

6.4.2 RXM MODULES

This discussion is applicable to the following Remote Extender Modules:

Model 4200-3; Primary RXM, Multi-mode Fiber Optics (set of 3 modules)
Model 4201-3; Remote RXM, Multi-mode Fiber Optics (set of 3 modules)

The RXM Multi-mode Fiber Optics modules allow I/O modules to be located several kilometers away from the Main Chassis. The RXM consists of three identical modules, serving as repeaters / extenders of the TRICON I/O bus, that also provide ground loop isolation. Each RXM module has single channel transmit and receive cabling ports. A Primary RXM module set is connected to the Remote RXM module set housed in a remote chassis. The RXM sets are available for fiber optic cables with a communication rate of 375 kbits/s. These sets provide maximum immunity against electrostatic and electromagnetic interference, and support configurations with optical modems and fiber optic point-to-point cabling. The interfacing cabling is unidirectional for each channel. One cable carries data transmitted from the Primary RXM to the Remote RXM. The second cable carries data received by the Primary RXM from the Remote RXM.

6.5 TRICON CHASSIS ASSEMBLIES

A TRICON system consists of one Main Chassis and up to fourteen additional chassis. The TRICON Main Chassis can support the following modules:

- Two Power Modules
- Three Main Processors
- Communications Modules (TCM)
- I/O Modules

The TRICON Expansion Chassis can support the following modules:

- Two Power Modules
- Communications Modules (in expansion chassis #2 only)
- I/O Modules

The TRICON RXM Chassis can support the following modules:

- Two Power Modules
- Three RXM modules
- I/O Modules

A TRICON controller contains three Main Processor modules. Each Main Processor controls a separate channel of the system and operates in parallel with the other Main Processors. A dedicated I/O processor on each Main Processor manages the data exchanged between the Main Processor and the I/O modules. A triplicated I/O bus, located on the chassis backplane, extends from chassis to chassis by means of I/O bus cables.

This triplicated I/O bus system is etched on the chassis backplane. It transfers data between the I/O modules and the Main Processors at 375 kbits/s. The I/O bus is carried along the bottom of the backplane. Each channel of the I/O bus runs between one Main Processor and the corresponding channels on the I/O module. The I/O bus extends between chassis using a set of three I/O bus cables.

A master-slave protocol is used for communication on the I/O bus. The IOC microprocessor is the master and controls the I/O messages on the bus. I/O modules only transmit messages upon request from the IOC microprocessor. All messages contain a 16-bit CRC to ensure the messages have not been corrupted. All legs on the I/O modules periodically check their transmitter to make sure their transmitter is not in a "Stuck On" state. If the transmitter is in the "Stuck On" state, the module fault LED is turned on and the fault condition is sent to the Main Processor.

6.6 POWER SUPPLY MODULES

This discussion is applicable to the following Power Supply Modules:

Model 8310; 120 Vac/Vdc – 175-Watt Power Module
Model 8311; 24 Vdc – 175-Watt Power Module
Model 8312; 230 Vac – 175-Watt Power Module

The Power Supply modules possess built in diagnostic circuitry to check for out-of-range voltages and/or over temperature conditions. Indicator LEDs on the front face of each power module provide module status as follows:

Indicator	Color	Description
PASS	Green	Input Power is OK
FAULT	Red	Power Module is not OK
ALARM	Red	Chassis Alarm Condition
TEMP	Yellow	Over-temperature Condition
BATT LOW	Yellow	Battery Low Condition

The chassis backplane provides terminal strip interfaces for power and alarm connections. The alarm feature operates independently for each power module. The alarm contacts on both main chassis power modules are actuated on the following states:

- System configuration does not match the control-program configuration
- A digital output module experiences a Load / Fuse error
- A module is missing somewhere in the system
- A Main Processor or I/O module in the main chassis fails
- An I/O module in an expansion chassis fails
- A Main Processor detects a system fault
- The inter-chassis I/O bus cables are incorrectly installed (i.e. cross connected)

The alarm contact on at least one Main Chassis power module is actuated when the following power conditions exist:

- A power module fails
- Primary power to a power module is lost
- A power module has a low battery or over temperature condition

The alarm contacts on at least one power module of an expansion chassis actuates when the following conditions exist:

- A power module fails
- Primary power to a power module is lost
- A power module has a over temperature condition

The alarm contacts on both power modules of an expansion chassis actuate when an I/O module fails.

Each TRICON chassis houses two Power Modules containing independent power supplies arranged in a dual redundant configuration.

Dual independent power rails are etched on the back plane of each chassis in a TRICON system. Both power rails feed each of the three legs on each I/O module and each Main Processor Module residing within the chassis through dual independent voltage regulators. Each power rail is fed from one of the two Power Supply Modules residing in the chassis. Under normal circumstances, each of the three legs on each I/O module and each Main Processor Module draw power from both power supplies through the dual power rails and the dual power regulators. If one of the power supplies or its supporting power line fails, the other power supply will increase its power output to support the requirements of all modules in the chassis. A short on a voltage rail disables the power regulators for that leg rather than affecting the power bus.

Each Power Supply module is capable of supporting all the power requirements for all the modules in the chassis within which it resides. All models of power modules are protected against reverse connection of the DC inputs.

The TRICON also has dual redundant batteries located on the Main Chassis backplane. If a total power failure occurs, these lithium batteries can maintain data and programs on the Main Processor modules for a cumulative period of six months. When less than 30 days of battery life remains, the system will generate an alarm.

6.7 TRICON TERMINATION PANELS

The termination panels are printed circuit boards utilized to facilitate landing of field wiring. This panel contains terminal blocks, resistors, fuses and blown fuse indicators. The standard panels are configured for specific applications (e.g. digital input, analog input, etc.). The thermocouple input termination panel provides cold-junction temperature sensors and can be ordered with upscale, downscale, or programmable burnout detection.

ATEX/Nuclear EMC ETPs will share the following mechanical design features (Reference 5.7):

- Two Protective Earth terminals, such as the Phoenix Contact 1704033), will be rated for:
- 24-14 AWG wire
- 20A minimum
- 200V minimum
- Horizontal entry
- Located on each end of ETP in such a manner as to minimize connection length to DIN rail mounted PE terminal blocks

ETPs that must meet the nuclear EMC requirements will share the following common design attributes (Reference 5.7):

- All ETP field I/O signals shall have capacitive filtering upon entering the ETP to Chassis Ground. This capacitance shall be nominally 0.001 µF.
- All single ended type I/O signals shall have a series ferrite and shunt capacitor to field ground.
- All differential type I/O signals shall have a series ferrite and differential shunt capacitor.
- Chassis and field ground shall have $800V_{DC}$ Isolation.

Each termination panel is packaged with a matched interface cable that connects between the termination panel and the TRICON backplane.

7.0 FMEA SUMMARY AND CONCLUSIONS

The failure modes and effects analysis (FMEA) tabulation is provided in Section 8.0 of this report. As shown, failure modes that can prevent the TRICON system from performing its function are detected by proper application-specific design, the built-in, on-line system diagnostics or by periodic off-line testing. Provided the results of this FMEA are applied to specific control system designs, the percentage of undetectable failures associated with safety-related functions will be very low (from Reference 5.9, it is typically less than 1%).

The general effect of failures in C1a & C1b category are single failures detected by the TRICON on-line diagnostics that do not affect PLC operability and I/O capability, as detailed in the Section 8.0 tabulation. Application-specific design features should be implemented to monitor the TRICON diagnostic alarms so that these failures can be annunciated and repaired in a timely manner (from Reference 5.8, the Mean Time to Repair Online is within 24 hours).

Category C2 includes single and multiple failures, not detected by PLC diagnostics, which do not affect PLC operability. It can be classified as follows:

a) Failures that would be detected by periodic off-line testing in accordance with the manufacturer's standard recommendations as described in the preceding sections.
b) Failures associated with PLC functions not used for safety-related functions.
c) Failures that could be detected by application-specific design considerations (e.g., monitoring for loss of external communications links, loss of loop power supplies, failures in termination cables and termination panels).

Category C3a includes single failure conditions where the PLC is unable to perform all of its safety functions. These failures are generally related to loss of a single I/O point or the I/O points on a single termination panel. Loss of a non-redundant loop power supply, I/O point fuse failures, termination panel or termination cable failures are also Category C3a failures. The majority of these failures would be detected by the PLC on-line diagnostics, as described in Section 6.0. Only five items, identified with the combination of failure categories C2 and C3a, are not detected by the PLC. These can be detected by either application-specific design features or by periodic channel checks and surveillance testing.

The next failure category defined by Section 4.0 is Category C3b, which includes multiple failure conditions where the PLC is unable to perform all of its safety functions. These failures include the effects of fire, flooding and missiles, which are minimized by applying standard industry design practices in specific system applications and are considered low-probability events. The remaining failures are either common cause hardware failures or software errors. These types of multiple failure scenarios are typically considered to be a small percentage of the total failures. The reliability analysis referenced in Section 5.8 uses a common cause Beta factor of 1 %. This Beta factor is typical of the factor used in process industry safety systems.

The final failure category defined by Section 4.0 is Category C4a & C4b, which includes single or multiple failure conditions where the PLC self-diagnostic capability is reduced, but the PLC remains operable. These failures, all fall in the category of single or double failures of triple redundant components, such as Main Processor modules, I/O modules, I/O Bus links, TRIBUS links or RXM modules. Most failures that reduce the on-line diagnostic capabilities are detected and hence are repaired quickly using the on-line repair capability of the TRICON system. The items that cannot be repaired on-line (i.e. chassis I/O bus, TRIBUS links) have very low failure rates that can typically be ignored.

With the TRICON system, the Safe Undetected Failure Rate, on average account for about 0.7% of the Total Failure Rate. The Dangerous Undetected Failure Rate, on average account for about 0.5% of the Total Failure Rate. The undetected failure rate data is very small as a result of TRICON's high Diagnostic Coverage, which is around 95% and above. This coverage enabled the majority of system failures to fall in the safe category. The Safe Failure Fraction average is about 99%. Furthermore, because of the TRICON's TMR architecture, it will need to have two undetected failures to get to the final fail-to-function state. (Refer to the Fail-to-Function Markov Model in the Reliability/ Availability Study document (See Section 5.8)). Any detected failure will be fixed at a given on-line repair rate (24 hours in the reliability/ availability study). This allows for the system to run in applications that require PFDavg in the range 10^{-4} to 10^{-3}.

The Safety Availability of the TRICON-UNDER-TEST MODULE configuration (Reference 5.1) is over 99.99% and exceeds the EPRI requirement of 99%. The Overall Availability of the TRICON-UNDER-TEST MODULE configuration is also over 99.99% and also exceeds the EPRI requirement of 99 %.

As stated in Section 4.0 of this report, the PLC utilizes a fault-tolerant triple modular redundant architecture. This system design identifies and compensates for failed system elements, which facilitates its use in critical and safety-related process applications. The TRICON self-diagnostic features, described in References 5.5 and 5.6 and summarized in Section 6.0 of this report, have been specifically designed to detect and alarm failures of sub-components within each module. Extensive testing has been performed on each module to validate that the on-line diagnostics will detect a very high percentage of the failures within each module. The diagnostic coverages for the Main Processors and the common processing circuitry on the I/O modules are in the 95 to 99% range. The diagnostic coverage of the I /O point circuitry on the I/O modules is 99%. Reference 5.8 shows the failure rates and diagnostic coverages of the TRICON Main Processors and I/O modules.

The TRICON system design information presented in References 5.5 and 5.6 includes recommendations for periodic off-line testing of field inputs and outputs. These recommendations establish general surveillance techniques and surveillance intervals intended to maintain the high reliability of the overall control system. It is strongly recommended that specific nuclear plant safety-related applications incorporate the specified methods and frequencies of Reference 5.5, 5.6 and 5.10 to maximize system reliability and operability.

8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR THE TRICON V10.2

It should be noted that the Failure Category column in the FMEA Table shows the **primary** failure categories. For example nearly all single failures on the TRICON modules are in the C1a and C1b category since the diagnostic coverage is in the 95 to 99 % range. Hence the C2a and C2b categories are not shown since the percent of undetected failures is so small.

The FMEA assumes that all loop power supplies are redundant (two power supplies). The FMEA also includes the termination panels and termination cables. These panels and cables have many single points of failure and these failures are typically considered as a part of the connected I/O device. In many cases they are neglected since the panel and cable failure rates are very low compared to the failure rate of the connected I/O device.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
CONTROL AND COMMUNICATIONS MODULE-RELATED FAILURES					
1) Main Chassis Processor Module: Model 3008; Enhanced TRICON Main Processor, 16 Mbytes DRAM	Loss of all three processor modules	Fire; flood; missiles; software common mode failure	C3b	Input signals will not be read. Analog and digital outputs fail low.	PLC fails to operate
2) Main Chassis Processor Module: Model 3008; Enhanced TRICON Main Processor, 16 Mbytes DRAM	Loss of one or two processor modules	Electronics or software failure	C1a, C1b, C4a, C4b	None	PLC continues to operate via intact processor module(s). Main processor diagnostics will detect and flag processor fault. See Sec. 6.3.
3) Main Chassis Communications Module: Model 4352A, TRICON Communication Module (TCM)	Failure of module to transmit or receive data on all three legs	Electronics or software failure	C1a, C1b	If safety related data is being transmitted, the receiving Main Processor will assume the data should be set to the fail safe state and put devices dependent on the data into a safe state.	PLC continues to operate. Communications to external network devices is interrupted. Main processor diagnostics will detect and flag communications fault if application software is so designed. Requires application-specific alarming in the external system. See Sec. 6.4.1. A faulty TCM module can be replaced while the controller is online.
4) Main Chassis Communications Module: Model 4352A, TRICON Communication Module (TCM)	Failure of com module to communicate with one or two of the Main Processor..	Electronics or software failure	C1a, C1b	None	Third leg will still communicate with the MP.

CONTROL AND COMMUNICATIONS MODULE-RELATED FAILURES (CONTINUED)					
5) Model 4200-3; Primary Remote Extender Module (RXM), Multi-mode Fiber Optics (set of 3 modules)	Loss of all three RXM modules	Fire; flood; missiles; software common mode failure	C3b	Input signals in affected RXM chassis will not be read. Analog and digital outputs fail low.	PLC continues to operate, with loss of I/O function in the failed RXM chassis as noted, and all downstream chassis assemblies. Main processor diagnostics will detect and flag RXM communications fault. See Sec. 6.4.2.
6) Model 4200-3; Primary Remote Extender Module (RXM), Multi-mode Fiber Optics (set of 3 modules)	Loss of one or two RXM modules	Electronics or software failure	C1a, C1b, C4a, C4b	None	PLC continues to operate via intact RXM module(s). Main processor diagnostics will detect and flag RXM module fault. See Sec. 6.4.2.
7) Model 4201-3; Remote Extender Module (RXM), Multi-mode Fiber Optics (set of 3 modules)	Loss of all three RXM modules	Fire; flood; missiles; software common mode failure	C3b	Input signals in affected RXM chassis will not be read. Analog and digital outputs fail low.	PLC continues to operate, with loss of I/O function in the failed RXM chassis as noted, and all downstream chassis assemblies. Main processor diagnostics will detect and flag RXM communications fault. See Sec. 6.4.2.
8) Model 4201-3; Remote Extender Module (RXM), Multi-mode Fiber Optics (set of 3 modules)	Loss of one or two RXM modules	Electronics or software failure	C1a, C1b, C4a, C4b	None	PLC continues to operate via intact RXM module(s). Main processor diagnostics will detect and flag RXM module fault. See Sec. 6.4.2.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
PLC I/O MODULE-RELATED FAILURES					
1) Digital input modules: Model 3501T; 115 Vac/Vdc Model 3502E; 48 Vac/Vdc Model 3503E; 24 Vac/Vdc	Input point(s) stuck OFF on one leg.	Electronic component, or multiple components on different points.	C1a, C1b; C2a, C2b if point is normally OFF	None	PLC continues operation. If point is normally OFF, then condition will only be detected for Model 3501T DI module, which includes Stuck Off diagnostic capability. See Sec. 6.1.1.
2) Digital input modules: Model 3501T; 115 Vac/Vdc Model 3502E; 48 Vac/Vdc Model 3503E; 24 Vac/Vdc	Input point(s) stuck OFF on multiple legs.	Multiple electronic component failures on same point or fuse failure	C1a, C1b, C3b,and C2a, C2b if point is normally OFF	Affected digital input(s) will fail low	PLC unable to correctly determine the state of the affected point(s). If point is normally OFF, then condition will only be detected for Model 3501T DI module, which includes Stuck Off diagnostic capability. See Sec. 6.1.1.
3) Digital input modules: Model 3501T; 115 Vac/Vdc Model 3502E; 48 Vac/Vdc Model 3503E; 24 Vac/Vdc	Input point(s) stuck ON for one leg	Electronic component failure, or multiple component failures on different points.	C1a, C1b; C2a, C2b only for 3501T if point is normally ON.	None	PLC continues operation. Condition will be detected for all DI modules except Model 3501T if the point is normally ON, which does not include Stuck On diagnostic capability. See Sec. 6.1.1.
4) Digital input modules: Model 3501T; 115 Vac/Vdc Model 3502E; 48 Vac/Vdc Model 3503E; 24 Vac/Vdc	Input point(s) stuck ON for multiple legs	Multiple electronic component failures on same point or fuse failure	C1a, C1b,, C3b C2a, C2b only for 3501T if point is normally ON.	Affected digital input(s) will fail high.	PLC unable to correctly determine the state of the affected point(s). Condition will be detected for all DI modules except Model 3501T if the point is normally ON, which does not include Stuck On diagnostic capability. See Sec. 6.1.1.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
PLC I/O MODULE-RELATED FAILURES (CONTINUED)					
5) Digital input modules: Model 3501T; 115 Vac/Vdc Model 3502E; 48 Vac/Vdc Model 3503E; 24 Vac/Vdc	Common processing failure on one or two legs.	Electronic component failure(s)	C1a, C1b	None	PLC continues operation. Main processor diagnostics will detect and flag board fault. Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.1.1.
6) Digital input modules: Model 3501T; 115 Vac/Vdc Model 3502E; 48 Vac/Vdc Model 3503E; 24 Vac/Vdc	Common processing failure on all three legs.	Electronic component failures on all legs or comm. Software failure	C3b	Affected digital inputs will not be read.	PLC will treat all affected input points as OFF. Main processor diagnostics will detect and flag board fault(s). Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.1.1.
7) Digital output modules: Model 3601T; 115 Vac Model 3603T; 120 Vdc Model 3607E; 48 Vdc Model 3625; 24 Vdc	Output point fails high or low on one leg	Electronic component failure	C1a, C1b	None	PLC continues operation. DO module OVD diagnostics will detect the fault on all modules except for the 3601T if the output point is not being toggled periodically. See Sec. 6.2.1.
8) Digital output modules: Model 3601T; 115 Vac Model 3603T; 120 Vdc Model 3607E; 48 Vdc Model 3625; 24 Vdc	Output point fails high or low on multiple legs	Multiple electronic component failures or fuse failure	C3b	Affected digital outputs will fail to the corresponding output state, or will go OFF if fuse fault.	PLC unable to control the affected output point(s). Condition will be detected by DO module field voltage detection circuit, which will activate the LOAD/FUSE alarm since the commanded DO state will not match the detected field voltage; or if fails to current state, will be detected during the OVD diagnostics, except on the 3601T. See Sec. 6.2.1.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
PLC I/O MODULE-RELATED FAILURES (CONTINUED)					
9) Digital output modules: Model 3601T; 115 Vac Model 3603T; 120 Vdc Model 3607E; 48 Vdc Model 3625; 24 Vdc	Common processing failure on one or two legs	Electronic component failure(s)	C1a, C1b	None	PLC continues operation. Main processor diagnostics will detect and flag board fault. Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.2.1.
10) Digital output modules: Model 3601T; 115 Vac Model 3603T; 120 Vdc Model 3607E; 48 Vdc Model 3625; 24 Vdc	Common processing failure on all legs	Multiple electronics failures or comm. Software failure	C3b	Affected output points will go OFF.	PLC unable to control the affected output points. Main processor diagnostics will detect and flag board fault. Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.2.1.
11) Supervised digital output modules: Model 3623T; 120 Vac Model 3625; 24 Vdc	Output point fails high or low on one leg.	Electronic component failure	C1a, C1b	None	PLC continues operation. SDO module OVD diagnostics will detect the fault . See Sec. 6.2.2.
12) Supervised digital output modules: Model 3623T; 120 Vac Model 3625; 24 Vdc	Output point fails high or low on multiple legs.	Multiple electronic component failures or fuse failure.	C3b	Affected digital outputs will fail to the corresponding output state, or will go OFF if fuse fault.	PLC unable to control the affected output point(s). Condition will be detected by SDO OVD diagnostics. Module, Load or Power alarm will be asserted based upon specific fault scenario. See Sec. 6.2.2.
13) Supervised digital output modules: Model 3623T; 120 Vac Model 3625; 24 Vdc	Common processing failure on one or two legs	Electronic component failure(s)	C1a, C1b	None	PLC continues operation. Main processor diagnostics will detect and flag board fault. Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.2.2.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
PLC I/O MODULE-RELATED FAILURES (CONTINUED)					
14) Supervised digital output modules: Model 3623T; 120 Vac Model 3625; 24 Vdc	Common processing failure on all legs	Multiple electronics failures or comm. Software failure	C3b	Affected output points will go OFF.	PLC unable to control the affected output points. Main processor diagnostics will detect and flag board fault. Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.2.2.
15) Analog input modules: Model 3701; 0-10 Vdc Model 3703E; 0-5, 0-10 Vdc Model 3704E; 0-5, 0-10 Vdc Model 3721; 0-5/-5 to +5 Vdc Model 3708E, Thermocouple	Input point fails high or low on single leg	Electronic component failure	C1a, C1b	None	PLC continues operation. Low or high range diagnostic monitoring alarm (channel violation of allowed tolerance) resulting in board fault alarm. Main processor diagnostics will detect and flag board fault via Main Chassis Power Module alarm circuit. See Sec. 6.1.3
16) Analog input modules: Model 3701; 0-10 Vdc Model 3703E; 0-5, 0-10 Vdc Model 3704E; 0-5, 0-10 Vdc Model 3721; 0-5/-5 to +5 Vdc Model 3708E, Thermocouple	Input point fails high or low on multiple legs	Multiple electronic component failures or fuse failure	C3b	Affected analog inputs will fail to the corresponding input state, or will go downscale if fuse fault.	PLC unable to correctly determine the value of the affected point(s). Low or high range diagnostic monitoring alarm (channel violation of allowed tolerance) resulting in board fault alarm. Main processor diagnostics will detect and flag board fault via Main Chassis Power Module alarm circuit. See Sec. 6.1.3
17) Analog input modules: Model 3701; 0-10 Vdc Model 3703E; 0-5, 0-10 Vdc Model 3704E; 0-5, 0-10 Vdc Model 3721; 0-5/-5 to +5 Vdc Model 3708E, Thermocouple	Common processing failure on one or two legs	Electronic component failure(s)	C1a, C1b	None	PLC continues operation. Main processor diagnostics will detect and flag board fault. Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.1.3.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
PLC I/O MODULE-RELATED FAILURES (CONTINUED)					
18) Analog input modules: Model 3701; 0-10 Vdc Model 3703E; 0-5, 0-10 Vdc Model 3704E; 0-5, 0-10 Vdc Model 3721; 0-5/-5 to +5 Vdc Model 3708E, Thermocouple	Common processing failure on all legs	Multiple electronics failures or comm. software failure	C3b	Affected input points will go downscale.	PLC will treat all affected input points as downscale. Main processor diagnostics will detect and flag board fault. Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.1.3.
19) Analog input modules: Model 3701; 0-10 Vdc Model 3703E; 0-5, 0-10 Vdc Model 3704E; 0-5, 0-10 Vdc Model 3721; 0-5/-5 to +5 Vdc Model 3708E, Thermocouple	Module accuracy out of specification on multiple legs.	Components of the self-calibration voltage-reference circuits for all legs drift over time.	C3b	Affected inputs could potentially be outside of the published accuracy.	PLC continues operation. Minimum proof test interval is once every 30 months to detect common cause drift. Reference 5.10.
20) Analog input modules: Model 3701; 0-10 Vdc Model 3703E; 0-5, 0-10 Vdc Model 3704E; 0-5, 0-10 Vdc Model 3721; 0-5/-5 to +5 Vdc Model 3708E, Thermocouple	Module accuracy out of specification on a single leg.	Components of the self-calibration voltage-reference circuits for all legs drift over time.	C1a, C2a	Affected inputs could potentially be outside of the published accuracy.	PLC continues operation. Significant deviations are detected and alarmed.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
PLC I/O MODULE-RELATED FAILURES (CONTINUED)					
21) Analog output module: Model 3805E; 4-20ma	Output signal fails high or low on one or two legs.	Electronic component failure(s)	C1a, C1b	None	PLC continues operation. Each analog output module sustains complete ongoing diagnostics for each leg. Failure of any diagnostic on any leg activates the module's Fault Indicator, which in turn activates the chassis alarm signal. Failure of all three legs for a given output will activate the Load Indicator, and output will not be driven. See Sec. 6.2.4.
22) Analog output module: Model 3805E; 4-20ma	Output signal fails high or low on all three legs.	Multiple electronic component failures or firmware failure	C3b	Affected analog outputs will fail to unknown value.	PLC unable to control the affected output points. Each analog output module sustains complete ongoing diagnostics for each leg. Failure of any diagnostic on any leg activates the module's Fault Indicator, which in turn activates the chassis alarm signal. See Sec. 6.2.4.
23) Analog output module: Model 3805E; 4-20ma	Common processing failure on one or two legs	Electronic component failure(s)	C1a, C1b	None	PLC continues operation. Main processor diagnostics will detect and flag board fault. Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.2.4.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
PLC I/O MODULE-RELATED FAILURES (CONTINUED)					
24) Analog output module: Model 3805E; 4-20ma	Common processing failure on all three legs.	Multiple module electronics failure or comm. software failure	C3b	Affected analog outputs will fail downscale.	PLC unable to control the affected output points. Main processor diagnostics will detect and flag board fault. Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.2.4.
25) Analog output module: Model 3805E; 4-20ma	Module accuracy out of specification on multiple legs.	Components of the self-calibration voltage-reference circuits for all legs drift over time.	C3b	Affected outputs could potentially be outside of the published accuracy.	PLC continues operation. Minimum proof test interval is once every 30 months to detect common cause drift. Reference 5.10.
26) Analog output module: Model 3805E; 4-20ma	Module accuracy out of specification on a single leg.	Components of the self-calibration voltage-reference circuits for all legs drift over time.	C1a, C2a	Affected outputs could potentially be outside of the published accuracy.	PLC continues operation. Significant deviations are detected and alarmed.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
PLC I/O MODULE-RELATED FAILURES (CONTINUED)					
27) Relay output module: Model 3636T; Relay Output	Relay output fails open or closed	Electronic component or fuse failure	C1a, C1b, C2a, C2b	If relay contact or fuse, affected field loads from relay outputs will fail to the corresponding output state. If internal fault, no effect on output.	PLC unable to control affected output points, if contact or fuse fault. Relay contact or fuse faults will not be detected. All internal faults will be detected by RO diagnostics and alarmed. See Sec. 6.2.3.
28) Relay output module: Model 3636T; Relay Output	Common processing failure on one or two legs	Electronic component failure(s)	C1a, C1b,C2a, C2b	None	PLC continues operation. Main processor diagnostics will detect and flag board fault. Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.2.3.
29) Relay output module: Model 3636T; Relay Output	Common processing failure on all three legs.	Module electronics failure or comm. software failure	C1a, C1b, C2a, C2b, C3b	Affected relay outputs will be OPEN.	PLC unable to control the affected output points. Main processor diagnostics will detect and flag board fault. Relay contact or fuse faults will not be detected. Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.2.3.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
PLC I/O MODULE-RELATED FAILURES (CONTINUED)					
30) Pulse input module: Model 3511; 8 pulse input	Input point fails high or low on single leg	Electronic component failure	C1a, C1b	None	PLC continues operation. Low or high range diagnostic monitoring alarm (channel violation of allowed tolerance) resulting in board fault alarm. Main processor diagnostics will detect and flag board fault via Main Chassis Power Module alarm circuit. See Sec. 6.1.2
31) Pulse input module: Model 3511; 8 pulse input	Input point fails high or low on multiple legs	Multiple electronic component failures	C3b	Affected inputs will fail to the corresponding input state.	PLC unable to correctly determine the value of the affected point(s). Low or high range diagnostic monitoring alarm (channel violation of allowed tolerance) resulting in board fault alarm. Main processor diagnostics will detect and flag board fault via Main Chassis Power Module alarm circuit. See Sec. 6.1.2
32) Pulse input module: Model 3511; 8 pulse input	Common processing failure on one or two legs	Electronic component failure(s)	C1a, C1b	None	PLC continues operation. Main processor diagnostics will detect and flag board fault. Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.1.2.
33) Pulse input module: Model 3511; 8 pulse input	Common processing failure on all legs	Multiple electronics failures or comm. software failure	C3b	Affected input points will go downscale.	PLC will treat all affected input points as downscale. Main processor diagnostics will detect and flag board fault. Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.1.2.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
POWER SUPPLY-RELATED FAILURES					
1) All chassis power supplies	Loss of all input power	Facility blackout	C3b	Input signals will not be read. Analog and digital outputs fail low.	PLC fails to operate
2) All chassis power supplies:	Power supply output fails high	Electronic component or fuse failure	N/A	None	PLC continues operation. The three terminal linear regulators are thermally protected, and the power supplies are over voltage-limited. Failure modes initiated by overvoltage conditions are therefore inapplicable. See Sec. 6.6.
3) Main Chassis power supply: Model 8310; 120Vac/Vdc Model 8311; 24Vdc Model 8312; 230Vac	Loss of one power supply output	Electronic component or fuse failure	C1a, C1b	None	PLC continues operation via redundant main chassis power supply. Main processor diagnostics will detect and flag board fault. Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.6.
4) Main Chassis power supply: Model 8310; 120Vac/Vdc Model 8311; 24Vdc Model 8312; 230Vac	Power supply outputs fail (both power supplies fail)	Electronic component or fuse failure	C3b	Main processors fail and all analog and digital outputs fail low	PLC fails to operate.
5) RXM or Expansion Chassis power supply: Model 8310; 120Vac/Vdc Model 8311; 24Vdc Model 8312; 230Vac	Loss of one power supply output	Electronic component or fuse failure	C1a, C1b	None	PLC continues operation via redundant RXM/Expansion chassis power supply. Main processor diagnostics will detect and flag board fault. Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.6.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
POWER SUPPLY-RELATED FAILURES (CONTINUED)					
6) RXM or Expansion Chassis power supply: Model 8310; 120Vac/Vdc Model 8311; 24Vdc Model 8312; 230Vac	Power supply outputs fail (both power supplies fail)	Electronic component or fuse failure	C3b	All outputs fail low on all modules in affected chassis.	PLC continues operation. Main processor diagnostics will detect and flag board fault. Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.6
7) Loop power supply for digital inputs: Model 3501T; 115 Vac/Vdc Model 3502E; 48 Vac/Vdc Model 3503E; 24 Vac/Vdc	power supply output voltage fails low (both power supplies fail)	Fire; flood; missile	C3b	Affected digital inputs will fail low	PLC continues operation. Condition will not be detected unless: (a) power supply failure was alarmed, or (b) DI point failures triggered alarms associated with measured parameters; or (c) by periodic channel checks or surveillance testing. DI point could also be wired as a power failure alarm to provide detection (application-specific). See Sec. 6.1.1.
8) Loop power supply for digital inputs: Model 3501T; 115 Vac/Vdc Model 3502E; 48 Vac/Vdc Model 3503E; 24 Vac/Vdc	power supply output voltage fails low (one power supply fails)	Electronic component or fuse failure	C1a, C1b, C2a, C2b	None	PLC continues operation. Condition will not be detected unless: (a) power supply failure was alarmed, or (b) by periodic channel checks or surveillance testing. DI point could also be wired as a power failure alarm to provide detection (application-specific). See Sec. 6.1.1.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
POWER SUPPLY-RELATED FAILURES (CONTINUED)					
9) Loop power supply for digital inputs: Model 3501T; 115 Vac/Vdc Model 3502E; 48 Vac/Vdc Model 3503E; 24 Vac/Vdc	Power supply output voltage fails high	Electronic component or fuse failure; fire; flood; missile	C3a, C3b	Affected digital inputs may fail low: provided failure voltage is high enough to burn out affected DI points	PLC continues operation. Main processor diagnostics will detect and flag board fault for modules with SAO/SAZ fault detection on the inputs. Fault alarm via Main Chassis Power Module alarm circuit. Application specific monitoring required to detect and alarm the failure for remaining modules. See Sec. 6.1.1.
10) Loop power supply for digital outputs: Model 3601T; 115 Vac Model 3603T; 120 Vdc Model 3607E; 48 Vdc Model 3625; 24 Vdc	Power supply output voltage fails low (both DC power supplies fail)	Electronic component or fuse failure	C3b	Affected digital outputs will fail low	PLC continues operation. Condition will be detected by the output voter diagnostics on the affected DO module, and by the DO module's field voltage detection circuit, which will activate the LOAD/FUSE alarm since the commanded DO state will not match the detected field voltage. See Sec. 6.2.1.
11) Loop power supply for digital outputs: Model 3601T; 115 Vac Model 3603T; 120 Vdc Model 3607E; 48 Vdc Model 3625; 24 Vdc	Power supply output voltage fails low (One power supply fails)	Electronic component or fuse failure	C1a, C1b, C2a, C2b	None	PLC continues operation. Condition will not be detected unless: (a) power supply failure was alarmed, or (b) by periodic channel checks or surveillance testing. DI point could also be wired as a power failure alarm to provide detection (application-specific). See Sec. 6.1.1.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
POWER SUPPLY-RELATED FAILURES (CONTINUED)					
12) Loop power supply for digital outputs: Model 3601T; 115 Vac Model 3603T; 120 Vdc Model 3607E; 48 Vdc Model 3625; 24 Vdc	Power supply output voltage fails high	Electronic component failure	C3a, C3b	Affected digital outputs may fail low; assuming failure voltage is high enough to burn out affected DO points	PLC continues operation. Main processor diagnostics will detect and flag board fault. Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.2.1.
13) Loop power supply for supervised digital outputs: Model 3623T; 120 Vac Model 3625; 24 Vdc	Power supply output voltage fails low (both power supplies fail)	Electronic component or fuse failure	C3b	Affected digital outputs will fail low	PLC continues operation. Loss of power will be detected by SDO circuitry, which will generate a Power Alarm and/or a Load Alarm. See Sec. 6.2.2.
14) Loop power supply for supervised digital outputs: Model 3623T; 120 Vac Model 3625; 24 Vdc	Power supply output voltage fails low (one power supply fails)	Electronic component or fuse failure	C1a, C1b, C2a, C2b	None	PLC continues operation. Condition will not be detected unless: (a) power supply failure was alarmed, or (b) by periodic channel checks or surveillance testing. DI point could also be wired as a power failure alarm to provide detection (application-specific). See Sec. 6.1.1.
15) Loop power supply for supervised digital outputs: Model 3623T; 120 Vac Model 3625; 24 Vdc	Power supply output voltage fails high	Electronic component failure	C3a, C3b	Affected digital outputs may fail low; assuming failure voltage is high enough to burn out affected DO points	PLC continues operation. Loss of power will be detected by SDO circuitry, which will generate a Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.2.2.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
POWER SUPPLY-RELATED FAILURES (CONTINUED)					
16) Loop power supply for analog input modules: Model 3701; 0-10 Vdc Model 3703E; 0-5, 0-10 Vdc Model 3704E; 0-5, 0-10 Vdc Model 3721; 0-5/-5 to +5 Vdc Model 3708E, Thermocouple	Power supply output voltage fails low (both power supplies fail)	Electronic component or fuse failure	C3b	Affected analog inputs will fail low (downscale)	PLC continues operation. Low range diagnostic monitoring alarm (channel violation of allowed tolerance) resulting in board fault alarm. Main processor diagnostics will detect and flag board fault via Main Chassis Power Module alarm circuit. See Sec. 6.1.3.
17) Loop power supply for analog input modules: Model 3701; 0-10 Vdc Model 3703E; 0-5, 0-10 Vdc Model 3704E; 0-5, 0-10 Vdc Model 3721; 0-5/-5 to +5 Vdc Model 3708E, Thermocouple	Power supply output voltage fails low (one power supply fails)	Electronic component or fuse failure	C1a, C1b, C2a, C2b	None	PLC continues operation. Low range diagnostic monitoring alarm (channel violation of allowed tolerance) resulting in board fault alarm. Main processor diagnostics will detect and flag board fault via Main Chassis Power Module alarm circuit. See Sec. 6.1.3.
18) Loop power supply for analog input modules: Model 3701; 0-10 Vdc Model 3703E; 0-5, 0-10 Vdc Model 3704E; 0-5, 0-10 Vdc Model 3721; 0-5/-5 to +5 Vdc Model 3708E, Thermocouple	Power supply output voltage fails high	Electronic component failure	C3a, C3b	Affected analog inputs may fail low (downscale); assuming failure voltage is high enough to burn out affected AI points	PLC continues operation. Low range diagnostic monitoring alarm (channel violation of allowed tolerance) resulting in board fault alarm. Main processor diagnostics will detect and flag board fault via Main Chassis Power Module alarm circuit. See Sec. 6.1.3.
19) Loop power supply for analog output module: Model 3805E; 4-20ma	Power supply output voltage fails low (both power supplies fail)	Electronic component or fuse failure	C3b	Affected analog outputs will fail low (downscale)	PLC continues operation. Each analog output module sustains complete ongoing diagnostics for each channel. Failure of any diagnostic on any channel activates the module's Fault Indicator, which in turn activates the chassis alarm signal. See Sec. 6.2.4.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
POWER SUPPLY-RELATED FAILURES (CONTINUED)					
20) Loop power supply for analog output module: Model 3805E; 4-20ma	Power supply output voltage fails low (one power supply fails)	Electronic component or fuse failure	C1a, C1b, C2a, C2b	None	PLC continues operation. Each analog output module sustains complete ongoing diagnostics for each channel. Failure of any diagnostic on any channel activates the module's Fault Indicator, which in turn activates the chassis alarm signal. See Sec. 6.2.4.
21) Loop power supply for analog output module: Model 3805E; 4-20ma	Power supply output voltage fails high	Electronic component failure	C3a, C3b	Affected analog outputs may fail low (downscale); assuming failure voltage is high enough to burn out affected AO points	PLC continues operation. Each analog output module sustains complete ongoing diagnostics for each channel. Failure of any diagnostic on any channel activates the module's Fault Indicator, which in turn activates the chassis alarm signal. See Sec. 6.2.4.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
POWER SUPPLY-RELATED FAILURES (CONTINUED)					
22) Loop power supply for relay output module: Model 3636T; Relay Output	Power supply output voltage fails low	Electronic component or fuse failure	C2a, C2b	Affected field loads from relay outputs will fail to the de-energized state	PLC continues operation. Condition will not be detected unless: (a) power supply failure was alarmed, or (b) RO point failures triggered alarms associated with controlled parameters; or (c) by periodic channel checks or surveillance testing. See Sec. 6.2.3.
23) Loop power supply for relay output module: Model 3636T; Relay Output	Power supply output voltage fails high	Electronic component failure	C2a, C2b	Affected field loads from relay outputs may fail to the de-energized state; assuming failure voltage is high enough to burn out field devices (application-specific failure).	PLC continues operation. Relay contacts may flash over if failure voltage exceeds maximum specified voltage. . See Sec. 6.2.3.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
PLC CHASSIS-RELATED FAILURES					
1) Main Chassis System Control keyswitch	Switch shorts or is closed to "STOP" position	Electrical power transient; fire; flood; missiles	C3b	Input signals will not be read. Analog and digital outputs fail low.	PLC fails to operate. STOP position shall be software-disabled per the Software Qualification Report. Multiple wafer switch, with switch state voted in MP. Credible single failures will be voted out.
2) Main Chassis power supply rails	Both rails fail open or short to ground	Electrical power transient; fire; flood; missiles	C3b	Input signals will not be read. Analog and digital outputs fail low.	PLC fails to operate. All analog, digital and relay outputs turn off.
3) Main Chassis power supply rails	One rail fails open or shorts to ground	Electrical power transient and/or motherboard insulation failure	C1a, C1b	None	PLC continues operation via redundant main chassis power supply. Main processor diagnostics will detect and flag power rail fault. Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.6.
4) Main Chassis TRIBUS serial links	All three links open or short to ground	Electrical power transient; fire; flood; missiles	C3b	Input signals will not be read. Analog and digital outputs fail low.	PLC fails to operate
5 Main Chassis TRIBUS serial links	One or two links open or short to ground.	Electrical power transient and/or motherboard insulation failure	C1a, C1b, C4a, C4b	None	PLC continues to operate via intact TRIBUS. Main processor diagnostics will detect and flag TRIBUS link fault. See Sec. 6.3.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
PLC CHASSIS-RELATED FAILURES CONTINUED)					
6) Main Chassis I/O Bus	All three buses open or short to ground	Electrical power transient; fire; flood; missiles	C3b	I/O signals downstream of an open bus will not be read. I/O signals will not be read for a shorted bus condition. Analog and digital outputs fail low at and past an open bus.	PLC microprocessors continue to operate, with I/O limitations as noted. Main processor diagnostics will detect and flag I/O bus fault. See Sec. 6.3.
7) Main Chassis I/O Bus	One or two buses open or short to ground	Electrical power transient and/or motherboard insulation failure	C1a, C1b, C4a, C4b	None	PLC continues to operate via intact I/O bus(es). Main processor diagnostics will detect and flag I/O bus fault. See Sec. 6.3.
8) Main Chassis Communications Bus	All buses open or short to ground	Electrical power transient; fire; flood; missiles	C4a, C4b	None	PLC continues to operate as a standalone device. Communications to external terminals is interrupted. Main processor diagnostics will detect and flag communications bus fault. Would require logic in the external system to detect and alarm this failure (application-specific). See Sec. 6.3.
9) Main Chassis Communications Bus	One or two buses open or short to ground	Electrical power transient and/or motherboard insulation failure	C1a, C1b, C4a, C4b	None	PLC continues to operate. Communications to external devices continues via intact communications bus(es). Main processor diagnostics will detect and flag communications bus fault. See Sec. 6.3.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
PLC CHASSIS-RELATED FAILURES CONTINUED)					
10 Main Chassis Communications Bus	Communication from one MP to the two others differs at the two other MPs	Failure of receiver at one receiving MP	C1a, C1b, C4a, C4b	None	Voted out and alarmed. See Sec. 6.3.
11) Main Chassis battery pack	Output voltage fails low	Battery aging or short circuit	C1a, C1b	None	PLC continues to operate, unless failure is concurrent with loss of all input power. Battery failure concurrent with all power failure will result in loss of main program memory from SRAM. Main processor diagnostics will detect and flag low battery voltage prior to failure. See Sec. 6.6.
12) RXM or Expansion Chassis power supply rails	Both rails fail open or short to ground	Electrical power transient; fire; flood; missiles	C3b	Input signals will not be read. Analog and digital outputs fail low for shorted rails, and fail low at and past the failure points for open rails.	PLC continues to operate, with loss of I/O function in the failed RXM or Expansion chassis as noted, and all downstream chassis assemblies. Main processor diagnostics will detect and flag power rail fault. Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.6
13) RXM or Expansion Chassis power supply rails	One rail fails open or shorts to ground	Electrical power transient and/or motherboard insulation failure	C1a, C1b	None	PLC continues operation via redundant RXM/Expansion chassis power supply. Main processor diagnostics will detect and flag power rail fault. Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.6.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
PLC CHASSIS-RELATED FAILURES CONTINUED)					
14) RXM or Expansion Chassis I/O Bus	All buses open or short to ground	Electrical power transient; fire; flood; missiles	C3b	Input signals downstream of an open bus will not be read. Input signals will not be read for a shorted bus condition. Analog and digital outputs fail low.	PLC microprocessors continue to operate, with I/O limitations in the specific RXM or Expansion chassis as noted, and all downstream chassis assemblies. Main processor diagnostics will detect and flag I/O bus fault. See Sec. 6.4.2.
15) RXM or Expansion Chassis I/O Bus	One or two buses open or short to ground	Electrical power transient and/or motherboard insulation failure	C1a, C1b, C4a, C4b	None	PLC continues to operate via intact I/O bus(es). Main processor diagnostics will detect and flag I/O bus fault. See Sec. 6.4.2.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
PLC CABLE-RELATED FAILURES					
1) Main Chassis-to-RXM Chassis I/O Expansion Cables (set of 3 cables)	Open circuit, short circuit or hot short in all three cables	Fault in adjacent power cable; fire; flood; missiles	C3b	Input signals downstream of the faulted cables will not be read. Analog and digital outputs fail low.	PLC microprocessors continue to operate, with I/O limitations downstream of the I/O Expansion cable fault as noted. Main processor diagnostics will detect and flag I/O cable fault. See Sec. 6.4.2.
2) Main Chassis-to-RXM Chassis I/O Expansion Cables (set of 3 cables)	Open circuit, short circuit or hot short in one or two cables	Fault in adjacent power cable; cable cut	C1a, C1b, C4a, C4b	None	PLC continues to operate via intact I/O cable(s). Main processor diagnostics will detect and flag I/O cable fault. See Sec. 6.4.2.
3 RXM Chassis-to-Expansion Chassis I/O Expansion Cables (set of 3 cables)	Open circuit, short circuit or hot short in all three cables	Fault in adjacent power cable; fire; flood; missiles	C3b	Input signals downstream of the faulted cables will not be read. Analog and digital outputs fail low.	PLC microprocessors continue to operate, with I/O limitations downstream of the I/O Expansion cable fault as noted. Main processor diagnostics will detect and flag I/O cable fault. See Sec. 6.4.2.
4) RXM Chassis-to-Expansion Chassis I/O Expansion Cables (set of 3 cables)	Open circuit, short circuit or hot short in one or two cables	Fault in adjacent power cable; cable cut	C1a, C1b, C4a, C4b	None	PLC continues to operate via intact I/O cable(s). Main processor diagnostics will detect and flag I/O cable fault. See Sec. 6.4.2.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
PLC CABLE-RELATED FAILURES (CONTINUED)					
5) Main Chassis Communications Module: Model 4352A, TRICON Communication Module (TCM) – network cable	Open circuit, short circuit or hot short in cable	Fault in adjacent power cable; cable cut	C1a, C1b, C2a, C2b	None	PLC continues to operate. Communications to external network devices is interrupted. Main processor diagnostics will detect and flag communications fault. Requires application-specific alarming in the external system. See Sec. 6.4.1.
6) Model 4200-3; Primary Remote Extender Module (RXM) to Model 4201-3; Remote Extender Module, Multi-mode Fiber Optics (set of 6 fiber optic cables)	Loss of all three RXM transmit or receive cables	Fire; flood, missiles	C3b	Input signals in affected RXM chassis will not be read. Analog and digital outputs fail low.	PLC continues to operate, with loss of I/O function in the failed RXM chassis as noted. Main processor diagnostics will detect and flag RXM communications fault. See Sec. 6.4.2.
7) Model 4200-3; Primary Remote Extender Module (RXM) to Model 4201-3; Remote Extender Module, Multi-mode Fiber Optics (set of 6 fiber optic cables)	Loss of one or two RXM transmit or receive cables	Fire or cable cut	C1a, C1b, C4a, C4b	None	PLC continues to operate via intact RXM cable(s). Main processor diagnostics will detect and flag RXM communications fault. See Sec. 6.4.2.
8) Chassis to termination cable for digital inputs: Model 3501T; 115 Vac/Vdc Model 3502E; 48 Vac/Vdc Model 3503E; 24 Vac/Vdc	Open circuit or short circuit to ground	Fault in adjacent power cable; cable cut; fire; flood; missiles	C2a, C2b, C3a	Affected digital inputs will fail low	PLC continues operation. Condition will not be detected unless: (a) DI point failures triggered alarms associated with measured parameters; or (b) by periodic channel checks or surveillance testing. See Sec. 6.1.1.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
PLC CABLE-RELATED FAILURES (CONTINUED)					
9) Chassis to termination cable for digital inputs: Model 3501T; 115 Vac/Vdc Model 3502E; 48 Vac/Vdc Model 3503E; 24 Vac/Vdc	Short circuit across DI point	Fire or cable cut; term panel short	C2a, C2b, C3a	Affected digital inputs will fail high	PLC continues operation. Condition will not be detected unless: (a) DI point failures triggered alarms associated with measured parameters; or (b) by periodic channel checks or surveillance testing; or (c) a single DI point has been used to indicate supply of external power as an application specific alarm. See Sec. 6.1.1.
10) Chassis to termination cable for digital inputs: Model 3501T; 115 Vac/Vdc Model 3502E; 48 Vac/Vdc Model 3503E; 24 Vac/Vdc	Hot short	Fault in adjacent power cable	C3a	Affected digital inputs may fail low; provided failure voltage is high enough to burn out affected DI points	PLC continues operation. Main processor diagnostics will detect and flag board fault. Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.1.1.
11) Chassis to termination cable for digital outputs: Model 3601T; 115 Vac Model 3603T; 120 Vdc Model 3607E; 48 Vdc Model 3625; 24 Vdc	Open circuit	Fault in adjacent power cable; cable cut; fire; flood; missiles	C2a, C2b, C3a	PLC digital outputs will not be affected, but field devices will fail low	PLC continues operation. Condition will not be detected unless: (a) DO point failures triggered alarms associated with measured parameters; or (b) by periodic channel checks or surveillance testing. See Sec. 6.2.1.
12) Chassis to termination cable for digital outputs: Model 3601T; 115 Vac Model 3603T; 120 Vdc Model 3607E; 48 Vdc Model 3625; 24 Vdc	Short circuit to ground	Fault in adjacent power cable; fire; flood; missiles	C3a	Affected digital outputs will fail low	PLC continues operation. Condition will be detected by DO module field voltage detection circuit, which will activate the LOAD/FUSE alarm since the commanded DO state will not match the detected field voltage. See Sec. 6.2.1.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
PLC CABLE-RELATED FAILURES (CONTINUED)					
13) Chassis to termination cable for digital outputs: Model 3601T; 115 Vac Model 3603T; 120 Vdc Model 3607E; 48 Vdc Model 3625; 24 Vdc	Hot short	Fault in adjacent power cable	C3a	Affected digital outputs may fail low; assuming failure voltage is high enough to burn out affected DO points	PLC continues operation. Main processor diagnostics will detect and flag board fault. Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.2.1.
14) Chassis to termination cable for supervised digital outputs: Model 3623T; 120 Vac Model 3625; 24 Vdc	Open circuit	Fault in adjacent power cable; cable cut; fire; flood; missiles	C3a	PLC digital outputs will not be affected, but field devices will fail low	PLC continues operation. Loss of field loops will be detected by SDO circuitry, which will generate a Power Alarm and/or a Load Alarm. See Sec. 6.2.2.
15) Chassis to termination cable for supervised digital outputs: Model 3623T; 120 Vac Model 3625; 24 Vdc	Short circuit to ground	Fault in adjacent power cable; fire; flood; missiles	C3a	Affected digital outputs will fail low	PLC continues operation. Fault will be detected by SDO circuitry, which will generate a Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.2.2.
16) Chassis to termination cable for supervised digital outputs: Model 3623T; 120 Vac Model 3625; 24 Vdc	Hot short	Fault in adjacent power cable	C3a	Affected digital outputs may fail low; assuming failure voltage is high enough to burn out affected DO points	PLC continues operation. Fault will be detected by SDO circuitry, which will generate a Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.2.2.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
PLC CABLE-RELATED FAILURES (CONTINUED)					
17) Chassis to termination cable for analog input modules: Model 3701; 0-10 Vdc Model 3703E; 0-5, 0-10 Vdc Model 3704E; 0-5, 0-10 Vdc Model 3721; 0-5/-5 to +5 Vdc Model 3708E. Thermocouple	Open circuit or short circuit to ground	Fault in adjacent power cable; cable cut; fire; flood; missiles	C3a	Affected analog inputs will fail low (downscale)	PLC continues operation. Low range diagnostic monitoring alarm (channel violation of allowed tolerance) resulting in board fault alarm. Main processor diagnostics will detect and flag board fault via Main Chassis Power Module alarm circuit. See Sec. 6.1.3.
18) Chassis to termination cable for analog input modules: Model 3701; 0-10 Vdc Model 3703E; 0-5, 0-10 Vdc Model 3704E; 0-5, 0-10 Vdc Model 3721; 0-5/-5 to +5 Vdc Model 3708E, Thermocouple	Hot short	Fault in adjacent power cable	C3a	Affected analog inputs may fail low (downscale); assuming failure voltage is high enough to burn out affected AI points	PLC continues operation. Low or high range diagnostic monitoring alarm (channel violation of allowed tolerance) resulting in board fault alarm. Main processor diagnostics will detect and flag board fault via Main Chassis Power Module alarm circuit. See Sec. 6.1.3.
19) Chassis to termination cable for analog output module: Model 3805E; 4-20ma	Open circuit	Fault in adjacent power cable; cable cut; fire; flood; missiles	C3a	Affected analog output end devices will fail low (downscale)	PLC continues operation. Each analog output module sustains complete ongoing diagnostics for each channel. Failure of any diagnostic on any channel activates the module's Load Indicator, which in turn activates the chassis alarm signal. See Sec. 6.2.4.
20) Chassis to termination cable for analog output module: Model 3805E; 4-20ma	Short circuit to ground or hot short	Fault in adjacent power cable; fire; flood; missiles	C3a	Affected analog outputs will fail downscale for a short circuit, and may fail low for a hot short; assuming failure voltage is high enough to burn out affected AO points	PLC continues operation. Each analog output module sustains complete ongoing diagnostics for each channel. Failure of any diagnostic on any channel activates the module's Fault Indicator, which in turn activates the chassis alarm signal. See Sec. 6.2.4.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
PLC CABLE-RELATED FAILURES (CONTINUED)					
21) Chassis to termination cable for relay output module: Model 3636T: Relay Output	Open circuit or short circuit to ground	Fault in adjacent power cable; cable cut; fire; flood; missiles	C2a, C2b	Affected field loads from relay outputs will fail to the de-energized state	PLC continues operation. Condition will not be detected unless: (a) RO point failures triggered alarms associated with controlled parameters: or (b) by periodic channel checks or surveillance testing. See Sec. 6.2.3.
22) Chassis to termination cable for relay output module: Model 3636T: Relay Output	Hot short	Fault in adjacent power cable	C2a, C2b	Affected field loads from relay outputs may fail to the de-energized state; assuming failure voltage is high enough to burn out field devices (application-specific failure).	PLC continues operation. Relay contacts may flash over if failure voltage exceeds maximum specified voltage. See Sec. 6.2.3.
23) Chassis to termination cable for pulse input module: Model 3510: 8 pulse input Model 3511; 8 pulse input	Open circuit or short circuit to ground	Fault in adjacent power cable; cable cut; fire; flood; missiles	C3a	Affected pulse inputs will fail low	PLC continues operation. Condition will not be detected unless: (a) PI point failures triggered alarms associated with controlled parameters; or (b) by periodic channel checks or surveillance testing. See Sec. 6.1.2.
24) Chassis to termination cable for pulse input module: Model 3511; 8 pulse input	Hot short	Fault in adjacent power cable	C3a	Affected pulse inputs may fail low; assuming failure voltage is high enough to burn out field devices (application-specific failure).	PLC continues operation. Condition will not be detected unless: (a) PI point failures triggered alarms associated with controlled parameters: or (b) by periodic channel checks or surveillance testing. See Sec. 6.1.2.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
PLC CABLE-RELATED FAILURES (CONTINUED)					
25) Combined I/O bus of various chassis – Expansion to Expansion, Main to Expansion, Main to RXM, RXM to Expansion	Open/short on all three busses	Fault in adjacent power cable; cable cut; fire; flood; missiles	C1a, C1b, C3b	Unable to transmit signals to the I/O modules on faulted busses.	Set the outputs to fail safe mode.
TERMINATION PANEL-RELATED FAILURES					
1) Termination panel for digital inputs: Model 3501T; 115 Vac/Vdc Model 3502E; 48 Vac/Vdc Model 3503E; 24 Vac/Vdc	Open circuit or short circuit to ground	Fire; flood; missiles; term panel fuse failure or short	C2a, C2b, C3b	Affected digital inputs will fail low	PLC continues operation. Condition will not be detected unless: (a) DI point failures triggered alarms associated with measured parameters; or (b) by periodic channel checks or surveillance testing. See Sec. 6.1.1.
2 Termination panel for digital inputs: Model 3501T; 115 Vac/Vdc Model 3502E; 48 Vac/Vdc Model 3503E; 24 Vac/Vdc	Short circuit across DI point	Fire or cable cut; term panel short	C2a, C2b, C3a	Affected digital inputs will fail high	PLC continues operation. Condition will not be detected unless: (a) DI point failures triggered alarms associated with measured parameters; or (b) by periodic channel checks or surveillance testing. See Sec. 6.1.1.
3) Termination panel for digital inputs: Model 3501T; 115 Vac/Vdc Model 3502E; 48 Vac/Vdc Model 3503E; 24 Vac/Vdc	Hot short	Fault in adjacent power cable	C3a	Affected digital inputs may fail low; provided failure voltage is high enough to burn out affected DI points	PLC continues operation. Main processor diagnostics will detect and flag board fault. Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.1.1.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
TERMINATION PANEL-RELATED FAILURES (CONTINUED)					
4) Termination panel for digital outputs: Model 3601T; 115 Vac Model 3603T; 120 Vdc Model 3607E; 48 Vdc Model 3625; 24 Vdc	Open circuit	Fire; flood; missiles; term panel fuse failure	C2a, C2b, C3b	PLC digital outputs will not be affected, but field devices will fail low	PLC continues operation. Condition will not be detected unless: (a) DO point failures triggered alarms associated with measured parameters; or (b) by periodic channel checks or surveillance testing. See Sec. 6.2.1.
5 Termination panel for digital outputs: Model 3601T; 115 Vac Model 3603T; 120 Vdc Model 3607E; 48 Vdc Model 3625; 24 Vdc	Short circuit to ground	Fire; flood; missiles or cable fault; term panel short	C3a, C3b	Affected digital outputs will fail low	PLC continues operation. Condition will be detected by DO module field voltage detection circuit, which will activate the LOAD/FUSE alarm since the commanded DO state will not match the detected field voltage; or by the OVD diagnostic if the failed state matches the current demanded state. See Sec. 6.2.1.
6) Termination panel for digital outputs: Model 3601T; 115 Vac Model 3603T; 120 Vdc Model 3607E; 48 Vdc Model 3625; 24 Vdc	Hot short	Fault in adjacent power cable	C3a	Affected digital outputs may fail low; assuming failure voltage is high enough to burn out affected DO points	PLC continues operation. Main processor diagnostics will detect and flag board fault. Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.2.1.
7) Termination panel for supervised digital outputs: Model 3623T; 120 Vac Model 3625; 24 Vdc	Open circuit	Fire; flood; missiles; term panel fuse failure	C3a, C3b	PLC digital outputs will not be affected, but field devices will fail low	PLC continues operation. Loss of field loops will be detected by SDO circuitry, which will generate a Power Alarm and/or a Load Alarm. See Sec. 6.2.2.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
TERMINATION PANEL-RELATED FAILURES (CONTINUED)					
8) Termination panel for supervised digital outputs: Model 3623T; 120 Vac Model 3625; 24 Vdc	Short circuit to ground	Fire; flood; missiles or cable fault; term panel short	C3a, C3b	Affected digital outputs will fail low	PLC continues operation. Fault will be detected by SDO circuitry, which will generate a Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.2.2.
9) Termination panel for supervised digital outputs: Model 3623T; 120 Vac Model 3625; 24 Vdc	Hot short	Fault in adjacent power cable	C3a	Affected digital outputs may fail low; assuming failure voltage is high enough to burn out affected DO points	PLC continues operation. Fault will be detected by SDO circuitry, which will generate a Fault alarm via Main Chassis Power Module alarm circuit. See Sec. 6.2.2.
10) Termination panel for analog input modules: Model 3701; 0-10 Vdc Model 3703E; 0-5, 0-10 Vdc Model 3704E; 0-5, 0-10 Vdc Model 3721; 0-5/-5 to +5 Vdc Model 3708E, Thermocouple	Open circuit or short circuit to ground	Fire; flood; missiles; term panel fuse failure or short	C3a, C3b	Affected analog inputs will fail low (downscale)	PLC continues operation. Low range diagnostic monitoring alarm (channel violation of allowed tolerance) resulting in board fault alarm. Main processor diagnostics will detect and flag board fault via Main Chassis Power Module alarm circuit. See Sec. 6.1.3.
11) Termination panel for analog input modules: Model 3701; 0-10 Vdc Model 3703E; 0-5, 0-10 Vdc Model 3704E; 0-5, 0-10 Vdc Model 3721; 0-5/-5 to +5 Vdc Model 3708E, Thermocouple	Hot short	Fault in adjacent power cable	C3a	Affected analog inputs may fail high or low (downscale); assuming failure voltage is high enough to burn out affected AI points	PLC continues operation. Low or high range diagnostic monitoring alarm (channel violation of allowed tolerance) resulting in board fault alarm. Main processor diagnostics will detect and flag board fault via Main Chassis Power Module alarm circuit. See Sec. 6.1.3.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
TERMINATION PANEL-RELATED FAILURES (CONTINUED)					
12 Termination panel for analog output module: Model 3805E; 4-20ma	Open circuit	Fire; flood; missiles; term panel fuse failure or short	C3a, C3b	Affected analog output end devices will fail low (downscale)	PLC continues operation. Each analog output module sustains complete ongoing diagnostics for each leg. Failure of any diagnostic on any leg activates the module's Load Indicator, which in turn activates the chassis alarm signal. See Sec. 6.2.4.
13) Termination panel for analog output module: Model 3805E; 4-20ma	Short circuit to ground or hot short	Fault in adjacent power cable	C3a	Affected analog outputs will fail downscale for a short circuit, and may fail low for a hot short; assuming failure voltage is high enough to burn out affected AO points	PLC continues operation. Each analog output module sustains complete ongoing diagnostics for each leg. Failure of any diagnostic on any leg activates the module's Fault Indicator, which in turn activates the chassis alarm signal. See Sec. 6.2.4.
14) Termination panel for relay output module: Model 3636T; Relay Output	Open circuit or short circuit to ground	Fire; flood; missiles; term panel fuse failure or short	C2a, C2b	Affected field loads from relay outputs will fail to the de-energized state	PLC continues operation. Condition will not be detected unless: (a) RO point failures triggered alarms associated with controlled parameters; or (b) by periodic channel checks or surveillance testing. See Sec. 6.2.3.
15) Termination panel for relay output module: Model 3636T; Relay Output	Hot short	Fault in adjacent power cable	C2a, C2b	Affected field loads from relay outputs may fail to the de-energized state; assuming failure voltage is high enough to burn out field devices (application-specific failure).	PLC continues operation. Relay contacts may flash over if failure voltage exceeds maximum specified voltage. See Sec. 6.2.3.

SECTION 8.0 FAILURE MODES AND EFFECTS ANALYSIS FOR TRICON V10.2 TMR PROGRAMMABLE LOGIC CONTROLLER					
Affected Components	**Failure Mode**	**Failure Mechanism**	**Failure Category**	**Effect on PLC Inputs and Outputs**	**Effect on PLC Operability**
TERMINATION PANEL-RELATED FAILURES (CONTINUED)					
16) Termination panel for pulse input module: Model 3511; 8 pulse input	Open circuit or short circuit to ground	Fire; flood; missiles	C2a, C2b, C3b	Affected pulse inputs will fail low	PLC continues operation. Condition will not be detected unless: (a) PI point failures triggered alarms associated with controlled parameters; or (b) by periodic channel checks or surveillance testing. See Sec. 6.1.2.
17) Termination panel for pulse input module: Model 3511; 8 pulse input	Hot short	Fault in adjacent power cable	C2a, C2b, C3a	Affected pulse inputs may fail low; assuming failure voltage is high enough to burn out field devices (application-specific failure).	PLC continues operation. Condition will not be detected unless: (a) PI point failures triggered alarms associated with controlled parameters; or (b) by periodic channel checks or surveillance testing. See Sec. 6.1.2.

EMI/RFI TEST REPORT

Document No: 9600164-527

Revision 3

(02/12)

Prepared by: Frank Kloer

Document Change History			
Revision	**Date**	**Change**	**Preparer**
0	07/20/07	Initial Issue	M. Albers
1	07/26/07	Incorporated results of Triconex Qualification Project Anomaly Report (QPAR) No. 055	M. Albers
2	04/30/08	Added Supplement 1. Revised Reference 9.29 in response to NUPIC audit corrective action (Reference CAR 2528-1).	S. Landas
3	02/12	Reformatted document. Revised Section 8.5 and Table 8-2 to include IEC 61000-4-10 anomalous test results (ARR 962). Corrected typographical error in Section 7.2.5. E07908	F. Kloer

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1.0 EXECUTIVE SUMMARY

The TRICON v10 Nuclear Qualification Project Electromagnetic Interference / Radiofrequency Interference (EMI/RFI) Test was performed on February 16 to April 17, 2007 at National Technical Systems (NTS) Laboratories in Boxborough, Massachusetts. As required by Triconex Document No. 9600164-500, "Master Test Plan," (Reference 9.1), the EMI/RFI Test was executed to demonstrate acceptable performance of the TRICON v10 Programmable Logic Controller (PLC) in accordance with the EMI/RFI criteria specified in U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide (RG) 1.180, Revision 1, "Guidelines for Evaluating Electromagnetic and Radio-Frequency Interference in Safety-Related Instrumentation and Control Systems," (Reference 9.2).

MPR Procedure No. 9600164-510, "EMI/RFI Test Procedure," (Reference 9.3) was developed in accordance with the requirements of NRC RG 1.180 (Reference 9.2), EPRI TR-107330, "Generic Requirements Specification for Qualifying a Commercially Available PLC for Safety-Related Applications in Nuclear Power Plants," (Reference 9.4), Triconex Document No. 9600164-500 (Reference 9.1), and Triconex Document No. 9600164-002, "Nuclear Qualification Quality Plan," (Reference 9.5). The procedure included steps to direct: 1) proper setup of the TRICON-Under-Test (TUT) and test system prior to testing, 2) measurement of EMI/RFI emissions from the TUT components, 3) application of EMI/RFI disturbance signals to the TUT components, 4) acquisition of TUT operational parameters during testing, and 5) evaluation of acceptable TUT performance during testing. The TUT executed a verified and validated Test Specimen Application Program (TSAP) throughout EMI/RFI Testing. The TSAP revision used was "V10_TSAP_REV_0". EMI/RFI Testing was performed by MPR certified Project Test Engineers and witnessed by Triconex Project Quality Assurance.

Triconex Drawing No. 9600164-100, "TRICON v10 Nuclear Qualification Project TRICON-Under-Test, General Arrangement," (Reference 9.6), shows the basic configuration of the TUT components for EMI/RFI Testing. a.

The following EMI/RFI emissions tests were performed in accordance with Department of Defense Interface Standard MIL-STD-461E, "Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment," (Reference 9.7):

- MIL-STD-461E, Test Method CE101, Conducted Emissions, 30 Hz to 10 kHz
- MIL-STD-461E, Test Method CE102, Conducted Emissions, 10 kHz to 2 MHz
- MIL-STD-461E, Test Method RE101, Radiated Emissions, 30 Hz to 100 kHz
- MIL-STD-461E, Test Method RE102, Radiated Emissions, 2 MHz to 1 GHz

The following EMI/RFI susceptibility tests were performed in accordance with the referenced International Electrotechnical Commission (IEC) Standards:

- IEC Standard 61000-4-3, "Electromagnetic Compatibility (EMC), Part 4-3: Testing and Measurement Techniques, Radiated, Radio-Frequency, Electromagnetic Field Immunity Test," (Reference 9.8), 26 MHz to 1 GHz
- IEC Standard 61000-4-6, "Electromagnetic Compatibility (EMC), Part 4-6: Testing and Measurement Techniques, Immunity to Conducted Disturbances, Induced by Radio-Frequency Fields," (Reference 9.9), 150 kHz to 80 MHz
- IEC Standard 61000-4-8, "Electromagnetic Compatibility (EMC), Part 4-8: Testing and Measurement Techniques, Power Frequency Magnetic Field Immunity Test," (Reference 9.10)
- IEC Standard 61000-4-9, "Electromagnetic Compatibility (EMC), Part 4-9: Testing and Measurement Techniques, Pulse Magnetic Field Immunity Test," (Reference 9.11)
- IEC Standard 61000-4-10, "Electromagnetic Compatibility (EMC), Part 4-10: Testing and Measurement Techniques, Damped Oscillatory Magnetic Field Immunity Test," (Reference 9.12)
- IEC Standard 61000-4-13, "Electromagnetic Compatibility (EMC), Part 4-13: Testing and Measurement Techniques, Harmonics and Interharmonics Including Mains Signaling at A.C. Power Port, Low Frequency Immunity Tests," (Reference 9.13)
- IEC Standard 61000-4-16, "Electromagnetic Compatibility (EMC), Part 4-16: Testing and Measurement Techniques, Test for Immunity to Conducted, Common Mode Disturbances in the Frequency Range 0 Hz to 150 kHz," (Reference 9.14)

The EMI/RFI emissions test results demonstrate that the Triconex TRICON v10 PLC does not fully comply with the allowable emissions levels of NRC RG 1.180 (Reference 9.2) for MIL-STD-461E, CE101 and CE102 testing. The Triconex TRICON v10 PLC does fully comply with the allowable emissions levels of NRC RG 1.180 for MIL-STD-461E, RE101 and RE102 testing.

The EMI/RFI susceptibility test results show that the TRICON v10 PLC system complies with the minimum susceptibility levels required by NRC RG 1.180 (Reference 9.2). The main processors continued to function correctly throughout testing. The transfer of input and output data was not interrupted. There were no interruptions or inconsistencies in the operation of the system or the software.

The EMI/RFI susceptibility test results show that the following TRICON v10 PLC input/output hardware does not fully comply with the minimum susceptibility thresholds required by NRC RG 1.180 (Reference 9.2) for the listed susceptibility tests:

IEC Standard 61000-4-3 Testing

- RTD Signal Conditioning Module 1600083-600 (threshold levels determined)
- RTD Signal Conditioning Module 1600083-200 (threshold levels determined)
- RTD Signal Conditioning Module 1600024-030 (threshold levels determined)
- RTD Signal Conditioning Module 1600024-020 (threshold levels determined)

IEC Standard 61000-4-6 Testing

- RTD Signal Conditioning Module 1600081-001 (no threshold levels determined)
- Digital Output Module 3601T (115 VAC) w/ ETP 9663-610N (threshold levels determined)

IEC Standard 61000-4-16 Testing

- Digital Input Module 3503E (24V AC/DC) w/ ETP 9563-810N (threshold levels determined)
- Digital Output Module 3625 (24V DC) w/ ETP 9662-810N (threshold levels determined)
- Digital Output Module 3625 (24V DC) w/ ETP 9662-610N (threshold levels determined)

NOTE: The susceptibility test results given above are contingent on a TRICON v10 PLC installation design that separates and isolates the 24 VDC field power supplies to the discrete and analog input and output module circuits.

The specific TRICON v10 PLC hardware which was tested (chassis, power supplies, modules, external termination assemblies and interconnecting cabling) is identified in Triconex Document No. 9600164-540, "Master Configuration List," (Reference 9.15).

During testing the 3503E Digital Input and 3625 Digital Output modules had shown susceptibilities during IEC 61000-4-16 testing for Conducted Susceptibility, Short Duration Disturbance at 0 Hz (DC). (Specifically, the susceptible points were detected as being on by Trilogger when in fact they were off.) Due to time constraints at the test facility this problem was not investigated during the original qualification testing. Instead, this problem was investigated during supplemental testing in Irvine. The details of this testing are presented in Supplement 1 to this report.

It has been determined that testing performed to IEC 61000-4-10 (Radiated Susceptibility Testing, Pulsed Magnetic Field) by NTS on the Tricon V10 nuclear qualification program was not in full compliance with the standard. Due to test execution anomalies, the results of testing to IEC 61000-4-10 were determined not to be valid. Therefore, compliance with IEC 61000-4-10 is indeterminate.

2.0 PURPOSE

The purpose of this test report is to summarize the results of EMI/RFI Testing of the TRICON v10 Nuclear Qualification Project TRICON-Under-Test (TUT) to meet the requirements of NRC RG 1.180 (Reference 9.2). The format of this test report conforms to Section 8.3.(4) of IEEE Standard 323-1974, "Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations," (Reference 9.16).

Details regarding the performance and results of the EMI/RFI Testing are recorded in the completed MPR Procedure No. 9600164-510, "EMI/RFI Test Procedure," (Reference 9.17). Conclusions from the EMI/RFI Testing are provided in Section 8.0 of this test report.

3.0 TEST OBJECTIVE

NRC RG 1.180 (Reference 9.2) states that EMI/RFI Testing is required to demonstrate compliance with NRC regulations on testing to address the effects of EMI/RFI and power surges on safety-related instrumentation and control systems. Appendix 8 of Triconex Document No. 9600164-500 (Reference 9.1) states that EMI/RFI Testing shall demonstrate acceptable performance of the TRICON v10 Programmable Logic Controller (PLC) in accordance with the EMI/RFI criteria specified in NRC RG 1.180. MPR Procedure No. 9600164-510 (Reference 9.3) states that EMI/RFI Testing shall demonstrate the suitability of the TRICON v10 PLC for qualification as a safety-related device with respect to EMI/RFI emissions and susceptibility levels.

4.0 DESCRIPTION OF TEST SPECIMEN

The equipment tested consists of four TRICON v10 PLC chassis populated with selected main processor, input, output, communication, chassis interface and chassis power supply modules. The tested equipment also includes external termination panels (ETPs) provided for connection of field wiring to the TRICON v10 input and output modules, and interfacing cable assemblies for connection of the ETPs to the TRICON v10 chassis and for interconnection of the TRICON v10 chassis.

Triconex Drawing No. 9600164-100 (Reference 9.6), shows the basic configuration of the TUT components for EMI/RFI Testing. Triconex Drawing No. 9600164-103, "TRICON v10 Nuclear Qualification Project System Block Diagram," (Reference 9.18), shows the general arrangement and interconnection of the TUT chassis. Triconex Document No. 9600164-541, "TRICON v10 Nuclear Qualification Project, System Description," (Reference 9.19), provides an overview and description of the TUT and test system. A detailed identification of the tested equipment is provided in Triconex Document No. 9600164-540 (Reference 9.15).

During testing, the TUT was executing a Test Specimen Application Program (the TSAP) developed specifically for the qualification project and designed to support the test procedures, which demonstrate the functionality of the TUT during all phases of qualification testing. Requirements for operation of the TSAP are defined in Triconex Document No. 9600164-517, "Test Specimen Application Program (TSAP) Software Requirements Specification (SRS)," (Reference 9.20). The completed MPR Procedure No. 9600164-510 (Reference 9.17) identifies the TSAP revision used during this testing as "V10_TSAP_REV_0". Triconex Document No. 9600164-540 (Reference 9.15) identifies the revision level of all TUT firmware.

5.0 TEST SETUP AND INSTRUMENTATION

The following sections describe the setup of the TUT during EMI/RFI Testing, the instrumentation used to generate and measure the applied EMI/RFI test conditions, and the instrumentation used to measure TUT performance during and after testing. The TUT setup is documented in the completed MPR Procedure No. 9600164-510 (Reference 9.17). Specifications for test instrumentation supplied by NTS Laboratories are included in NTS Test Procedure No. TP62987-07N-EMI, "Test Procedure for EMI/RFI Testing of the TRICON v10 Nuclear Qualification Project TRICON-Under-Test," (Reference 9.21).

5.1 TRICON-Under-Test Mounting

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5.2 TRICON-Under-Test Chassis and Module Configuration

Section 4.0 above describes the general arrangement of the TUT which was maintained throughout all of the qualification testing. Chassis configurations for EMI/RFI Testing are documented in Triconex Document No. 9600164-540 (Reference 9.15).

5.3 TRICON-Under-Test Power Supply and Wiring Configuration

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NRC RG 1.180 (Reference 9.2) does not include specific requirements for configuration of equipment power supplies or wiring during EMI/RFI Testing.

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5.4 NTS Instrumentation

NTS provided the test instrumentation for generating, applying, and monitoring the EMI/RFI Test signals. NTS also provided instrumentation for measuring temperature and relative humidity inside the anechoic test chamber during EMI/RFI Testing. These instruments are identified in NTS Test Report No. TR62987-07N-EMI (Reference 9.29).

5.5 Triconex and MPR Instrumentation

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Details on the identification, configuration and calibration of the test instrumentation described above are included in the completed MPR Procedure No. 9600164-510 (Reference 9.17), and the completed Pre-EMI/RFI Testing Run No. 3.6 of Triconex Procedure No. 9600164-502, "System Setup and Checkout Procedure," (Reference 9.31).

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5.6 Instrument Calibration

All tests were performed using calibrated test instruments. Calibration certifications are held by NTS, MPR and Triconex. NTS Test Report No. TR62987-07N-EMI (Reference 9.29) documents the calibration status of the test instrumentation used by NTS. The completed MPR Procedure No. 9600164-510 (Reference 9.17) documents the calibration status of the test instrumentation used by MPR. The completed Triconex Procedure No. 9600164-502 (Reference 9.31) documents the calibration status of the test instrumentation used by Triconex.

6.0 TEST PROCEDURES

EMI/RFI Testing of the TUT was performed to the requirements of Sections 3 and 4 of NRC RG 1.180 (Reference 9.2). Section 3 of NRC RG 1.180 addresses EMI/RFI emissions testing. Section 4 of NRC RG 1.180 addresses EMI/RFI susceptibility testing. Each section endorses both Military Standard MIL-STD-461E series and IEC 61000 series EMI/RFI test methods. The qualifier has the option to use either series of test methods, although NRC RG 1.180 stipulates that for emissions or susceptibility testing, the chosen series of test methods must be applied in its entirety (i.e., there should be no selective application or mixing of the MIL-STD and IEC test methods).

EMI/RFI emissions testing of the TUT included both radiated and conducted emissions testing done to the MIL-STD-461E series test methods (Reference 9.7) specified in Section 3 of NRC RG 1.180 (Reference 9.2). EMI/RFI susceptibility testing of the TUT included both radiated and conducted susceptibility testing done to the IEC 61000 series test methods (References 9.8 through 9.14) specified in Section 4 of NRC RG 1.180, Rev. 1 (Reference 9.2).

The following sections describe the approach to satisfying the requirements of the referenced documents for EMI/RFI Testing of the TUT. The test procedure used by NTS to perform EMI/RFI Testing of the TUT is NTS Test Procedure No. TP62987-07N-EMI (Reference 9.21). The test procedure used by MPR to perform EMI/RFI Testing of the TUT is MPR Procedure No. 9600164-510 (Reference 9.3).

6.1 Test Sequence

Figure 2 of Triconex Document No. 9600164-500 (Reference 9.1) shows the sequence of qualification testing performed on the TUT. In accordance with the test sequence shown in Figure 2, EMI/RFI Testing was performed after Radiation Exposure, Environmental, and Seismic Testing, and prior to Electrical Fast Transient Testing, Surge Withstand, Electrostatic Discharge and Class 1E to Non-1E Isolation Testing.

6.2 Test Method

Section 3 of NRC RG 1.180 (Reference 9.2) includes the requirements for EMI/RFI emissions testing of safety-related instrumentation and control (I&C) systems. EMI/RFI emissions testing of the TUT included both radiated and conducted emissions testing done to the following MIL-STD-461E series test methods (Reference 9.7):

- MIL-STD-461E, Test Method CE101, Conducted Emissions, Low Frequency (30 Hz to 10 kHz), AC and DC Power Leads
- MIL-STD-461E, Test Method CE102, Conducted Emissions, High Frequency (10 kHz to 2 MHz), AC and DC Power Leads
- MIL-STD-461E, Test Method RE101, Radiated Emissions, Magnetic Field (30 Hz to 100 kHz), TUT Surfaces and Leads
- MIL-STD-461E, Test Method RE102, Radiated Emissions, Electric Field (2 MHz to 1 GHz), Antenna Measurement

Section 4 of NRC RG 1.180 (Reference 9.2) includes the requirements for EMI/RFI susceptibility testing of safety-related instrumentation and control (I&C) systems. EMI/RFI susceptibility testing of the TUT included both radiated and conducted testing done to the following IEC series test methods:

- IEC Standard 61000-4-3, Radiated Susceptibility, High Frequency (26 MHz to 1 GHz), Antenna Exposure (Reference 9.8)
- IEC Standard 61000-4-6, Conducted Susceptibility, Radio Frequency (150 kHz to 80 MHz), Power and Signal Leads (Reference 9.9)
- IEC Standard 61000-4-8, Radiated Susceptibility, Power Line Frequency (60 Hz) Magnetic Field, Helmholtz Coil Exposure (Reference 9.10)
- IEC Standard 61000-4-9, Radiated Susceptibility, Pulsed Magnetic Field, Helmholtz Coil Exposure (Reference 9.11)
- IEC Standard 61000-4-10, Radiated Susceptibility, Damped Oscillatory Magnetic Field (100 kHz and 1 MHz), Helmholtz Coil Exposure (Reference 9.12)
- IEC Standard 61000-4-13, Conducted Susceptibility, Harmonics and Interharmonics (16 Hz to 2.4 kHz), Power Leads (Reference 9.13)
- IEC Standard 61000-4-16, Conducted Susceptibility, Common-Mode Disturbances (15 Hz to 150 kHz), Power and Signal Leads (Reference 9.14)

6.3 Test Levels

The following lists the EMI/RFI Testing emissions acceptance levels and applied susceptibility test levels from the applicable figures and tables of NRC RG 1.180 (Reference 9.2).

EMI/RFI Emissions Test Method	NRC RG 1.180, Rev. 1 Acceptance Level
MIL-STD-461E, CE101	Figure 3.1
MIL-STD-461E, CE102	Figure 3.2

MIL-STD-461E, RE101	Figure 3.3
MIL-STD-461E, RE102	Figure 3.4

EMI/RFI Susceptibility Test Method	NRC RG 1.180, Rev. 1 Test Level	
IEC Standard 61000-4-3	Sect. 4.3.3:	10 V/m
IEC Standard 61000-4-6	Sect. 4.1.2:	Power Leads, 140 dBμV
IEC Standard 61000-4-6	Table 15:	Signal Leads, 130 dBμV
IEC Standard 61000-4-8	Table 19:	Continuous, 30 A/m
IEC Standard 61000-4-8	Table 19:	Short Duration, 300 A/m
IEC Standard 61000-4-9	Table 19:	300 A/m
IEC Standard 61000-4-10	Table 19:	30 A/m
IEC Standard 61000-4-13	Table 10:	See Table 10
IEC Standard 61000-4-16	Table 11:	Power Leads, See Table 11
IEC Standard 61000-4-16	Table 11:	Signal Leads: 3/10 of Power Leads

6.4 TRICON-Under-Test Operation

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6.5 TRICON-Under-Test Performance Monitoring

Appendix 7 of Triconex Document No. 9600164-500 (Reference 9.1) and Section 6.6 of this test report list the EMI/RFI Test acceptance criteria. Appendix 7 states that monitoring of normal TUT operation during EMI/RFI Testing will demonstrate satisfaction of the acceptance criteria. In order to clarify the definition of normal operation, Appendix 7 provides the following additional EMI/RFI Testing acceptance criteria adapted from Section 4.3.7 of EPRI TR-107330 (Reference 9.4):

i.) The main processors shall continue to function.
ii.) The transfer of I/O data shall not be permanently interrupted.
iii.) The applied EMI/RFI disturbances shall not cause the discrete I/O to change state.

iv.) Analog I/O levels shall not vary more than 3% (of full scale).

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EPRI TR-107330 (Reference 9.4) requires that a portion of the Operability and Prudency Tests (as defined in the TR) be performed during EMI/RFI Testing.

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6.6 Test Acceptance Criteria

The following EMI/RFI Test acceptance criteria are as given in Appendix 7 of Triconex Document No. 9600164-500 (Reference 9.1), and Section 4.3.7 of EPRI TR-107330 (Reference 9.4).

a) The TUT shall meet allowable equipment emission limits as specified in Section 3 of NRC RG 1.180 (Reference 9.2) for the following MIL-STD-461E Emissions Test Methods:

CE101 – Conducted Emissions, 30 Hz to 10 kHz (NRC RG 1.180, Figure 3.1)
CE102 – Conducted Emissions, 10 kHz to 2 MHz (NRC RG 1.180, Figure 3.2)
RE101 – Radiated Emissions, 30 Hz to 100 kHz (NRC RG 1.180, Figure 3.3)
RE102 – Radiated Emissions, 2 MHz to 1 GHz (NRC RG 1.180, Figure 3.4)

b) The TUT shall operate as intended during and after application of the EMI/RFI test levels specified in Section 4 of NRC RG 1.180 (Reference 9.2) for the following IEC Standard Susceptibility Test Methods:

IEC 61000-4-3 – Radiated Susceptibility, High Frequency, 26 MHz to 1 GHz
IEC 61000-4-6 – Conducted Susceptibility, Radio Frequency, 150 kHz to 80 MHz
IEC 61000-4-8 – Radiated Susceptibility, Magnetic Field, 60 Hz
IEC 61000-4-9 – Radiated Susceptibility, Pulsed Magnetic Field
IEC 61000-4-10 – Radiated Susceptibility, Damped Magnetic Field, 100 kHz and 1 MHz
IEC 61000-4-13 – Conducted Susceptibility, Harmonics/Interharmonics, 16 Hz to 2.4 kHz
IEC 61000-4-16 – Conducted Susceptibility, Common Mode Disturb., 15 Hz to 150 kHz

Evaluation of normal operating performance data (inputs, outputs and diagnostic indicators) shall demonstrate operation as intended, including the following specific operational performance from Section 4.3.7 of EPRI TR-107330 (Reference 9.4):

i.) The main processors shall continue to function.
ii.) The transfer of I/O data shall not be interrupted.
iii.) The emissions shall not cause the discrete I/O to change state.
iv.) Analog I/O levels shall not vary more than 3%.

7.0 TEST RESULTS

This section summarizes the results of EMI/RFI Testing of the TUT. This section also discusses performance or data anomalies which were observed or recorded during the testing.

7.1 EMI/RFI Test Setup and Checkout Testing

Triconex Procedure No. 9600164-502, "System Setup and Checkout Procedure," (Reference 9.32) directs setup of the TUT for the different qualification tests to be performed, and verifies proper operation of the TUT and test system prior to start of testing. EMI/RFI Testing of the TUT was performed following Seismic Testing and upon completion of the Pre-EMI/RFI Testing Run No. 3.6 of Triconex Procedure No. 9600164-502 (Reference 9.31). Results of Reference 9.31 show that the system was operating correctly prior to start of EMI/RFI Testing.

7.2 EMI/RFI Testing

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7.2.1 Conducted Emissions from 30 Hz to 10 kHz (MIL-STD-461E, CE101)

Conducted emissions measurements were recorded on the TUT chassis power supply leads using the methodology defined in MIL-STD-461E, CE101 (Reference 9.7). The chassis power supply lead emissions were measured and recorded from 30 Hz to 10 kHz. Emission measurements were recorded on the 120 VAC chassis power supply line and neutral leads, the 230 VAC chassis power supply line and neutral leads, the 24 VDC chassis power supply high and low side leads, and the test system power supply ground lead (which was common to the 120 VAC, 230 VAC and 24 VDC chassis power supply circuits). The test system power supply cabling was arranged such that each lead test measured the emissions from all of the specified chassis power supply types included in the four TUT chassis.

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The recorded CE101 conducted emissions data for the TUT chassis power supplies are included in NTS Test Report No. TR62987-07N-EMI (Reference 9.29). The data show that the TRICON v10 PLC does not fully comply with the allowable equipment emission levels shown in Figure 3.1 of NRC RG 1.180 (Reference 9.2). Specifically, the following non-compliances were noted:

a) 120 VAC Chassis Power Supply Line Lead. Conducted emission limits exceeded at:

179.7 Hz by 11.2 dBμA	538.8 Hz by 8.9 dBμA
299.8 Hz by 13.8 dBμA	659.7 Hz by 2.1 dBμA
419.7 Hz by 13.0 dBμA	899.6 Hz by 1.5 dBμA

b) 120 VAC Chassis Power Supply Neutral Lead. Conducted emission limits exceeded at:

179.9 Hz by 11.0 dBμA	539.7 Hz by 9.6 dBμA
299.8 Hz by 14.9 dBμA	659.9 Hz by 2.8 dBμA
419.3 Hz by 13.1 dBμA	

c) 230 VAC Chassis Power Supply Line Lead. Conducted emission limits exceeded at:

179.9 Hz by 4.0 dBμA	539.7 Hz by 7.6 dBμA
299.8 Hz by 8.3 dBμA	659.7 Hz by 6.0 dBμA

419.7 Hz by 8.7 dBµA	779.6 Hz by 1.7 dBµA

d) 230 VAC Chassis Power Supply Neutral Lead. Conducted emission limits exceeded at:

179.9 Hz by 3.8 dBµA	539.7 Hz by 7.5 dBµA
299.8 Hz by 8.2 dBµA	659.7 Hz by 5.9 dBµA
419.7 Hz by 8.6 dBµA	779.6 Hz by 1.6 dBµA

7.2.2 Conducted Emissions from 10 kHz to 2 MHz (CE102)

Conducted emissions measurements were recorded on the TUT chassis power supply leads using the methodology defined in MIL-STD-461E, CE102 (Reference 9.7). The chassis power supply lead emissions were measured and recorded from 10 kHz to 2 MHz. Emission measurements were recorded on the 120 VAC chassis power supply line and neutral leads, the 230 VAC chassis power supply line and neutral leads, the 24 VDC chassis power supply high and low side leads, and the test system power supply ground lead (which was common to the 120 VAC, 230 VAC and 24 VDC chassis power supply circuits). The test system power supply cabling was arranged such that each lead test measured the emissions from all of the specified chassis power supply types included in the four TUT chassis.

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7.2.3 Radiated Magnetic Field Emissions from 30 Hz to 100 kHz (RE101)

The TUT radiated magnetic field emissions were measured and recorded using the methodology defined in MIL-STD-461E, RE101 (Reference 9.7). The radiated magnetic field emissions were recorded from 30 Hz to 100 kHz. Loop antenna were used to take measurements of the magnetic field emissions from all six faces (front, back, right, left, top and bottom) of the hardware mounted in each of Cabinets 1 and 2. Measurements were also taken along the length of each of the four chassis power supply cable bundles, the peripheral communication cable bundle, the analog input and output signal cable bundle, the RTD/Thermocouple/Pulse Input signal cable bundle, the discrete input and output signal cable bundle, and the ETP power supply cable bundle.

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The recorded RE101 magnetic field emissions data for the TUT are included in NTS Test Report No. TR62987-07N-EMI (Reference 9.29). The data show that the TRICON v10 PLC fully complies with the allowable equipment emissions level shown in Figure 3.3 of NRC RG 1.180 (Reference 9.2).

7.2.4 Radiated Electric Field Emissions from 2 MHz to 1 GHz (RE102)

The TUT radiated electric field emissions were measured and recorded using the methodology defined in MIL-STD-461E, RE102 (Reference 9.7). The radiated electric field emissions were recorded from 2 MHz to 1 GHz. Vertically and horizontally oriented receiving antenna were used to take measurements of the electric field emissions from both the front and rear faces of the hardware mounted in each of Cabinets 1 and 2.

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The recorded RE102 electric field emissions data for the TUT are included in NTS Test Report No. TR62987-07N-EMI (Reference 9.29). The data show that the TRICON v10 PLC fully complies with the allowable equipment emissions level shown in Figure 3.4 of NRC RG 1.180 (Reference 9.2).

7.2.5 Radio Frequency Conducted Susceptibility from 150 kHz to 80 MHz (IEC Standard 61000-4-6)

The susceptibility of the TUT to electromagnetic disturbances coming from intended radio frequency transmitters was tested over the frequency range of 150 kHz to 80 MHz. The test was conducted in accordance with the methodology defined in IEC Standard 61000-4-6 (Reference 9.9).

Tests of the 120 VAC and 230 VAC chassis power supplies were performed using coupling transformers connected to the power supply line, neutral and ground leads. Tests of the 24 VDC chassis power supplies were performed using a coupling transformer connected to the power supply high side, low side and ground leads. The test system power supply cabling was arranged such that each test injected the electromagnetic disturbances onto all of the specified chassis power supply types included in the four TUT chassis. Section 4.1.3 of NRC RG 1.180 (Reference 9.2) gives the susceptibility amplitude level acceptance criteria for IEC Standard 61000-4-6 testing of power supply leads as 140 dBμV.

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The TUT successfully passed the IEC Standard 61000-4-6 tests. There were no interruptions or inconsistencies in the operation of the system or software. However, based on the recorded Trilogger/TriStation Console data, the hardware combination of the Model 3721 analog input module, the Model 9764-310N RTD external termination panel (ETP) and the Model 7B14-C-02-1 RTD signal conditioning module (Triconex Part No. 1600081-001, 0 to 120°C, Cu) showed susceptibilities during testing. The internal TUT variable representing the signal monitored by this hardware did not agree with the expected values to within ± 3% full scale.

The susceptibilities occurred during the following tests:

- 120 VAC Chassis Power Supplies: 11.0 to 11.5 MHz at 140 dBμV
- 230 VAC Chassis Power Supplies: Unrecorded Frequencies at 140 dBμV
- 24 VAC Chassis Power Supplies: 7.0 to 7.2 MHz at 140 dBμV
- 24 VAC Chassis Power Supplies: 11.4 to 12.2 MHz at 140 dBμV
- Peripheral Communication Cable Bundle: 12 MHz at 130 dBμV
- ETP Power Supply Cable Bundle: 7.3 to 8.4 MHz at 130 dBμV
- Analog Input/Output Signal Cable Bundle: 7.3 to 7.6 MHz at 130 dBμV
- RTD, T/C and Pulse Input Signal Cable Bundle: 5.8 to 6.6 MHz at 130 dBμV

During testing, the Trilogger/TriStation Console monitored seven additional RTD input points through the Model 3721 analog input module and the Model 9764-310N RTD ETP combination. None of these points showed any susceptibilities throughout IEC Standard 61000-4-6 testing. Therefore, it is concluded that the Model 3721 analog input module and the Model 9764-310N RTD ETP are not susceptible to IEC Standard 61000-4-6 testing, but that the Model 7B14-C-02-1 RTD signal conditioning module is susceptible to IEC Standard 61000-4-6 testing. Additional testing was not performed to establish susceptibility threshold levels for the Model 7B14-C-02-1 RTD signal conditioning module.

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7.2.6 Harmonic and Interharmonic Conducted Susceptibility (IEC Standard 61000-4-13)

The susceptibility of the TUT to harmonic and interharmonic electromagnetic disturbance voltages coupled onto the 60 Hz AC power input power lines (120 VAC and 230 VAC) was tested over a coupled signal frequency range of 16 Hz to 2.4 kHz. The test was conducted in accordance with the methodology defined in IEC Standard 61000-4-13 (Reference 9.13). a

The TUT successfully passed the IEC Standard 61000-4-13 tests. There were no interruptions or inconsistencies in the operation of the system or software. None of the chassis power supply modules, main processor modules, RXM modules, peripheral communication modules, or input/output modules exhibited any susceptibilities to the applied harmonic and interharmonic electromagnetic disturbance voltages. NTS Test Report No. TR62987-07N-EMI (Reference 9.29) and the completed MPR Procedure No. 9600164-510 (Reference 9.17) provide more details on performance of the IEC Standard 61000-4-13 tests and evaluation of the TUT normal operating performance data recorded during the tests.

7.2.7 Common-Mode Disturbance Conducted Susceptibility from 15 Hz to 150 kHz (IEC Standard 61000-4-16)

The susceptibility of the TUT to conducted, common-mode electromagnetic disturbances from sources such as power line currents and ground system return leakage currents was tested over the frequency range of 15 Hz to 150 kHz. The test was conducted in accordance with the methodology defined in IEC Standard 61000-4-16 (Reference 9.14).

The electromagnetic disturbance signals were coupled onto the TUT chassis power supply leads and the interconnecting signal leads. In accordance with Section 4.1.3 and Table 11 of NRC RG 1.180 (Reference 9.2), IEC Standard 61000-4-16 susceptibility testing of the TUT power supplies included:

24 VDC Power Supply:

- Continuous Disturbance at 0 Hz (DC) applied for at least 60 seconds
- Short Duration Disturbance at 0 Hz (DC) applied at the test level voltage for one second, repeated multiple times during a 60 second interval
- Conducted Disturbance applied as a frequency sweep from 15 Hz to 150 kHz

120 VAC and 230 VAC Power Supplies:

- Continuous Disturbance at 0 Hz (DC) applied for at least 60 seconds
- Short Duration Disturbance at 0 Hz (DC) applied at the test level voltage for one second, repeated multiple times during a 60 second interval
- Continuous Disturbance at 60 Hz applied for at least 60 seconds
- Short Duration Disturbance at 60 Hz applied at the test level voltage for one second, repeated multiple times during a 60 second interval
- Conducted Disturbance applied as a frequency sweep from 15 Hz to 150 kHz

In accordance with Section 4.2 and Table 13 of NRC RG 1.180, IEC Standard 61000-4-16 susceptibility testing of the TUT interconnecting signal leads included:

24 VDC DI/DO, 48 VDC DI/DO, 120 VDC DI/DO, AI, AO and Communication Interfaces:

- Continuous Disturbance at 0 Hz (DC) applied for at least 60 seconds
- Short Duration Disturbance at 0 Hz (DC) applied at the test level voltage for one second, repeated multiple times during a 60 second interval
- Conducted Disturbance applied as a frequency sweep from 15 Hz to 150 kHz

120 VAC DI/DO:

- Continuous Disturbance at 0 Hz (DC) applied for at least 60 seconds
- Short Duration Disturbance at 0 Hz (DC) applied at the test level voltage for one second, repeated multiple times during a 60 second interval
- Continuous Disturbance at 60 Hz applied for at least 60 seconds
- Short Duration Disturbance at 60 Hz applied at the test level voltage for one second, repeated multiple times during a 60 second interval
- Conducted Disturbance applied as a frequency sweep from 15 Hz to 150 kHz

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Section 4.1.3 and Table 11 of NRC RG 1.180 specify Level 3 conducted disturbances for IEC Standard 61000-4-16 testing of power leads. From Table 11, the applied continuous DC and 60 Hz disturbance test levels were 10 Vrms. The applied short-duration DC and 60 Hz disturbance test levels were 100 Vrms. The applied frequency sweep disturbance test levels varied according to the test level specification given in Table 11.

Section 4.2 and Table 15 of NRC RG 1.180 specify Level 2 conducted disturbances for IEC Standard 61000-4-16 testing of interconnecting signal leads. From Table 15, the applied continuous DC and 60 Hz disturbance test levels were 3 Vrms. The applied short-duration DC and 60 Hz disturbance test levels were 30 Vrms. The applied frequency sweep disturbance test levels were 3/10 of the values specified in Table 11.

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NTS Test Report No. TR62987-07N-EMI (Reference 9.29) and the completed MPR Procedure No. 9600164-510 (Reference 9.17) provide more details on performance of the IEC Standard 61000-4-16 tests and evaluation of the TUT normal operating performance data recorded during the tests.

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Table 7.1: Summary of IEC Standard 61000-4-16 Final Test Results

7.2.8 Power Line Frequency Magnetic Field Radiated Susceptibility (IEC Standard 61000-4-8)

The susceptibility of the TUT to power line frequency (60 Hz) radiated magnetic fields was tested. The test was conducted in accordance with the methodology defined in IEC Standard 61000-4-8 (Reference 9.10). The test field was applied through an induction coil placed around the TUT in different orientations covering three orthogonal directions (front-to-back, side-to-side, and top-to-bottom). Each of the two TUT cabinets was tested separately. NTS personnel concluded that one coil placement per orthogonal direction was sufficient to ensure complete immersion of the TUT. For each induction coil placement, the TUT was exposed to a continuously applied magnetic field for approximately 5 minutes, and to a pulsed magnetic field (10 seconds on, 10 seconds off) for approximately 2 minutes. The test durations were selected to both meet the criteria of IEC Standard 61000-4-8 and to provide sufficient time for potential TUT susceptibilities to be reflected in the monitored normal operating data.

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Table 19 of NRC RG 1.180 (Reference 9.2) lists the required IEC Standard 61000-4-8 test levels for Class 4 environments for both continuous and short duration power line frequency magnetic field exposures. The applied test levels were 30 A/m (152 dBpT) for continuous exposures and 300 A/m (172 dBpT) for short duration (pulsed) exposures.

The TUT successfully passed the IEC Standard 61000-4-8 tests. There were no interruptions or inconsistencies in the operation of the system or software. None of the chassis power supply modules, main processor modules, RXM modules, peripheral communication modules, or input/output modules exhibited any susceptibilities to the applied magnetic fields. NTS Test Report No. TR62987-07N-EMI (Reference 9.29) and the completed MPR Procedure No. 9600164-510 (Reference 9.17) provide more details on performance of the IEC Standard 61000-4-8 tests and evaluation of the TUT normal operating performance data recorded during the tests.

7.2.9 Pulsed Magnetic Field Radiated Susceptibility, 100 kHz and 1 MHz (IEC Standard 61000-4-9)

The susceptibility of the TUT to 100 kHz and 1 MHz pulsed magnetic fields was tested. The test was conducted in accordance with the methodology defined in IEC Standard 61000-4-9 (Reference test field was applied through an induction coil placed around the TUT in different orientations covering three orthogonal directions (front-to-back, side-to-side, and top-to-bottom). Each of the two TUT cabinets was tested separately. NTS personnel concluded that one coil placement per orthogonal direction was sufficient to ensure complete immersion of the TUT. For each induction coil placement, the TUT was exposed to 5 positive polarity magnetic field pulses and 5 negative polarity magnetic field pulses. The time interval between pulses was no less than 10 seconds.

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Table 19 of NRC RG 1.180 (reference 9.2) lists the required IEC Standard 61000-4-9 test level for Class 4 environments for 100 kHz and 1 MHz pulsed magnetic field exposures. The applied test level was 300 A/m (172 dBpT) for both 100 kHz and 1 MHz pulsed magnetic field exposures.

The TUT successfully passed the IEC Standard 61000-4-9 tests. There were no interruptions or inconsistencies in the operation of the system or software. None of the chassis power supply modules, main processor modules, RXM modules, peripheral communication modules, or input/output modules exhibited any susceptibilities to the applied magnetic fields. NTS Test Report No. TR62987-07N-EMI (Reference 9.29) and the completed MPR Procedure No. 9600164-510 (Reference 9.17) provide more details on performance of the IEC Standard 61000-4-9 tests and evaluation of the TUT normal operating performance data recorded during the tests.

7.2.10 Damped Oscillatory Magnetic Field Radiated Susceptibility, 100 kHz and 1 MHz (IEC Standard 61000-4-10)

The susceptibility of the TUT to 100 kHz and 1 MHz damped oscillatory magnetic fields was tested. The test was conducted in accordance with the methodology defined in IEC Standard 61000-4-10 (Reference 9.12). The test field was applied through an induction coil placed around the TUT in different orientations covering three orthogonal directions (front-to-back, side-to-side, and top-to-bottom). Each of the two TUT cabinets was tested separately. NTS personnel concluded that one coil placement per orthogonal direction was sufficient to ensure complete immersion of the TUT. For each induction coil placement, the TUT was exposed to the 100 kHz damped oscillatory magnetic field for 5 minutes at a repetition rate

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Section 4.3.3 of NRC RG 1.180 (Reference 9.2) lists the required IEC Standard 61000-4-3 test level for Level 3 environments for 26 MHz to 1 GHz radiated electromagnetic field exposures. The applied test level was 10 V/m.

The TUT successfully passed the IEC Standard 61000-4-3 tests. There were no interruptions or inconsistencies in the operation of the system or software. However, based on the recorded Trilogger/TriStation Console data, the hardware combination of the Model 3721 analog input module, the Model 9764-310N RTD external termination panel (ETP) and the following RTD signal conditioning modules (which are plugged into the Model 9764-310N ETP) showed susceptibilities during testing. The internal TUT variables representing the signals monitored by these signal conditioning modules did not agree with the expected values to within ± 3% full scale.

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7.3 Post-EMI/RFI Operability and Prudency Tests

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Section 5.5 of EPRI TR-107330 (Reference 9.4) requires Operability and Prudency testing to be performed during EMI/RFI Testing.

As reported by Triconex, the completed Performance Proof Test Run No. 3.7 of Triconex Procedure No. 9600164-503, "Operability Test Procedure," (Reference 9.38) and the completed Performance Proof Test Run No. 3.4 of Triconex Procedure No. 9600164-504, "Prudency Test Procedure," (Reference 9.39) performed at the completion of all qualification testing demonstrate acceptable system performance following EMI/RFI Testing.

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8.0 CONCLUSIONS

8.1 Test Methodology

EMI/RFI Testing of the TUT was performed in accordance with the applicable requirements of NRC RG 1.180 (Reference 9.2). The following EMI/RFI Tests were performed on the TUT:

- Radiated Magnetic Field Emissions from 30 Hz to 100 kHz (MIL-STD-461E, RE101)
- Radiated Electric Field Emissions from 2 MHz to 1 GHz (MIL-STD-461E, RE102)

- Low Frequency Conducted Emissions from 30 Hz to 10 kHz (MIL-STD-461E, CE101)
- High Frequency Cond. Emissions from 10 kHz to 2 MHz (MIL-STD-461E, CE102)
- High Frequency Radiated Susceptibility from 26 MHz to 1 GHz (IEC 61000-4-3)
- Radio Frequency Conducted Susceptibility from150 kHz to 80 MHz (IEC 61000-4-6)
- Magnetic Field Radiated Susceptibility at 60 Hz (IEC 61000-4-8)
- Pulsed Magnetic Field Radiated Susceptibility (IEC 61000-4-9)
- Damped Magnetic Field Radiated Suscept. at 100 kHz and 1 MHz (IEC 61000-4-10)
- Harmonics and Interharmonics Conducted Susceptibility (IEC 61000-4-13)
- Common Mode Disturb. Conducted Suscept., 15 Hz to 150 kHz (IEC 61000-4-16)

The specific TRICON v10 PLC hardware which was tested (chassis, power supplies, modules, external termination assemblies and interconnecting cabling) is identified in Triconex Document No. 9600164-540 (Reference 9.15).

Section 5.5 of EPRI TR-107330 (Reference 9.4) requires Operability and Prudency testing to be performed during EMI/RFI Testing. The test system as configured for EMI/RFI Testing did not support Operability or Prudency Testing (see Section 6.5 of this test report). The normal operating performance data recorded during EMI/RFI Testing demonstrates system performance during EMI/RFI exposure.

8.2 Emissions Testing

a. The TUT fully complies with the allowable equipment emissions levels defined in NRC RG 1.180 (Reference 9.2) for MIL-STD-461E, RE101 and RE102 testing.

b. The TUT does not fully comply with the allowable equipment emissions levels defined in NRC RG 1.180 (Reference 9.2) for MIL-STD-461E, CE101 and CE102 testing. Sections 7.2.1 and 7.2.2 of this test report provide a detailed description of the non-compliances in emissions which were measured during CE101 and CE102 testing.

   An understanding of the electromagnetic emissions from a device is necessary to minimize the potential for the device to adversely affect the operation of other equipment that is physically located near the device, shares common electrical connections with it, or has wires or cables routed in close proximity to it. Therefore, prior to installing the TRICON v10 PLC in a nuclear safety-related or non-safety related application, an evaluation of the device emission levels should be made to determine whether the emission levels are acceptable for the planned application, or if mitigating actions would be required. The TRICON v10 PLC EMI/RFI emissions testing documented in this report provides the data required to perform such an evaluation. The TRICON v10 PLC was tested without the benefit of a secondary enclosure, additional cable and wire shielding, or installed power line filtering. Mitigating actions to address the non-compliances in measured emission levels would likely incorporate these common in-plant installation features.

8.3 Susceptibility Testing

NOTE: The following susceptibility test results are contingent on a TRICON v10 PLC installation design that separates and isolates the 24 VDC field power supplies to the discrete and analog input and output module circuits.

a. The TUT successfully passed all of the EMI/RFI susceptibility tests listed in Section 8.1. The main processors continued to function correctly throughout testing. The transfer of input and output data was not interrupted. There were no interruptions or inconsistencies in the operation of the system or the software.

b. The TUT main processor, chassis power supply, remote extender, and communication modules fully comply with the minimum susceptibility thresholds required by NRC RG 1.180 (Reference 9.2) for all of the EMI/RFI susceptibility tests listed in Section 8.1.

c. The EMI/RFI susceptibility test results show that the following TUT discrete and analog input/output hardware does not fully comply with the minimum susceptibility thresholds required by NRC RG 1.180 (Reference 9.2) for the EMI/RFI susceptibility tests listed in Section 8.1:

IEC Standard 61000-4-3 Testing

- RTD Signal Conditioning Module 1600083-600
- RTD Signal Conditioning Module 1600083-200
- RTD Signal Conditioning Module 1600024-030
- RTD Signal Conditioning Module 1600024-020

IEC Standard 61000-4-6 Testing

- RTD Signal Conditioning Module 1600081-001
- Digital Output Module 3601T (115 VAC) w/ ETP 9663-610N

IEC Standard 61000-4-16 Testing

- Digital Input Module 3503E (24V AC/DC) w/ ETP 9563-810N
- Digital Output Module 3625 (24V DC) w/ ETP 9662-810N
- Digital Output Module 3625 (24V DC) w/ ETP 9662-610N

Sections 7.2.5, 7.2.7 and 7.2.11 of this test report provide a detailed description of the module susceptibilities which were measured during each of the tests listed above, and the results of threshold testing which was performed. Module susceptibilities included spurious changes in the state of the discrete inputs and outputs, and variations in RTD input levels of greater than ± 3% of the expected levels.

d. An understanding of the electromagnetic susceptibility of a device is necessary to ensure that its operation will not be adversely affected by EMI/RFI levels already present or permitted in the area where the device will be located. Therefore, prior to installing the TRICON v10 PLC in a nuclear safety-related application, an evaluation of the input, output and communication module susceptibilities should be performed. An evaluation of the module susceptibilities should also be performed for non-safety related applications if there is a potential for the PLC to impact plant reliability and availability. The TRICON v10 PLC EMI/RFI susceptibility testing documented in this test report provides the data required to perform such an evaluation.

   To address the impact of the TRICON v10 PLC input and output module EMI/RFI susceptibilities for a specific plant application, one or more of the following approaches may be pursued:

   i. Demonstrate that the EMI/RFI levels at which the PLC modules are susceptible are not credible threats at the point of installation.

   ii. Demonstrate that the type of susceptibility failures that occurred during the EMI/RFI Testing will not adversely affect the safety function of the PLC or plant operation. For example, variations in analog input and output levels in excess of ± 3% may not impact the safety-related function of the PLC or adversely affect plant operation.

   iii. Implement actions to mitigate unacceptable EMI/RFI sources. The TRICON v10 PLC was tested without the benefit of a secondary enclosure, additional cable and wire shielding, or installed power line filtering. Mitigating actions to address module susceptibility levels would likely incorporate these common in-plant installation features. Mitigating actions might also include administrative controls on the EMI/RFI sources.

e. Tables 8-1 and 8-2 included at the end of this section provide a summary of the EMI/RFI conducted and radiated susceptibility test results for each module installed in the TUT. The purpose of the tables is to identify a set of modules which demonstrated acceptable susceptibility performance at the required test levels specified in NRC RG 1.180 (Reference 9.2).

8.4 Post-EMI/RFI Operability and Prudency Testing

As reported by Triconex, the completed Performance Proof Test Run No. 3.7 of Triconex Procedure No. 9600164-503, "Operability Test Procedure," (Reference 9.38) and the completed Performance Proof Test Run No. 3.4 of Triconex Procedure No. 9600164-504, "Prudency Test Procedure," (Reference 9.39) demonstrate acceptable system performance following EMI/RFI Testing.

8.5 Test Anomalies

Several test anomalies were encountered during EMI/RFI Testing as described in Section 7.5 of this test report. Each of the test anomalies was dispositioned for its impact on the validity of the test results. Test system revisions were made and/or repeat testing was performed as necessary to correct any negative impact the test anomalies may have had on the validity of the test results.

During testing the 3503E Digital Input and 3625 Digital Output modules had shown susceptibilities during IEC 61000-4-16 testing for Conducted Susceptibility, Short Duration Disturbance at 0 Hz (DC). (Specifically, the susceptible points were detected as being on by Trilogger when in fact they were off.) This problem was investigated during supplemental testing (see Supplement 1 to this report). These modules are no longer considered susceptible as reflected in Table 8-1.

It has been determined that testing performed to IEC 61000-4-10 (Radiated Susceptibility Testing, Pulsed Magnetic Field) by NTS on the Tricon V10 nuclear qualification program was not in full compliance with the standard. Due to test execution anomalies, the results of testing to IEC 61000-4-10 were determined not to be valid. Therefore, compliance with IEC 61000-4-10 is indeterminate. Table 8-2 has been updated accordingly (See Reference 9.41).

TABLE 8-1: SUMMARY OF EMI/RFI CONDUCTED SUSCEPTIBILITY TEST RESULTS

Module Model No.	ETP Model No.	Module Type	IEC 61000-4-6 Radio Frequency 150 kHz - 80 MHz	IEC 61000-4-13 Harmonics and Interharmonics	IEC 61000-4-16 Common-Mode Disturbances
3008	---	Main Processor	Pass	Pass	Pass
8310	---	Power Supply, 115 VAC	Pass	Pass	Pass
8311	---	Power Supply, 230 VAC	Pass	Pass	Pass
8312	---	Power Supply, 24 VDC	Pass	Pass	Pass
4200	---	Remote Extender	Pass	Pass	Pass
4201	---	Remote Extender	Pass	Pass	Pass
4352A	---	Communication	Pass	Pass	Pass
3511	9794-110N	Pulse Input	Pass	Pass	Pass
3708E	9782-110N	Thermocouple Input	Pass	Pass	Pass
3501T	9561-810N	Digital Input, 115 VAC	Pass	Pass	Pass
	9561-110N	Digital Input, 115 VAC	Pass	Pass	Pass

TABLE 8-1: SUMMARY OF EMI/RFI CONDUCTED SUSCEPTIBILITY TEST RESULTS

Module Model No.	ETP Model No.	Module Type	IEC 61000-4-6 Radio Frequency 150 kHz - 80 MHz	IEC 61000-4-13 Harmonics and Interharmonics	IEC 61000-4-16 Common-Mode Disturbances
3623T	9664-810N	Digital Output, 120 VDC	Pass	Pass	Pass
3603T	9664-810N	Digital Output, 120 VDC	Pass	Pass	Pass
3601T	9663-610N	Digital Output, 115 VAC	**Susceptible**	Pass	Pass
3503E	9563-810N	Digital Input, 24 VDC	Pass	Pass	**Pass**
3625	9662-810N	Digital Output, 24 VDC	Pass	Pass	**Pass**
	9662-610N	Digital Output, 24 VDC	Pass	Pass	**Pass**
3636T	9668-110N	Relay Output	Pass	Pass	Pass
3607E	9667-810N	Digital Output, 48 VDC	Pass	Pass	Pass
3502E	9562-810N	Digital Input, 48 VDC	Pass	Pass	Pass
3701	9795-610N	Analog Input, 0-10 VDC	Pass	Pass	Pass
	9783-110N	Analog Input, 0-10 VDC	Pass	Pass	Pass
3703E	9790-610N	Analog Input, 0-10 VDC	Pass	Pass	Pass
	9783-110N	Analog Input, 0-10 VDC	Pass	Pass	Pass
3805E	9860-610N	Analog Output, 4-20 mA	Pass	Pass	Pass
3721	9764-310N	RTD, No. 1600083-600	Pass	Pass	Pass
		RTD, No. 1600083-200	Pass	Pass	Pass
		RTD, No. 1600024-040	Pass	Pass	Pass
		RTD, No. 1600024-030	Pass	Pass	Pass
		RTD, No. 1600024-020	Pass	Pass	Pass
		RTD, No. 1600024-010	Pass	Pass	Pass
		mV, No. 1600082-001	Pass	Pass	Pass
		RTD, No. 1600081-001	**Susceptible**	Pass	Pass
3721	9783-110N	Analog Input, 0-5 VDC	Pass	Pass	Pass
	9790-610N	Analog Input, 0-5 VDC	Pass	Pass	Pass
	9783-110N	Analog Input, 0-5 VDC	Pass	Pass	Pass

TABLE 8-2: SUMMARY OF EMI/RFI RADIATED SUSCEPTIBILITY TEST RESULTS

Module Model No.	ETP Model No.	Module Type	IEC 61000-4-3 High Frequency 26 MHz - 1 GHz	IEC 61000-4-8 60 Hz Magnetic Field	IEC 61000-4-9 Pulsed Magnetic Field	IEC 61000-4-10 Oscillatory Magnetic Field
3008	---	Main Processor	Pass	Pass	Pass	**Indeterminate**
8310	---	Power Supply, 115 VAC	Pass	Pass	Pass	**Indeterminate**
8311	---	Power Supply, 230 VAC	Pass	Pass	Pass	**Indeterminate**
8312	---	Power Supply, 24 VDC	Pass	Pass	Pass	**Indeterminate**
4200	---	Remote Extender	Pass	Pass	Pass	**Indeterminate**
4201	---	Remote Extender	Pass	Pass	Pass	**Indeterminate**
4352A	---	Communication	Pass	Pass	Pass	**Indeterminate**
3511	9794-110N	Pulse Input	Pass	Pass	Pass	**Indeterminate**
3708E	9782-110N	Thermocouple Input	Pass	Pass	Pass	**Indeterminate**
3501T	9561-810N	Digital Input, 115 VAC	Pass	Pass	Pass	**Indeterminate**
	9561-110N	Digital Input, 115 VAC	Pass	Pass	Pass	**Indeterminate**
3623T	9664-810N	Digital Output, 120 VDC	Pass	Pass	Pass	**Indeterminate**
3603T	9664-810N	Digital Output, 120 VDC	Pass	Pass	Pass	**Indeterminate**
3601T	9663-610N	Digital Output, 115 VAC	Pass	Pass	Pass	**Indeterminate**
3503E	9563-810N	Digital Input, 24 VDC	Pass	Pass	Pass	**Indeterminate**
3625	9662-810N	Digital Output, 24 VDC	Pass	Pass	Pass	**Indeterminate**
3636T	9668-110N	Relay Output	Pass	Pass	Pass	**Indeterminate**
3607E	9667-810N	Digital Output, 48 VDC	Pass	Pass	Pass	**Indeterminate**
3502E	9562-810N	Digital Input, 48 VDC	Pass	Pass	Pass	**Indeterminate**
3701	9795-610N	Analog Input, 0-10 VDC	Pass	Pass	Pass	**Indeterminate**
	9783-110N	Analog Input, 0-10 VDC	Pass	Pass	Pass	**Indeterminate**
3703E	9790-610N	Analog Input, 0-10 VDC	Pass	Pass	Pass	**Indeterminate**
	9783-110N	Analog Input, 0-10 VDC	Pass	Pass	Pass	**Indeterminate**
3805E	9860-610N	Analog Output, 4-20 mA	Pass	Pass	Pass	**Indeterminate**
3721	9764-310N	RTD, No. 1600083-600	**Susceptible**	Pass	Pass	**Indeterminate**
		RTD, No. 1600083-200	**Susceptible**	Pass	Pass	**Indeterminate**
		RTD, No. 1600024-040	Pass	Pass	Pass	**Indeterminate**
		RTD, No. 1600024-030	**Susceptible**	Pass	Pass	**Indeterminate**
		RTD, No. 1600024-020	**Susceptible**	Pass	Pass	**Indeterminate**
		RTD, No. 1600024-010	Pass	Pass	Pass	**Indeterminate**
		mV, No. 1600082-001	Pass	Pass	Pass	**Indeterminate**
		RTD, No. 1600081-001	Pass	Pass	Pass	**Indeterminate**

TABLE 8-2: SUMMARY OF EMI/RFI RADIATED SUSCEPTIBILITY TEST RESULTS

Module Model No.	ETP Model No.	Module Type	IEC 61000-4-3 High Frequency 26 MHz - 1 GHz	IEC 61000-4-8 60 Hz Magnetic Field	IEC 61000-4-9 Pulsed Magnetic Field	IEC 61000-4-10 Oscillatory Magnetic Field
3721	9783-110N	Analog Input, 0-5 VDC	Pass	Pass	Pass	**Indeterminate**
	9790-610N	Analog Input, 0-5 VDC	Pass	Pass	Pass	**Indeterminate**
	9783-110N	Analog Input, 0-5 VDC	Pass	Pass	Pass	**Indeterminate**

9.0 REFERENCES

Note: Triconex qualification project documentation and hardware are configuration controlled under the Triconex Quality Assurance Program. Triconex Document No. 9600164-540, "Master Configuration List," (Reference 9.15) provides a record of the currently applicable revision level of all Triconex documents, procedures and drawings throughout performance of the qualification program. As recorded in the completed MPR Procedure No. 9600164-510 (Reference 9.17), Triconex Document No. 9600164-540, Rev. 10 was in effect at the start of EMI/RFI Testing.

9.1 Triconex Document No. 9600164-500, "Master Test Plan," Rev. 4

9.2 U.S. Nuclear Regulatory Commission Regulatory Guide 1.180, Revision 1, "Guidelines for Evaluating Electromagnetic and Radio-Frequency Interference in Safety-Related Instrumentation and Control Systems," October 2003

9.3 MPR Procedure No. 9600164-510, "EMI/RFI Test Procedure," Rev. 0

9.4 EPRI TR-107330, "Generic Requirements Specification for Qualifying a Commercially Available PLC for Safety-Related Applications in Nuclear Power Plants," Final Report dated December, 1996

9.5 Triconex Document No. 9600164-002, "Nuclear Qualification Quality Plan," Rev. 3

9.6 Triconex Drawing No. 9600164-100, "TRICON v10 Nuclear Qualification Project TRICON Under Test - General Arrangement," Rev. 1

9.7 Department of Defense Interface Standard MIL-STD-461E, "Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment," August 20, 1999

9.8 IEC Standard 61000-4-3, "Electromagnetic Compatibility (EMC), Part 4-3: Testing and Measurement Techniques, Radiated, Radio-Frequency, Electromagnetic Field Immunity Test," September 2002

9.9 IEC Standard 61000-4-6, "Electromagnetic Compatibility (EMC), Part 4-6: Testing and Measurement Techniques, Immunity to Conducted Disturbances, Induced by Radio-Frequency Fields," November 2004

9.10 IEC Standard 61000-4-8, "Electromagnetic Compatibility (EMC), Part 4-8: Testing and Measurement Techniques, Power Frequency Magnetic Field Immunity Test," March 2001

9.11 IEC Standard 61000-4-9, "Electromagnetic Compatibility (EMC), Part 4-9: Testing and Measurement Techniques, Pulse Magnetic Field Immunity Test," March 2001

9.12 IEC Standard 61000-4-10, "Electromagnetic Compatibility (EMC), Part 4-10: Testing and Measurement Techniques, Damped Oscillatory Magnetic Field Immunity Test," March 2001

9.13 IEC Standard 61000-4-13, "Electromagnetic Compatibility (EMC), Part 4-13: Testing and Measurement Techniques, Harmonics and Interharmonics Including Mains Signaling at A.C. Power Port, Low Frequency Immunity Tests," March 2002

9.14 IEC Standard 61000-4-16, "Electromagnetic Compatibility (EMC), Part 4-16: Testing and Measurement Techniques, Test for Immunity to Conducted, Common Mode Disturbances in the Frequency Range 0 Hz to 150 kHz," July 2002

9.15 Triconex Document No. 9600164-540, "Master Configuration List," Rev. 18

9.16 IEEE Standard 323-1974, "Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations"

9.17 Completed MPR Procedure No. 9600164-510, "EMI/RFI Test Procedure," Rev. 0, MPR Review and Approval Dated July 16, 2007

9.18 Triconex Drawing No. 9600164-103, "TRICON v10 Nuclear Qualification Project System Block Diagram," Rev. 2

9.19 Triconex Document No. 9600164-541, "TRICON v10 Nuclear Qualification Project, System Description," Rev. 0

9.20 Triconex Document No. 9600164-517, "Test Specimen Application Program (TSAP) Software Requirements Specification (SRS)," Rev. 3

9.21 National Technical Systems Test Procedure No. TP62987-07N-EMI, "Test Procedure for Electromagnetic Compatibility Qualification of the TRICON v10 Nuclear Qualification Project TRICON-Under-Test," Rev. 0

9.22 Triconex Drawing No. 9600164-201, Sheets 1 and 2, "TRICON v10 Nuclear Qualification Project - Power Distribution Wiring Diagram," Rev. 1

9.23 Triconex Drawing No. 9600164-202, Sheet 1, "TRICON v10 Nuclear Qualification Project - Test Chassis #1 Power Distribution Wiring Diagram," Rev. 0

9.24 Triconex Drawing No. 9600164-203, Sheets 1 and 2, "TRICON v10 Nuclear Qualification Project - Test Chassis #2 Power Distribution Wiring Diagram," Rev. 0

9.25 Triconex Drawing No. 9600164-204, Sheets 1 and 2, "TRICON v10 Nuclear Qualification Project - Test Chassis #3 Power Distribution Wiring Diagram," Rev. 0

9.26 Triconex Drawing No. 9600164-205, Sheets 1 and 2, "TRICON v10 Nuclear Qualification Project - Test Chassis #4 Power Distribution Wiring Diagram," Rev. 2

9.27 Triconex Drawing No. 9600164-206, Sheet 1, "TRICON v10 Nuclear Qualification Project - Simulator Chassis #5 Power Distribution Wiring Diagram," Rev. 0

9.28 Triconex Drawing No. 9600164-207, Sheet 1, "TRICON v10 Nuclear Qualification Project - Simulator Chassis #6 Power Distribution Wiring Diagram," Rev. 0

9.29 National Technical Systems Test Report No. TR62987-07N-EMI, "Test Report for Electromagnetic Compatibility Qualification of the TRICON v10 Nuclear Qualification Project TRICON-Under-Test," Rev. 1

9.30 Triconex Document No. 9600164-700, "TRICON v10 Nuclear Qualification Project Wiring Schedule," Rev. 3

9.31 Completed Pre-EMI/RFI Testing Run No. 3.6 of Triconex Procedure No. 9600164-502, "System Setup and Checkout Procedure," Rev. 4

9.32 Triconex Procedure No. 9600164-502, "System Setup and Checkout Procedure," Rev. 4

9.33 Triconex Qualification Project Anomaly Report (QPAR) No. 045, "Isolation Ground Resistance (Chassis 3 and Chassis 4)"

9.34 MPR Nonconformance Report NCR-2007-04 dated March 9, 2007, "Incorrect Configuration of TRICON-Under-Test Analog I/O Circuits"

9.35 MPR Document No. 0449-0602-RWP-001 dated March 9, 2007, "Rework Procedure for the TRICON v10 Nuclear Qualification Project TRICON-Under-Test (TUT)," Rev. 0

9.36 Triconex Qualification Project Anomaly Report (QPAR) No. 044, "Load Fuse Errors on Module 3623T"

9.37 Triconex Letter 9600164-025T dated February 6, 2007 to MPR Associates, "Internally Generated Frequencies - TRICON v10 EMI/RFI Testing"

9.38 Completed Performance Proof Run No. 3.7 of Triconex Procedure No. 9600164-503, "Operability Test Procedure," Rev. 3

9.39 Completed Performance Proof Run No. 3.4 of Triconex Procedure No. 9600164-504, "Prudency Test Procedure," Rev. 1

9.40 Triconex Qualification Project Anomaly Report (QPAR) No. 055, "3636T Relay Output Module IEC 61000-4-16 Analysis"

9.41 Triconex Action Request Report (ARR) No. 962, "Testing by NTS to IEC 61000-4-10 was not in full compliance to the standard"

10.0 ATTACHMENTS

Attachment 1: Example Plots of TUT Normal Operating Data

11.0 SUPPLEMENTS

Supplement 1: Supplemental Testing to IEC 61000-4-16, Short Duration Disturbance at 0 Hz (DC)

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EMI/RFI
TEST REPORT

Supplement 1

Supplemental Testing to
IEC 61000-4-16, Short Duration Disturbance at 0 Hz (DC)

Document No.: 9600164-527

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1.0 EXECUTIVE SUMMARY

The TRICON v10 Nuclear Qualification Project Electromagnetic Interference / Radiofrequency Interference (EMI/RFI) Test was performed on February 16 to April 17, 2007 at National Technical Systems (NTS) Laboratories in Boxborough, Massachusetts. During that testing, the following Digital Input and Digital Output modules had shown susceptibilities during IEC 61000-4-16 testing for Conducted Susceptibility, Short Duration Disturbance at 0 Hz (DC). (Specifically, the susceptible points were detected as being on by Trilogger when in fact they were off.)

- Digital Input Module 3503E (24V AC/DC) with ETA 9563-810N
- Digital Output Module 3625 (24V DC) with ETA 9662-810N
- Digital Output Module 3625 (24V DC) with ETA 9662-610N

Due to time constraints at the test facility this problem was not investigated during the original qualification testing. Instead, this problem was investigated during supplemental testing in Irvine. The digital inputs are optically isolated and should be resilient to common mode disturbances well beyond the 30V disturbances of the short duration test. Therefore, Triconex performed supplemental testing in order to duplicate and troubleshoot the failures.

As required by Triconex Document No. 9600164-800, "Supplemental Test Plan," (Reference 9.11), the Supplemental EMI/RFI Test (i.e. "Supplemental Test") to IEC 61000-4-16, Testing for Conducted Susceptibility, Short Duration Disturbance at 0 Hz (DC), was executed to demonstrate acceptable performance of the TRICON v10 Programmable Logic Controller (PLC) in accordance with the acceptance criteria specified in U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide (RG) 1.180, Revision 1, "Guidelines for Evaluating Electromagnetic and Radio-Frequency Interference in Safety-Related Instrumentation and Control Systems," (Reference 9.2).

The Supplemental Test was performed at the I-T facility from January 15 to January 18, 2008. The supplemental testing validated that the aforementioned modules are not susceptible to IEC 61000-4-16, Testing for Conducted Susceptibility, Short Duration Disturbance at 0 Hz (DC).

2.0 PURPOSE

The purpose of this supplement is to summarize the results of supplemental testing to IEC 61000-4-16; Testing for Conducted Susceptibility, Short Duration Disturbance at 0 Hz (DC), of the TRICON v10 Nuclear Qualification Project TRICON-Under-Test (TUT) to meet the requirements of NRC RG 1.180, Revision 1 (Reference 9.2).

Conclusions and details regarding the performance and results of the Supplemental Testing are provided in Section 8.0 of this supplement.

3.0 TEST OBJECTIVE

The supplemental testing was performed to determine the cause of and to duplicate and troubleshoot the failures that had occurred previously at the National Technical Systems (NTS) Laboratories.

4.0 DESCRIPTION OF TEST SPECIMEN

The equipment tested consists of the same four TRICON v10 PLC chassis populated with selected main processor, input, output, communication, chassis interface and chassis power supply modules that had undergone testing previously. The tested equipment also includes the same external termination panels (ETPs) provided for connection of field wiring to the TRICON v10 input and output modules, and interfacing cable assemblies for connection of the ETPs to the TRICON v10 chassis and for interconnection of the TRICON v10 chassis.

No changes or modifications were made to the general arrangement and interconnection of the TUT chassis or test system. A detailed identification of the tested equipment is provided in Triconex Document No. 9600164-540 (Reference 9.8).

During testing, the TUT was executing the same Test Specimen Application Program (the TSAP) developed specifically for the qualification project and designed to support the test procedures, which demonstrate the functionality of the TUT during all phases of qualification testing.

5.0 TEST SETUP AND INSTRUMENTATION

The following sections describe the setup of the TUT during Supplemental Testing, the instrumentation used to generate and measure the applied Supplemental test conditions, and the instrumentation used to measure TUT performance during and after testing. The TUT setup is documented in the completed Setup and Checkout Procedure No. 9600164-502 (Reference 9.20).

5.1 TRICON-Under-Test Mounting

For Supplemental Testing, the TUT was located at the I-T (Invensys-Triconex) facility. The TUT was mounted in two metal frame instrument cabinets (with all sides removed) as follows:

- Cabinet 1: TUT Chassis No. 1 and 2, with external termination panels
- Cabinet 2: TUT Chassis No. 3 and 4, with external termination panels

This is the same configuration that was used at the National Technical Systems (NTS) Laboratories. However, since it was not necessary for the specific tests performed, Cabinets 1 and 2 were not located in an anechoic test chamber.

Grounding of the TUT was in accordance with approved project documents and duplicated the previously tested configuration as detailed on Triconex Drawing Nos. 9600164-201 through 9600164-207 (References 9.13 through 9.19).

5.2 TRICON-Under-Test Chassis and Module Configuration

Section 4.0 above describes the general arrangement of the TUT which was maintained throughout all of the qualification testing. Chassis configurations for EMI/RFI Testing are documented in Triconex Document No. 9600164-540 (Reference 9.8).

a, b

5.3 TRICON-Under-Test Power Supply and Wiring Configuration

a, b

5.4 Instrumentation

a, b

Details on the identification, configuration and calibration of the test instrumentation described above are included in the completed Setup & Checkout Procedure (9600 164-502), Pre-Supplemental 4-16 Test (Run ID: 3.2, Supp 4-1 6) (Reference 9.20).

5.6 Instrument Calibration

All tests were performed using calibrated test instruments. Calibration certifications are held by Triconex. The completed Triconex Procedure No. 9600164-502 (Reference 9.20) documents the calibration status of the test instrumentation used by Triconex.

6.0 TEST PROCEDURES

The Supplemental Testing of the TUT was performed to the requirements of Section 4 of NRC RG 1.180, Revision 1 (Reference 9.2). Section 4 of NRC RG 1.180 addresses EMI/RFI susceptibility testing.

The following sections describe the approach to satisfying the requirements of the referenced documents for Supplemental Testing of the TUT. The same test procedures used by MPR and NTS to perform EMI/RFI Testing of the TUT were utilized (MPR Procedure No. 9600164-510, Reference 9.3, and NTS Test Procedure No.TP62987-07N-EMI, Reference 9.12). Only the applicable portions to IEC 61000-4-16 of the procedures were implemented.

6.1 Test Sequence

Requirements for conducting testing activities were duplicated from previous testing during the V10 Nuclear Qualification Project. Three categories of tests were conducted to satisfy the supplemental testing requirements in order to show qualification in accordance with IEC 61000-4-16 Testing for Conducted Susceptibility, Short Duration Disturbance at 0 Hz (DC):

(1) **Pre-qualification tests** conducted prior to qualification testing to determine that the system operates correctly and to provide baseline data on equipment performance, and

(2) **Qualification tests** to demonstrate compliance with specification requirements and suitability of equipment while subject to stress conditions

(3) **Performance Proof tests** conducted at the Invensys Triconex facilities upon conclusion of all testing to confirm satisfactory operation after being subjected to Qualification test conditions. Performance proof tests are merely a repeat of selected pre-qualification baseline tests to identify any changes in equipment performance.

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6.2 Test Method

Section 4 of NRC RG 1.180, Revision 1 (Reference 9.2) includes the requirements for EMI/RFI susceptibility testing of safety-related instrumentation and control (I&C) systems. The Supplemental susceptibility testing of the TUT included conducted testing done to IEC Standard 61000-4-16, Conducted Susceptibility, Common-Mode Disturbances (15 Hz to 150 kHz), Power and Signal Leads (Reference 9.7). Testing was for Short Duration Disturbance at 0 Hz (DC) only.

6.3 Test Levels

The following lists the Supplemental Testing applied susceptibility test levels from the applicable figures and tables of NRC RG 1.180 (Reference 9.2).

EMI/RFI Susceptibility Test Method	NRC RG 1.180, Rev. 1 Test Level
IEC Standard 61000-4-16	Table 11: Signal Leads: 3/10 of Power Leads

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6.4 TRICON-Under-Test Operation

6.5 TRICON-Under-Test Performance Monitoring

During Supplemental Testing, operation of the TUT was monitored and recorded by the DAS and the Trilogger/TriStation Console interface. The recorded data was evaluated for time periods before, during and after each Supplemental Test. Section 7.3 of this test report includes a set of figures showing the normal operation of the data points which were monitored during Supplemental Testing. The data was monitored for deviations or trends from the normal operation shown in the figures.

6.6 Test Acceptance Criteria

The following EMI/RFI Test acceptance criteria are as given in Appendix 7 of Triconex Document No. 9600164-500 (Reference 9.1), and Section 4.3.7 of EPRI TR-107330 (Reference 9.4).

> The TUT shall operate as intended during and after application of the EMI/RFI test levels specified in Section 4 of NRC RG 1.180, Revision 1 (Reference 9.2) for the following IEC Standard Susceptibility Test Methods:
>
> IEC 61000-4-16 – Conducted Susceptibility, Common Mode Disturb., 15 Hz to 150 kHz
>
> Evaluation of normal operating performance data (inputs, outputs and diagnostic indicators) shall demonstrate operation as intended, including the following specific operational performance from Section 4.3.7 of EPRI TR-107330 (Reference 9.4):
>
> i.) The main processors shall continue to function.
> ii.) The transfer of I/O data shall not be interrupted.
> iii.) The emissions shall not cause the discrete I/O to change state.
> iv.) Analog I/O levels shall not vary more than 3%.

7.0 TEST RESULTS

This section summarizes the results of supplemental EMI/RFI Testing of the TUT. This section also discusses performance or data anomalies which were observed or recorded during the testing.

7.1 Supplemental Test Setup and Checkout Testing

Triconex Procedure No. 9600164-502, "System Setup and Checkout Procedure," (Reference 9.21) directs setup of the TUT for the different qualification tests to be performed, and verifies proper operation of the TUT and test system prior to start of testing. In accordance with Attachment 1 of the Supplemental Test Plan (Reference 9.11) only applicable portions of the procedure were implemented (10.1, 10.2, 10.5, 10.6, 10.8, 10.14, 10.15, 10.16, and 10.17). Supplemental Testing of the TUT was performed upon completion of the Setup & Checkout Procedure (9600164-502), Pre-Supplemental 4-16 Test (Run ID: 3.2, Supp 4-1 6). Results of Reference 9.20 show that the system was operating correctly prior to start of Supplemental Testing. Prior to performing Triconex Procedure No. 9600164-502, "System Setup and Checkout Procedure," it was discovered that a chassis power supply had failed. QPAR 056 (Reference 9.26) was written and the power supply was replaced with a spare. Testing was then continued.

7.2 Pre-Qualification Testing

Triconex Procedure No. 9600164-503, "Operability Test Procedure" provides instructions for operability and power quality tolerance testing to be performed on the TUT. In accordance with Attachment 2 of the Supplemental Test Plan (Reference 9.11) only applicable portions of the procedure were implemented (Section 1 – General Overview, Section 4 – Discrete Input Test, Section 5 – Discrete Output Test). Results of Executed Operability Test Procedure 9600164-503 Run 3.1, Supp4-16 (Reference 9.22) indicate that all acceptance criteria were satisfied.

Triconex Procedure No. 9600164-504 provides instructions for Prudency testing to be performed on the TUT. In accordance with Attachment 3 of the Supplemental Test Plan (Reference 9.11) only applicable portions of the procedure were implemented (Section 1 – General Overview Section 2 – Burst of Events Test). Results of Executed Prudency Test Procedure 9600164-504 Run 3.1, Supp4-16 (Reference 9.23) indicate that all acceptance criteria were satisfied.

7.3 Supplemental Testing

Supplemental Testing of the TUT was performed in accordance with Attachment 4 of the Supplemental Test Plan, 9600164-800. This included Sections 10.7.147 thru 10.7.173 as applicable to Table 7.1, Tests 7.7.b, 7.8.b, and 7.9.b, including TERR #17of MPR Procedure No. 9600164-510 (Reference 9.3), and applicable portions of Section 7.7.4, and Figure 5 of NTS Test Procedure No. TP62987-07N-EMI (Reference 9.12). All testing was performed with the TUT energized and operating under control of the executing TSAP software. Prior to execution of the 61000-4-16 test, the test setup was verified to meet the requirements of 61000-4-16. a, b

a, b

Table 7.1: Summary of IEC Standard 61000-4-16 Supplemental Test Results						
	Cont. DC (3 V)	Short Dur. DC (30 V)*	Cont. 60 Hz (3 Vrms)	Short Dur. 60 Hz (30 Vrms)	Frequency Sweep	Threshold Testing Required?
Discrete Input/Output Modules						
Module 3-2T	---	Test 136[1]	---	---	---	No
Module 3-3T	---	Test 138[1]	---	---	---	No
Module 3-3B	---	Test 140[1]	---	---	---	No

Note (1): Tests replace test no. 118, 121, and 126 of previous tests, respectively.

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a, b

a, b

7.4 Performance Proof Testing

Triconex Procedure No. 9600164-503, "Operability Test Procedure" provides instructions for operability and power quality tolerance testing to be performed on the TUT. In accordance with Attachment 2 of the Supplemental Test Plan (Reference 9.11) only applicable portions of the procedure were implemented (Section 1 – General Overview, Section 4 – Discrete Input Test, Section 5 – Discrete Output Test). Results of Executed Operability Test Procedure 9600164-503 Run 3.7, Supp4-16 (Reference 9.23) indicate that all acceptance criteria were satisfied.

Triconex Procedure No. 9600164-504 provides instructions for Prudency testing to be performed on the TUT. In accordance with Attachment 3 of the Supplemental Test Plan (Reference 9.11) only applicable portions of the procedure were implemented (Section 1 – General Overview Section 2 – Burst of Events Test). Results of Executed Prudency Test Procedure 9600164-504 Run 3.3, Supp4-16 (Reference 9.25) indicate that all acceptance criteria were satisfied.

Therefore, the aforementioned operability and prudency testing demonstrate acceptable system performance following Supplemental Testing.

7.5 Procedure Deviations

There were no significant procedural deviations taken during Supplemental Testing. A portion of the testing was repeated when the TUT initially failed the susceptibility testing. It was determined that the DAS ground was tied to earth in the DAS, thereby causing the common mode disturbance to be seen differentially by the digital input. This occurrence is discussed in detail in Section 7.2.

a, b

7.6 Test Anomalies

8.0 CONCLUSIONS

8.1 Test Methodology

Supplemental Testing of the TUT was performed in accordance with the applicable requirements of NRC RG 1.180, Revision 1 (Reference 9.2). The following EMI/RFI Test was performed on the TUT:

- IEC 61000-4-16 testing for Conducted Susceptibility, Short Duration Disturbance at 0 Hz (DC)

The specific TRICON v10 PLC hardware which was tested (chassis, power supplies, modules, external termination assemblies and interconnecting cabling) is identified in Triconex Document No. 9600164-540 (Reference 9.8).

8.2 Susceptibility Testing

The TUT successfully passed the Supplemental susceptibility tests. The main processors continued to function correctly throughout testing. The transfer of input and output data was not interrupted. There were no interruptions or inconsistencies in the operation of the system or the software.

Table 8-1 provides a summary of the Supplemental conducted susceptibility test results for Discrete Input/Output modules installed in the TUT. The purpose of the table is to identify that the Digital Input Module 3503E (24V AC/DC) w/ ETP 9563-810N, Digital Output Module 3625(24V DC) w/ ETP 9662-810N, and Digital Output Module 3625 (24V DC) w/ ETP 9662-610N have been shown to demonstrate acceptable susceptibility performance at the required test levels specified in NRC RG 1.180, Revision 1 (Reference 9.2).

8.3 Post-Supplemental Test Operability and Prudency Testing

The completed Operability Test Procedure 9600164-503 Run 3.7, Supp4-16" (Reference 9.23) and the completed Prudency Test Procedure 9600164-504 Run 3.3, Supp4-16 (Reference 9.25) demonstrate acceptable system performance following Supplemental Testing.

8.4 Test Anomalies

Four test anomalies were encountered during Supplemental Testing as described in Sections 7.1, 7.3, and 7.6 of this test report. The test anomalies were dispositioned for their impact on the validity of the test results. Test system revisions were made and/or repeat testing was performed as necessary to correct the conditions identified by anomaly reports.

TABLE 8-1: SUMMARY OF SUPPLEMENTAL EMI/RFI CONDUCTED SUSCEPTIBILITY TEST RESULTS					
Module Model No.	**ETP Model No.**	**Module Type**	**IEC 61000-4-6** **Radio Frequency 150 kHz - 80 MHz**	**IEC 61000-4-13** **Harmonics and Interharmonics**	**IEC 61000-4-16** **Common-Mode Disturbances**
3503E	9563-810N	Digital Input, 24 VDC	(Not Tested)	(Not Tested)	**PASS**
3625	9662-810N	Digital Output, 24 VDC	(Not Tested)	(Not Tested)	**PASS**
	9662-610N	Digital Output, 24 VDC	(Not Tested)	(Not Tested)	**PASS**

x.

9.0 REFERENCES

9.1 Triconex Document No. 9600164-500, "Master Test Plan," Rev. 5

9.2 U.S. Nuclear Regulatory Commission Regulatory Guide 1.180, Revision 1, "Guidelines for Evaluating Electromagnetic and Radio-Frequency Interference in Safety-Related Instrumentation and Control Systems," October 2003

9.3 MPR Procedure No. 9600164-510, "EMI/RFI Test Procedure," Rev. 0

9.4 EPRI TR-107330, "Generic Requirements Specification for Qualifying a Commercially Available PLC for Safety-Related Applications in Nuclear Power Plants," Final Report dated December, 1996

9.5 Triconex Document No. 9600164-002, "Nuclear Qualification Quality Plan," Rev. 3

9.6 Triconex Drawing No. 9600164-100, "TRICON v10 Nuclear Qualification Project TRICON Under Test - General Arrangement," Rev. 1

9.7 IEC Standard 61000-4-16, "Electromagnetic Compatibility (EMC), Part 4-16: Testing and Measurement Techniques, Test for Immunity to Conducted, Common Mode Disturbances in the Frequency Range 0 Hz to 150 kHz," July 2002

9.8 Triconex Document No. 9600164-540, "Master Configuration List," Rev. 21

9.9 IEEE Standard 323-1974, "Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations"

9.10 Completed MPR Procedure No. 9600164-510, "EMI/RFI Test Procedure," Rev. 0

9.11 Triconex Document No. 9600164-800, "TRICON v10 Nuclear Qualification Project Supplemental test Plan," Rev. 2

9.12 National Technical Systems Test Procedure No. TP62987-07N-EMI, "Test Procedure for Electromagnetic Compatibility Qualification of the TRICON v10 Nuclear Qualification Project TRICON-Under-Test," Rev. 1

9.13 Triconex Drawing No. 9600164-201, Sheets 1 and 2, "TRICON v10 Nuclear Qualification Project - Power Distribution Wiring Diagram," Rev. 1

9.14 Triconex Drawing No. 9600164-202, Sheet 1, "TRICON v10 Nuclear Qualification Project - Test Chassis #1 Power Distribution Wiring Diagram," Rev. 0

9.15 Triconex Drawing No. 9600164-203, Sheets 1 and 2, "TRICON v10 Nuclear Qualification Project - Test Chassis #2 Power Distribution Wiring Diagram," Rev. 0

9.16 Triconex Drawing No. 9600164-204, Sheets 1 and 2, "TRICON v10 Nuclear Qualification Project - Test Chassis #3 Power Distribution Wiring Diagram," Rev. 0

9.17 Triconex Drawing No. 9600164-205, Sheets 1 and 2, "TRICON v10 Nuclear Qualification Project - Test Chassis #4 Power Distribution Wiring Diagram," Rev. 2

9.18 Triconex Drawing No. 9600164-206, Sheet 1, "TRICON v10 Nuclear Qualification Project - Simulator Chassis #5 Power Distribution Wiring Diagram," Rev. 0

9.19 Triconex Drawing No. 9600164-207, Sheet 1, "TRICON v10 Nuclear Qualification Project - Simulator Chassis #6 Power Distribution Wiring Diagram," Rev. 0

9.20 Completed Setup & Checkout Procedure (9600164-502), Pre-Supplemental 4-16 Test (Run ID: 3.2, Supp 4-1 6)

9.21 Triconex Procedure No. 9600164-502, "System Setup and Checkout Procedure," Rev. 4

9.22 Completed Operability Test Procedure (9600164-503), Rev. 3, Supplemental 4-16 Test (Run ID: 3.1, Supp 4-1 6)

9.23 Completed Operability Test Procedure (9600164-503), Rev. 3, Supplemental 4-16 Test (Run ID: 3.7, Supp 4-1 6)

9.24 Completed Prudency Test Procedure (9600164-504), Rev. 1, Supplemental 4-16 Test (Run ID: 3.1, Supp 4-1 6)

9.25 Completed Prudency Test Procedure (9600164-504), Rev. 1, Supplemental 4-16 Test (Run ID: 3.3, Supp 4-1 6)

9.26 Triconex Qualification Project Anomaly Report (QPAR) No. 056, "3636T Relay Output Module IEC 61000-4-16 Analysis"

9.27 Triconex Qualification Project Anomaly Report (QPAR) No. 057, "Isolation Ground Resistance (Chassis 3 and Chassis 4)"

9.28 Triconex Qualification Project Anomaly Report (QPAR) No. 058, "Load Fuse Errors on Module 3623T"

9.29 Triconex Qualification Project Anomaly Report (QPAR) No. 059, "Isolation Ground Resistance (Chassis 3 and Chassis 4)"