(Redacted Version)

Results and Observations from Duke Armored Control Cable Fire-Induced Spurious Operation Testing

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1 INTRODUCTION

1.1 Background

1.1.1 Post-Fire Safe-Shutdown Circuit Analysis

Appendix R to Title 10 of the Code of Federal Regulations Part 50 (10 CFR 50), “Fire Protection Program for Nuclear Power Facilities Operating Prior to January 1, 1979," became effective in early 1981. These fire protection regulations (Appendix R) required licensees to perform an analysis which identified electrical circuits necessary to achieve and maintain safe-shutdown in the event of a fire. Appendix R safe-shutdown circuit analysis proved a difficult task for the licensees to implement, and numerous generic communications were issued in the years that followed, including but not limited to:

Generic Letter 86-10 - “Implementation of Fire Protection Requirements”
Generic Letter 89-10 - “Safety Related Motor Operated Valve Testing and Surveillance”
Information Notice 92-18 - “Potential for Loss of Remote Shutdown Capability During a Control Room Fire”

In the late 1990's, NRC noticed, through inspection, an increased number of plant specific problems related to potential fire-induced electrical circuit failures that could prevent operation or cause maloperation of equipment necessary to achieve and maintain hot shutdown. NRC issued Enforcement Guidance Memorandum (EGM) 98-002, “Disposition of Violations of Appendix R, Section III.G and III.L Regarding Circuit Failures,” until the problem was fully understood and appropriate regulatory action could be taken. Information Notice 99-17, “Problems Associated With Post-Fire Safe-Shutdown Circuit Analysis,” documented the problems and because of the number of similar problems among different plants, the NRC decided to address this issue generically. A lack of technical understanding and data of circuit hot shorting and spurious actuations were thought to be the core of the problem, and to fill in this knowledge gap, industry undertook an initiative to increase knowledge of fire-induced circuit failures by performing cable fire tests.

In 2001, the Nuclear Energy Institute (NEI) and the Energy Power Research Institute (EPRI) partnered to conduct cable testing tailored to increase the knowledge and understanding of fire-induced circuit failures. The results of the NEI testing program was documented in EPRI Technical Report 1003326, “Characterization of Fire-Induced Circuit Faults - Results of Cable Fire Testing.” This cooperative test program conducted eighteen tests focused on control circuits varying the cable material types (thermoset and thermoplastic) and thermal exposure conditions, with all tests conducted at Omega Point Laboratories, in San Antonio, Texas.

The results from the NEI/EPRI testing were then evaluated and reviewed by an Expert Elicitation Panel that established best estimate probabilities for spurious actuations. The results of the Expert Elicitation are documented in EPRI Technical Report 1006961, “Spurious Actuation of Electrical Circuits Due to Cable Fires: Results of an Expert Elicitation.”

In March 2004, the NRC issued Regulatory Issue Summary (RIS) 2004-03, “Risk-Informed Approach for Post-Fire Safe-Shutdown Circuit Inspections.” [1] RIS 2004-03 informed licensees that the NRC had risk-informed its inspection procedure for post-fire safe-shutdown circuit

[1] RIS 2004-03 was revised in December 2004 to expand its scope from “associated circuits” to all post-fire safe-shutdown circuits.

analysis inspections to concentrate inspection on circuit failures that have a relatively high likelihood of occurrence in the event of a fire. RIS 2004-03 included six circuit configurations (referred to as “Bin 2 Items”) that may not warrant inspection under the risk-informed program, pending additional research.

There were no NEI or EPRI plans to perform this additional research. The NRC initiated an independent testing program to investigate each of the Bin 2 items and to provide a recommendation as to the ultimate resolution of each item - should the item move up to Bin 1 (Items to Be Considered During Inspection), or should the item be considered a circuit failure configuration that won't be included in the inspection procedure (Bin 3). This testing program is known as, CAROLFIRE [Cable Response to Live Fire] and is currently being conducted at Sandia National Laboratories. A NUREG/CR documenting the results of this testing will be made available in early 2007.

1.1.2 Post-Fire Safe-Shutdown Circuit Analysis -- Armored Cable

In the U.S. fleet of Nuclear Power Plants (NPPs), extensive use of armored cables is specific to Duke Nuclear Generations Company Plants, with the majority of NPPs using polymer jacketed cables, except in locations where cable physical protection and flexibility is desired (ie. connections between a motor and junction box). Due to the very small portion of cables in NPPs being of the metal armor type, the NRC sponsored CAROLFIRE testing program did not included armored cable in its testing matrix, and considered it a Duke specific issue.

In the NEI/EPRI tests conducted in 2001, two of the eighteen tests exposed steel armored, PVC jacketed cables to evaluate the effects armoring has on electrical response during fire conditions. The outcome of these two tests provided mixed results; [

] The mixed outcome of these two tests provided little to no advances in the understanding of fire-induced circuit failures in armored cable and provided for large uncertainties in the Expert Elicitation best estimate probabilities for spurious actuations of armored cable. Thus, further information would be an advancement in the understanding of circuit failure in armored cables.

To fill this knowledge gap in armored cable circuit failure mode likelihoods, Duke Power conducted full-scale supplementary fire testing. The tests were also focused on deriving circuit failure probabilities for use in an NFPA 805 application, per 10 CFR 50.48(c) “Performance-based Standard for Fire Protection for Light Water Reactor Electric Generating Plants.”

2 DUKE TESTING

2.1 Overview of Duke Testing Program

Duke Power, the dominant U.S. NPP user of armored control cables, conducted supplementary full-scale fire testing to further expand the knowledge base and understanding of armored control cable and electrical circuit response to fire. The testing involved exposing a filled cable tray of armored control cable to fire conditions in a small test enclosure. Response was measured as actuations of control devices (NEMA starters and switchgear breaker coils) in test circuits and by measurements of voltage and current in the individual cable conductors. The primary objective of this testing was to develop experimental information to provide a basis for determining probabilities of spurious device actuations and failure for risk-informed analysis. The armored cable tests were conducted at Intertek Testing Services NA, Inc. (formerly known as Omega Point Laboratories) during three testing periods, August 7th-18th, September 5th-8th, and September 18th-22nd, 2006.

This report documents independent observations and results of the armored cable fire tests conducted by Duke Nuclear Generation, made by an NRC staff member.

2.2 Purpose

Duke undertook full-scale armored control cable fire testing to develop experimental information that could provide a basis for determining probabilities of spurious device actuations and failures for risk-informed analysis. The tests were designed to represent Duke plant installations. Results obtained from these tests are also thought to help better understand the electrical response of armored control cables and associated circuits.

2.3 NRC Involvement and Content of this Report

The NRC reviewed and provided comments on Duke's original armored cable test plan on October 20, 2005. The comments, [ ], and original test plan have been attached to this report (Agencywide Documents Access and Management System (ADAMS) Accession Nos. ML052910084, [ ], and ML052900252, respectively). [ ] Prior to testing, Duke extended an invitation to NRC to witness the testing. The NRC accepted and sent a staff member to San Antonio, Texas to witness the entire test series. This individual was at the laboratory for the entire testing program and this report is based on his observations and test data collected and provided by the laboratory.

This report describes the general testing configuration and provides results of individual tests, noting any deviations from the general test setup. The attachments to this report provide additional information, relevant pictures and diagrams.

3 CABLE FIRE TESTING

This section provides the details of how the Duke testing was conducted. The description of the test setup that follows can be considered applicable to all tests and will be referred to as “the standard test setup.” All variations and observations made on individual tests are documented on an individual basis in the test results section of this report.

3.1 Test Plan

Duke armored cable testing was divided into 5 groups of tests, representing a variety of cable configurations found at Duke Plants. Each group consisted of four identical tests. Table 1 below shows the major variations (in **bold text**) between each test group. Group 1 is the base case (most common circuit configuration in Duke Plants).

Table 1 – Duke Test Matrix

Variable	Group 1 **Base Case** Tests 1 - 4	Group 2 Tests 5 - 9	Group 3 Tests 9 - 12	Group 4 Tests 13-16	Group 5 Tests 17 - 20
Cable Type (# of conductors)	8/C	8/C	8/C	8/C	**37/C**
Exterior Jacketing	PVC Jacketed	**Bare Armor**	PVC Jacketed	PVC Jacketed	PVC Jacketed
Tray fill (# rows)	3	3	3	3	**2**
# Monitored Cables	8	8	8	8	**2**
Power Source Configuration	120VAC CPT Ungrounded	120VAC CPT Ungrounded	120VAC CPT **Grounded**	**125VDC Source**	120VAC CPT Ungrounded

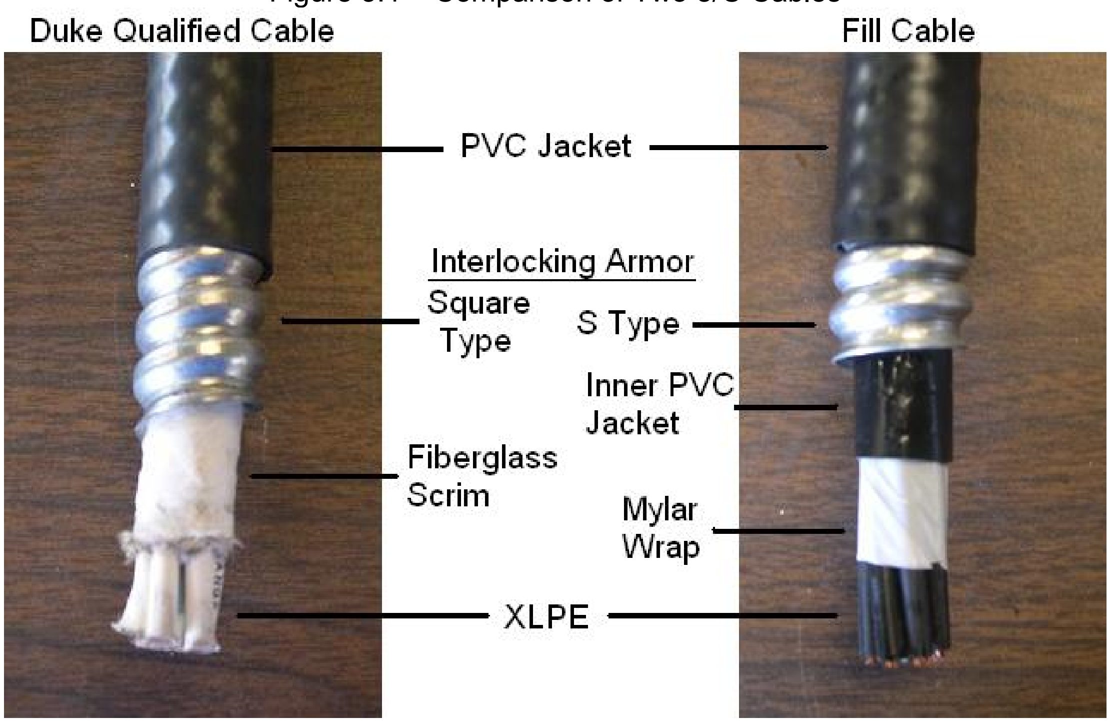
3.2 Test Cables

Cables evaluated for electrical response were representative of cables used in Duke NPPs. All cables tested were of a similar construction, specifically a #12 American Wire Gauge (AWG) tinned copper conductor, a flame retardant cross-linked polyethylene (XLPE) insulation, a galvanized steel interlocking armor, and a polyvinylchloride (PVC) exterior jacket.

In the eight conductor (8/C) cable tests two cable types were used; a Duke qualified cable (a.k.a. “Duke cable”) and a “fill cable.” The Duke cable was of the latest Duke plant (Catawba) specifications, which includes full IEEE-383 qualification, along with other non-regulatory required qualifications (ie. IEEE 1581 VW-1). The Duke qualified cable was taken from on hand stock at Duke’s warehouse and was manufactured by General Cable in 2005. The Duke cable was of a construction described above, with the addition of a fiberglass scrim between the steel armor and conductors. Flame retardant polypropylene filler was used in the Duke cable to achieve cable roundness. In the Duke cable, the galvanized steel interlocking armor was constructed with a square type interlock. The XLPE insulation was white in color and used the ICEA Method 3 Type E1 print identification. Appendix A contains the cable specification sheets.

An 8/C fill cable was used to simulate combustible material and thermal mass that would be in actual plant installations. The fill cable was of similar construction but only qualified to the IEEE-383 flame standard. The fill cable is not a cable used at Duke plants, but was bought for use in these test as a practical substitute. According to the Duke test plan, “the fill cable provided a practical, yet suitable consistency of material within the cable tray fill to maintain no air space between cables.” This fill cable was bought as a practical replacement to reduce project cost, because exclusive use of the Duke cable would be more expensive than using a cheaper fill cable. Besides being of a different qualification, the fill cable was also of a slightly different construction. Instead of a fiberglass scrim between the steel armor and conductors, a plastic mylar material was wrapped around the conductors, over which a PVC inner jacket was extruded. The inner PVC jacket was the same material used on the fill cables exterior PVC jacket. A Fourier transform infrared spectroscopy was conducted on the two jacket materials to confirm this (Attachment 4). The fill cable also differed from the Duke cable in its armor construction, such that the fill cable used an “S” type interlocking armor. Although the fill cable introduced another variable into the testing, it is speculated that because of the similar construction and identical diameters between the two cables, the fill cable did not reduce any conservatisms from this testing. Figure 3.1 below is a comparative photo of a Duke cable and fill cable.

Figure 3.1 – Comparison of Two 8/C Cables

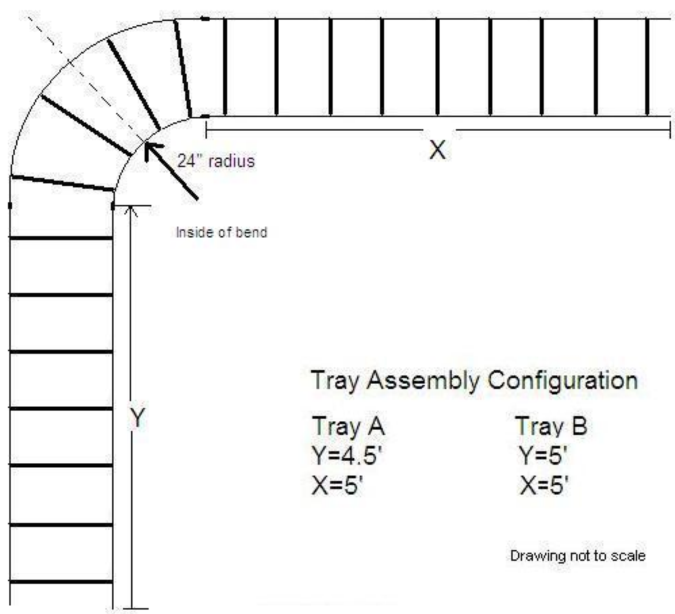


In the 37 conductor (37/C) cable tests, only one cable type was used in all tests. The 37/C cable used for testing was the same cable type used in Duke plants. The cable was taken from storage at a Duke facility where it had been stored in an outside but covered environment for approximately six years. The 37/C cable is qualified to the same standards as the 8/C Duke cable. Its construction consists of three layers of #12 AWG tinned copper conductors, each insulated with flame retardant XLPE, a galvanized steel square-type interlocking armor, and an extruded exterior PVC Jacket. Additional details on the construction of the 37/C cable are discussed in Section 3.5.3, “Cable Connection Configuration”.

3.3 Test assembly

The test assembly consists of a cable tray loaded with a cable arrangement. The cable tray was made of two 5-foot (1.5-meters) long straight segments of a 12-inch (0.3-meters) wide by 6-inch (0.15-meters) high galvanized steel ladder-back type cable tray, with each segment bolted to one end of a 24-inch (0.61-meter) radius 90° tray bend (see Figure 3.2). Cable tray rung spacing was approximately 9-inches (0.23-meters). This cable tray size, type, and bend radius are used throughout Duke NPPs. In all tests, the cable test assembly was positioned in a horizontal orientation. Two new cable trays were built for the testing. The two tray assemblies differed slightly in that one tray had a single straight segment measure 4-feet 6-inches (1.4-meters) instead of 5-feet (1.5-meters).

Figure 3.2 - Horizontal Tray Assembly



In the NEI/EPRI tests of 2001, a square 90° tray bend was used. In one armored cable test, the square bend allowed cables to exceed the minimum bend radius, which possibly biased hot shorting and spurious actuation results. In the Duke tests, the manufacture of the Duke qualified cable specified a minimum bend radius of 8-12 times the outside diameter of the cable. The 8/C Duke cable measured 1.1-inches in diameter, resulting in an 8.8-inch to 13.2-inch minimum bend radius. The 37/C cable measured 1.8-inches in diameter, resulting in a 14.4-inch to 21.6-inch minimum bend radius. In all Duke tests, there was a solid orderly filled tray with minimal air space and, therefore, the trays 24-inch 90° bend radius did not allow for the installed cables to exceed the manufactures specified minimum bend radius.

In the 8/C jacketed tests an array of three rows by eleven columns of cable were loaded into the tray (see Figure 3.3), eight cables were Duke cable (A-H), each connected to a device actuation circuit (discussed below in Section 3.5), which monitored the cables electrical response. Fill cables constituted the remaining of the cable tray fill. The fill cables were not monitored electrically; however one fill cable next to each Duke cable was instrumented with three to six thermocouples to monitor the thermal effects associated with the neighboring electrically monitored Duke cable. This is typically done to ensure that the thermocouple leads do not interact with the cables energizing electrical source characteristics during fire testing. Each

Duke cable was roughly 21-feet (6.4-meters) in length and the fill cables were 16-feet (4.9-meters) in length, which allowed for a single pass of cable through the tray assembly. The Duke cables were longer to allow for electrical connections to be made at each cable end. In the 8/C bare armor tests one additional column of cables was added to the tray fill to minimize air space. Specifics on bare armor tray fill are provided in the respective results section.

In the 37/C tests two rows by six columns of cable were loaded into the tray assembly (see Figure 3.4). Only 2 cables (1 and 2) were monitored for electrical response to fire in these tests, but each monitored cable was connected to four device actuation circuits. Again, cables next to the monitored cable were instrumented with thermocouples in the bend region of the test assembly to monitor the temperature associated with the neighboring electrically monitored cable.

Figure 3.3 - Tray Fill for 8/C Jacketed Test

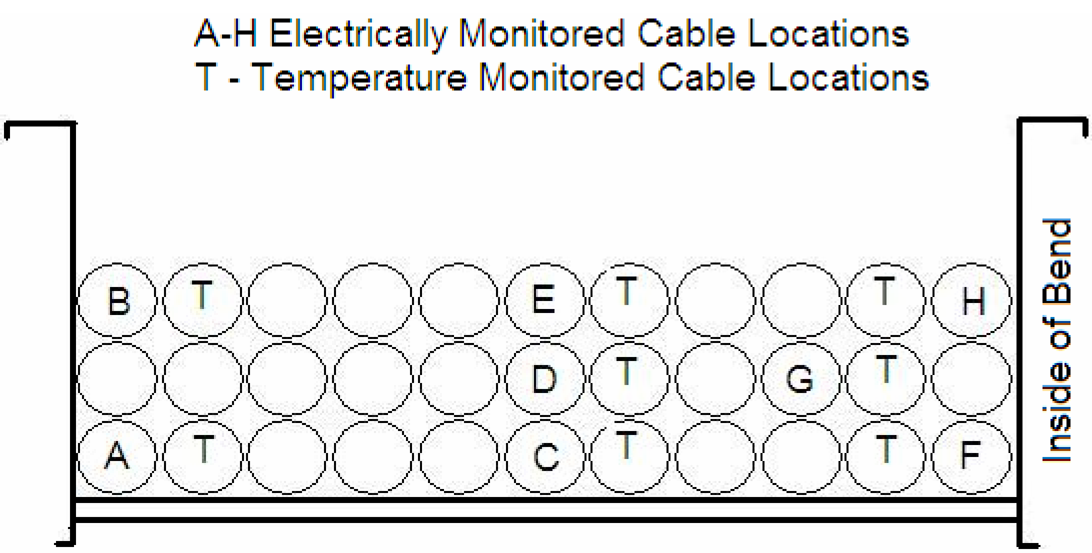
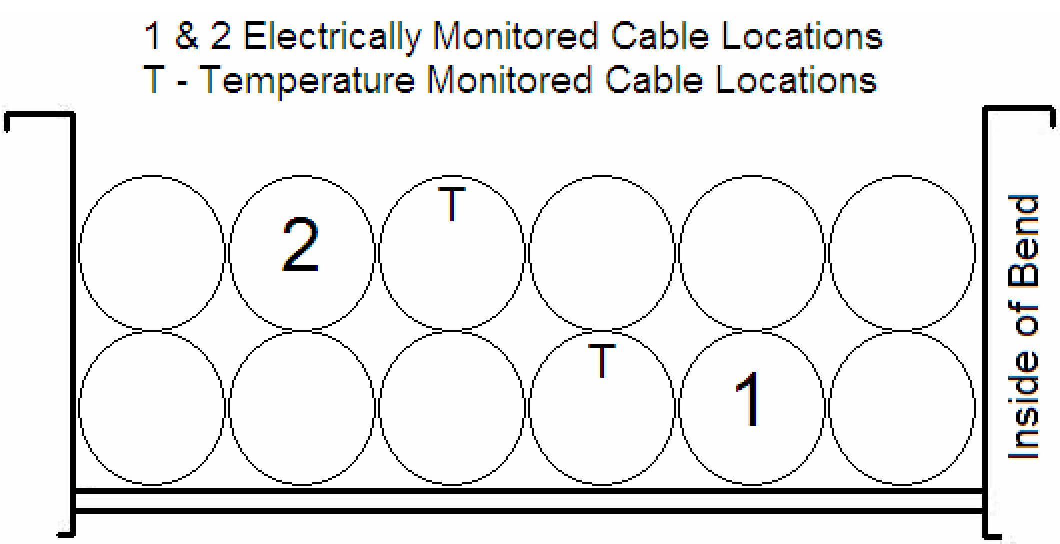


Figure 3.4 - Tray Fill for 37/C Test



3.4 **Test Chamber**

Tests were conducted in the same steel test chamber used in the NEI/EPRI tests of 2001. The test chamber was made out of 1/4-inch thick steel and measured ten feet by ten feet square with a height of eight feet (3 by 3 by 2.4-meters). The chamber rests on a concrete floor. There are two openings in the chamber. One opening is a standard door sized opening, where one end of the test assembly penetrated. The door opening measured 29-inches (0.74-meters) wide and 79-inches (2-meters) height. The other opening was a small rectangular opening (hole) cut into the chamber specifically for these tests. The opening was 16-inches (0.4-meters) wide by 8-inches (0.2-meters) high and was used to pass the opposite end of the test assembly through the steel fire test chamber to allow for cable connections to the device actuation circuits. The space between the cable tray and the rectangular hole opening was filled with Kaowool insulation before each test. The steel fire test chamber also had several holes that were not utilized for this testing and were filled with Kaowool insulation. The steel fire test chamber had a significant amount of oxidation (rust) on both the inside and outside surfaces, most likely from being stored outdoors.

After a test assembly was built (filled with cable and instrumented with thermocouples), it would be manually lifted and positioned within the steel fire test chamber such that one end of the test assembly would penetrate the square hole opening, while the other end penetrated the door opening. The test assembly was elevated ~38-inches (0.97-meters) from the floor and rested on two stacks of 5 concrete blocks located at each end of the tray, with a suspended steel chain supporting the bend section of the test assembly. Figure 3.5 shows the test room configuration and Figure 3.6 shows a photograph looking into the test chamber through the door opening.

Figure 3.5 - Test Assembly in Test Chamber (cables not shown)

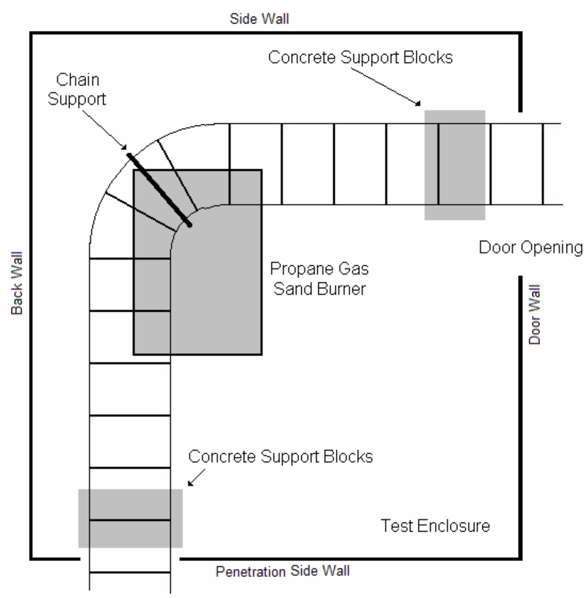


Figure 3.6 – Photo of Test Assembly Positioned in Test Chamber

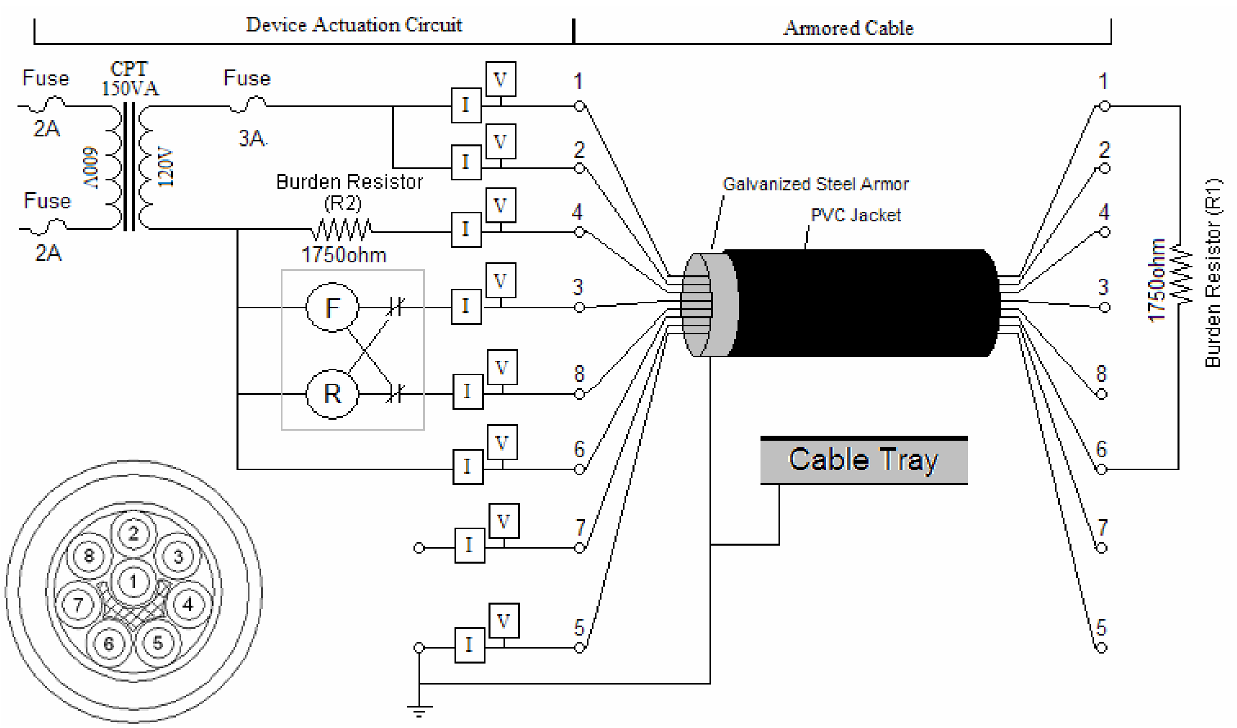
3.5 Electrical Response Monitoring - Device Actuation Circuit

Electrical response was measured as spurious device actuations and individual conductor voltage and current profiles, using a device actuation (DA) circuit similar to the one used in the EPRI/NEI tests (EPRI Technical Report 1003326). Both alternating current (AC) and direct current (DC) circuits were used in the testing to mimic a 120VAC Motor Operated Valve (MOV) or a 125VDC Switchgear breaker circuit. Section 3.5.1 discusses the 120VAC DA circuit, 3.5.2 discusses the 125VDC DA circuit, 3.5.3 explains the configuration used to connect the DA circuit to the cable conductors, and Section 3.5.4 explains how spurious actuations were determined. A complete listing of all circuit component specifications available can be found in Appendix A.

3.5.1 120VAC Device Actuation Circuit

The 120VAC DA circuit is similar to the one used in the NEI/EPRI tests of 2001 (EPRI Technical Report 1003326), except that an 8/C configuration was used. Eight DA circuits were built on a 4 foot by 8 foot sheet of plywood. A wiring harness was used to make connections (using wire nuts) between the DA circuit and associated test cable. Each DA circuit can be connected to 8 conductors labeled 1 through 8 in Figure 3.7. A cross-section of an 8/C cable is shown in the bottom left corner of Figure 3.7 to identify the conductor location within a cable which correspond to the DA circuit connections. Section 3.5.3, "Cable Connection Configuration," provides more detail on this arrangement.

Figure 3.7 - Device Actuation Circuit
120VAC MOV Circuit



In most motor control applications, control power is taken from two phases of a 3-phase power source that is used to power the MOV under control. Typical Duke MOV applications use a

600V supply to power MOVs. During these fire tests, the power for the device actuation circuits came from a single phase step-up transformer (not shown in Figure 3.7). The single phase step-up transformer increased the laboratories 208V power source to a 600V level (phase-to-phase), which was then supplied to the primary side of each control power transformer (CPT) (one per DA circuit).

As shown in the figure above, 2-amp fuses were placed on each phase of the 600V source between the single phase transformer (not shown) and the primary side of the CPT. A single 3-amp fuse was placed on the secondary side of the CPT to act as the primary circuit protection device, with the two 2-amp fuses providing backup protection.

In each circuit, a 150 Volt-Amp CPT was used to provide power. The CPTs used for testing, were the same type and size used in motor-control centers to feed safety-related MOV starter controls at Duke NPPs. The CPT was rated at 150VA and was connected in a configuration to produce 120V on the secondary side. Test measurements showed that the actual voltages produced by the CPTs under low-load conditions were between 126.75 and 128VAC. In some tests the secondary side of the CPT was grounded, however most tests involved an ungrounded circuit because this is the typical circuit configuration in the majority of Duke applications. Industry in general use both grounded and ungrounded circuits. It is speculated that the philosophy for using an ungrounded system is added reliability (ie. there needs to be more than one short-to-ground to cause mal-operation). Grounded systems are typically used to provide personal safety.

In the DA circuit above two conductors, conductor 3 (C-3) and conductor 8 (C-8), were connected to the forward and reverse coil of a motor starter, respectively. Motor starters were the actuation devices used in the 120VAC DA circuit. The motor starters were of the reversing type with NEMA 1 classification, manufactured by Josyln-Clark. The NEMA 1 starters had electrical and mechanical interlocks which only allowed for one of the two starter coils (forward or reverse) to be energized at anytime. Before the testing series began, Duke evaluated each NEMA 1 starter to determine pick-up and drop-out voltages of each coil. For most starters, full coil pickup occurred between 68-90 volts (56.6-75.0% nominal voltage) for all starter coils. A detailed discussion of starter testing can be found in Appendix B.

To indicate actuation of a device, both visual and electrical indications were utilized. An independent 14 volt DC power source was connected to one side of the main contacts on the motor starters and a DC lamp was connected to the other side. When a coil was energized, the DC lamp would illuminate indicating that the device has actuated. In parallel with the DC lamp were also connections to the data recording system which would record a positive 14 volts for the reverse coil actuation and negative 14 volts for the forward coil actuation. The positive and negative indication were from the fact that a 3-phase reversing starter simply interchanges two phases to cause a motor to operate in the opposite direction. Thus, the test labs used this to their advantage in determining which coil (reverse or forward) actuated. In addition to recording the actuations electrically, in every test a video camera was setup in a position which monitored all starter DC lamps and therefore their illumination would represent an actuation.

Two other conductors, C-1 and C-2, were connected to the DA circuit power source. C-1 was then connected on the load end to a burden resister (R1), with C-6 being the burden resister (R1) return path. The purpose of the burden resister is to simulate the load imposed by indicating lamps or any other continually energized devices. C-2 was not connected on the load end, but left electrically open (unconnected to anything). C-4 has a burden resistor connected to the return point of the CPT, but is not connected at the load end of the cable. This is to represent non-energized resistive loads (i.e. un-lit indication lamps).

Two spare conductors, C-5 and C-7 were connected in two different configurations. C-7 is not connected on either end of the cable, simulating a connection between two open contacts. C-5 is grounded on the DA circuit side of the cable and left unconnected on the load side. Grounding spare (unused) conductors is a practice that Duke utilizes throughout their plants per their specifications.

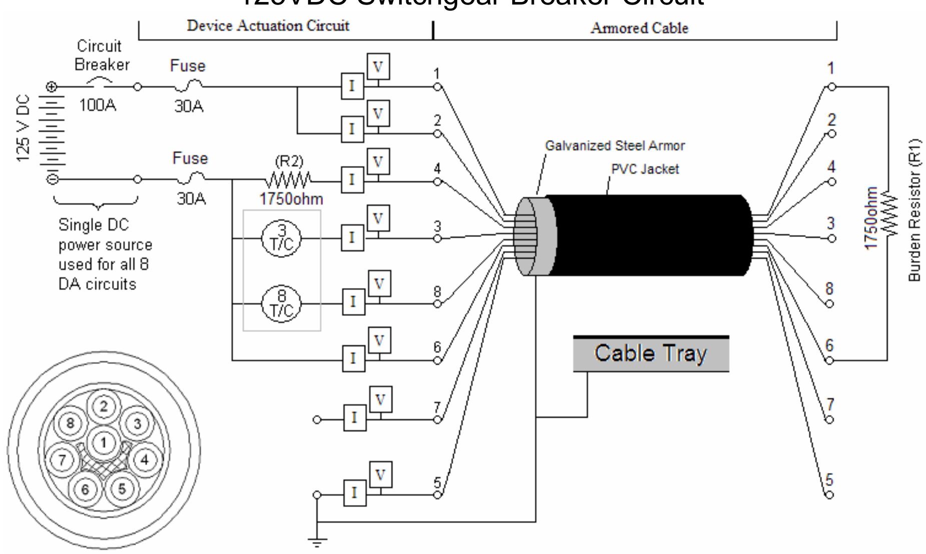
Voltage and current on each conductor connected to a DA circuit was measured by the use of self-powered voltage and current transducers. Section 3.5.4 provides detail on use of this type of transducer as it relates to spurious actuations. All voltage transducers referenced the CPT secondary side common terminal. Thus, all recorded voltage measurements are made with this reference point.

In all AC tests the cable tray, armor of monitored cables, test chamber, and C-5 were connected to earth ground. The grounding point was a metal electrical conduit that ran through the building where the tests were being conducted. In test Group 3 (tests 9-12), the CPT secondary was grounded to evaluate the effect that grounding had on circuit response. More on this setup can be found in the results section of this report (Section 4 – Group 3 Tests).

3.5.2 125VDC Device Actuation Circuit

The125VDC DA circuit layout is identical to the 120VAC circuit layout. The only difference being DC components replace the AC components. Figure 3.8 shows the 125VDC device actuation circuit. All eight 125VDC DA circuits were built on a new 4 foot by 9 foot sheet of plywood. A wiring harness was used to make connections (using wire nuts) between the DA circuit and associated test cable. Each DA circuit can be connected to 8 conductors labeled 1 through 8, as shown in Figure 3.8. A diagram of a cross section of an 8/C cable is shown in the bottom left corner of Figure 3.8 to identify the conductor location within a cable. More information on the specific DC components used can be found in the test results section and in Appendix A.

Figure 3.8 – Device Actuation Circuit
125VDC Switchgear Breaker Circuit



3.5.3 Cable Connection Configuration

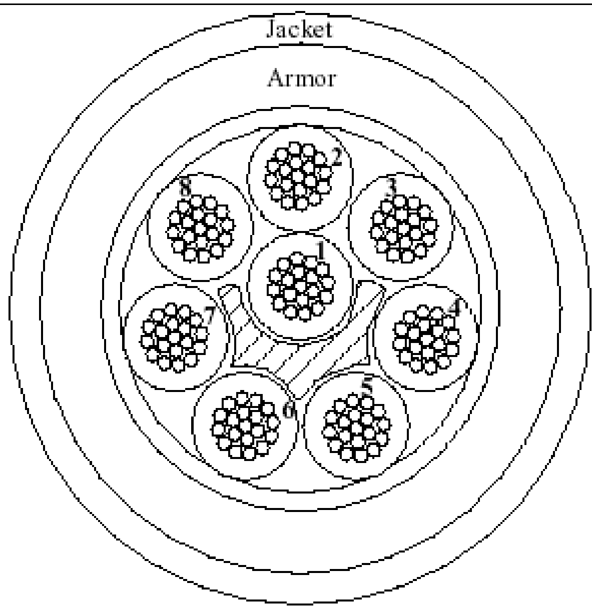
In all tests, a source centered conductor connection pattern was used. Duke selected this method because the NEI/EPRI test results showed that the source centered configuration resulted in having the highest probability to cause spurious actuations. In the Duke 8/C tests, the source centered conductor connection pattern places the two source conductors between the two target (actuation device) conductors. Figure 3.9 on the following page was taken from the Duke test plan and shows the source centered configuration used.

Figure 3.10 on the following page shows the 37/C connection pattern. In the 37/C tests, each cable contained four DA circuits. The 37/C cable is constructed with three layers of conductors. Seven conductors form the core of the cable, one DA circuit for each cable monitored was connected to the core layer in a source centered configuration, except that conductor 8 (open spare) was located in the middle layer. A middle layer of 12 conductors surround the core layer. One DA circuit was connected to this middle layer and is connected with the two source conductors next to the two target (actuation device) conductors. The outer layer contains 18 conductors which surround the middle layer. In the outer layer, two DA circuits were connected with the two source conductors next to the two target (actuation device) conductors. Five spare conductors in each 37/C cable were not connected to a particular DA circuit, and were either grounded, powered, or left unconnected. The spare powered source conductor was placed in the middle layer next to an actuation device conductor. Power for the spare conductor came from an independent CPT circuit which included voltage and current monitoring. Although the DA circuit connected to the core layer is connected in the source-centered configuration, all other DA circuits could be considered to be connected in either the source-centered or the actuation biased configuration (as shown in EPRI Report 100326). In this report, the 37/C cable connection configuration, as described above, will be referred to as the source-centered configuration. No matter how this configuration is referred to, it is speculated that the connection configuration discussed above will result in the highest probability of spurious actuations.

An important concept when conducting circuit and cable failure mode analysis is to know that each layer of conductors in the 37/C cable are spiraled in opposite direction to one another. Therefore, a conductor in the middle layer may be located next to a conductor in the outer layer at one cross section of the cable. However, a few inches down the cable, these two conductors may be located on opposites sides of the cables cross section. This method of cable construction plays an important role in the way that Duke chose to connect the device actuations circuits to the 37/C cable, as shown in Figure 3.10.

Also, in the 37/C tests, conductor 20 was not implemented as an open wire (as shown in Figure 3.10). Instead, the return path of the spare CPT was connected to conductor 20. This was done to provide a return path in the cable to create a closed circuit. Without this return path, the extra CPT source would not be capable of possibly causing a spurious actuation under fire conditions.

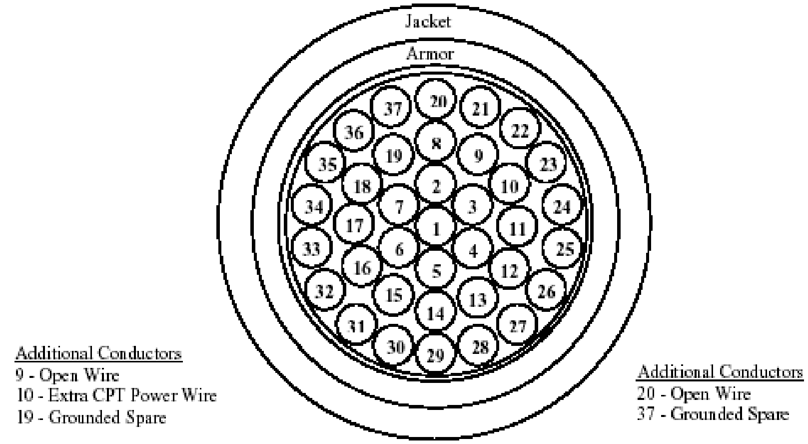
Figure 3.9 - Cable Conductor Arrangement - 8/C
(Taken from Duke Test Plan)



Conductors vs. Figure 2 Configuration:

1 – Control Power Source to Burden R1
2 – Control Power Source - Unloaded
3 – Actuating Device (Starter Forward or Breaker Close Coil)
4 – Burden Resistor R2 Load - Open
5 – Grounded Spare
6 – Control Power Source Return (from Burden R1)
7 – Open Wire (ex/ Open Contact)
8 – Actuating Device (Starter Reverse or Breaker Trip Coil)

Figure 3.10 - Cable Conductor Arrangement - 37/C
(Taken from Duke Test Plan)



NOTE: Center, middle, and outer layers are twisted in successive opposite directions. Therefore, the relative position between the 3 layers is continuously changing with cable length.

1st 8/C-Bundle (Source-Centered) Conductors
1 – CPT 1 Power Source to Burden R1-1
2 – CPT 1 Power Source - Unloaded
3 – Starter 1 Actuating Device (Forward)
4 – Burden Resistor R2-1 Load - Open
5 – Grounded Spare
6 – CPT 1 Return (from Burden R1-1)
7 – Starter 1 Actuating Device (Reverse)
8 – Open Wire (ex/ Open Contact)

2nd 8/C-Bundle (Middle-Ring) Conductors
11 – Starter 2 Actuating Device (Forward)
12 – CPT 2 Power Source to Burden R1-2
13 – Starter 2 Actuating Device (Reverse)
14 – CPT 2 Power Source - Unloaded
15 – Burden Resistor R2-2 Load - Open
16 – CPT 2 Return (from Burden R1-2)
17 – Open Wire (ex/ Open Contact)
18 – Grounded Spare

3rd 8/C-Bundle (Outer-Ring) Conductors
21 – Starter 3 Actuating Device (Forward)
22 – CPT 3 Power Source to Burden R1-3
23 – Starter 3 Actuating Device (Reverse)
24 – CPT 3 Power Source - Unloaded
25 – Burden Resistor R2-3 Load - Open
26 – CPT 3 Return (from Burden R1-3)
27 – Open Wire (ex/ Open Contact)
28 – Grounded Spare

4th 8/C-Bundle (Outer-Ring) Conductors
29 – Starter 4 Actuating Device (Forward)
30 – CPT 4 Power Source to Burden R1-4
31 – Starter 4 Actuating Device (Reverse)
32 – CPT 4 Power Source - Unloaded
33 – Burden Resistor R2-4 Load - Open
34 – CPT 4 Return (from Burden R1-4)
35 – Open Wire (ex/ Open Contact)
36 – Grounded Spare

3.5.4 Determination of Spurious Actuations

In the 120VAC DA circuit, self powered voltage and current transducers were instrumented on every conductor to take electrical measurements. In the early phases of testing, it was brought to the NRCs attention that the use of self powered transducers places a parasitic load on the circuit that is not present in actual plant installation. This parasitic transducer load could effectively draw enough power away from the CPT, such that the CPT would no longer be capable of providing its rated power and would effectively reduce the power available to cause a spurious actuation, if adverse fire conditions caused the circuit to be in a hot short condition. Effectively the self powered transducers could draw enough power from the CPT such that if a hot short were to occur in an orientation that would cause a spurious actuation, there may not be enough power to cause the starter coil to fully pick-up, but instead the relay would chatter (rapidly change states from being energized to non-energized). In the NEI/EPRI tests, spurious actuations were only credited when a starter relay coil achieved full locked-in. Relay (coil) chatter without full lock-in was not considered a spurious actuation.

The NRC brought this matter to the attention of Duke representatives running the testing and a subsequent conference call was held on August 8, 2006, before the start of any testing. During that conference call, Duke representatives discussed the parasitic transducer loading with NRC and Duke explained their intentions of identifying any starter relay chatter a spurious actuation. Therefore, in the Duke testing, any starter chatter or starter full lock-in was credited as a spurious actuation. The outcome of this conference call is documented in Attachment 6.

During all tests a video recorder was placed next to the DA circuit board to record any visual indication (lights) or physical movement of the NEMA 1 starters. Individuals running the test, also monitored the DA circuits for spurious actuations.

3.6 Thermal Response Monitoring - Thermocouple Placement

Type K, bead head, sheathed thermocouples (TCs) were used in all tests. Thermocouple placement was concentrated at the 90° cable tray bend, where the heat exposure was greatest. Both the tray and cables were instrumented with thermocouples, along with several TCs suspended in air just below the tray (~1-2 inches).

Thermocouples that measured cable temperatures were placed on the top exterior surface of a cables PVC jacket. At least one layer of 1/2-inch fiberglass tape was wrapped around the cable and thermocouple leads, capturing the bead of the TC in the center of the wraps. No internal cable temperatures were taken. Cables that were connected to a DA circuit were not instrumented with thermocouples; instead one cable next to each monitored cable was instrumented with several thermocouples. Figure 3.3 and 3.4 above, shows the cable locations with in the tray fill that were instrumented with thermocouples. Not every cable contained the same number of thermocouples, mainly due to the limitation on the number of available computer channels to record temperature data. Once a cable layer was placed inside a tray, thermocouples were placed on the cable at one of the following locations:

Center of tray bend symmetry line (T_{CEN})
One, two, or three feet to the left (away from door opening) of the symmetry line (T_{L1}, T_{L2}, T_{L3})
One, two, or three feet to the right (toward door opening) of the symmetry line (T_{R1}, T_{R2}, T_{R3})

Table 3, provides information as to how each cable was instrumented with thermocouples for the 8/C cable tests. The information in the table cells corresponds to thermocouple data recoding channel identification. Table 4 shows the locations of cable thermocouples for the 37/C tests which only used 10 thermocouples (5 per cable).

Table 3 – Cable thermocouple placement (8/C Tests)

Cable	T_{L3}	T_{L2}	T_{L1}	T_{CEN}	T_{R1}	T_{R2}	T_{R3}
A		5T A	6T A	7T A	8T A	9T A	
B		29T B	30T B	31T B	32T B	33T B	
C		1T C	2T C		3T C	4T C	
D	18T D	13T D	14T D		15T D	16T D	17T D
E		22T E	23T E		24T E	25T E	
F			10T F	11T F	12T F		
G			19T G	20T G	21T G		
H			26T H	27T H	28T H		

Table 4 – Cable thermocouple placement (37/C tests)

Cable	T_{L3}	T_{L2}	T_{L1}	T_{CEN}	T_{R1}	T_{R2}	T_{R3}
1		3T 1	2T 1	1T 1	4T 1	5T 1	
2		8T 2	8T 2	6T 2	9T 2	10T 2	

The tray was instrumented with thermocouple centralized at the bend of the tray and all tray TCs were attached to the tray using metal screws. On the inside bend rail, five TCs were installed at the mid height of the rail (3-inches). The outside of the bend also contained five TCs at the mid-height of the rail. Both the inside and outside tray rail TCs were uniformly spaced one foot from each other with the central TC located at the symmetry line of the 90° tray bend. Five screws were also installed on the bottom of the tray on five of the ladder rungs centralized at the 90° bend segment. Seven air drop TC were also installed. These air drop TCs were suspended in free air space approximately one inch below the tray bottom.

3.7 Thermal Exposure

A propane fueled, rectangular sand burner was used to produce a constant 350kW heat release rate (HRR) for all tests. The 350kW HRR produced flame heights of 3.5-to-4.5-feet (1.1-to-1.4-meters). The steel burner enclosure was 34.25 by 22.75-inches (0.87 by 0.58-meters) and 12-inches (0.31-meters) in height, and made out of 1/4-inch (0.635-centimeters) steel. The top of the sand was approximately 11-inches (0.28-meters) in height, above the ground (ie. top of sand was 1-inch below top of burner enclosure). The HRR was manually controlled by adjusting a valve to achieve a desired flow reading on a flow meter. During the first few minutes of each test, the gas flow would be adjusted to maintain a constant flow of 10.5 scfm, until the system stabilized.

During tests, smoke and products of combustion would exit the test chamber door opening and be exhausted to atmosphere by a fan driven exhaust hood.

3.8 Computer Data Acquisition System

Electrical and thermal data was collected by a computer data recording system running Labview™ software (Labview is a trademark software of National Instruments Corp.). During the first test series (tests 1-3, 5, and 9-12) a pre-existing system was used, which had a 15 second cycle time and used 2 computers to collect 191 channels of data. After reviewing the electrical data, it was determined by Duke that the 15 second cycle time was not adequate to capture the fast electrical response of the cables failures. With the slow cycle time, electrical failures (spurious actuations, hot shorting, etc.) were occurred within the cycle time and in several cases clear electrical response could not be obtained from the recorded data. Thus, a new computer data recording system was built which was capable of monitoring 200 channels with a 2 second cycle time. For the remainder of tests (tests 4, 6-8, and 13-20) the new computer data acquisition system was used to monitor electrical data only, while one of the computers from the pre-existing system was used to capture thermal data.

4 TEST RESULTS

This section provides individual test results. A brief description of the test group is provided at the beginning of each test group section. Each individual test result section describes any test deviations and provides a table of testing parameters. This is followed by temperature response graphs and a table of cable temperatures at the time of failure. Then graphs showing the electrical response of the DA circuits and a brief description of the failure characteristics are provided. A conclusion then summarizes that tests results.

It should be noted that the tests were not conducted in sequential order, as shown in the Duke test plan. Tests were conducted in the following order: Tests 9-12, 1-3, 5, 6, 4, 17-19, 13-14, 20, and 7. Tests 8 was not conducted due to time constraints, while tests 15 and 16 were not conducted because of equipment damage which occurred during test 14.

Group 1 - Ungrounded 120V CPT

Sections 4.1 through 4.4 provide the results from tests 1-4. Group 1 is the most common MOV circuit configuration used in Duke NPPs. Tests 1-4 used the standard tray fill shown in Figure 3.3 of Section 3.3, which included eight DA circuits connected to eight 8/C PVC jacketed Duke cables and placed among three rows of PVC jacketed fill cable within the standard ladder-back cable tray. All Duke cables were connected to the corresponding DA circuit in the source centered configuration. The DA circuits were ungrounded. The HRR for these tests was 350kW with the cable tray bend located in the gas sand burners plume (off center).

4.1 **Test #1** - 8/C PVC Jacketed Ungrounded 120V CPT

4.1.1 Description of Test Setup and Parameters

Test 1 was the first test completed in this group of four redundant tests. The standard test setup was used. Test parameters are shown in Table 4.1-1.

Table 4.1-1: Test 1 Parameters

Parameter	Value
Power Source	120VAC CPT 150VA Secondary Ungrounded
Computer Data Cycle Time	15 seconds
Cable	8 – conductor, PVC Jacketed
Tray Fill	3 rows (Duke and fill cable used)
Tray Assembly Used	Tray A
Tray Height◊	38-inches (0.965-meters)
Burner Position	Center of burner offset ~7-inches (0.177-meters) from center of tray bend
HRR	350kW
Actuation Devices	Josyln-Clark NEMA 1 reversible motor starters

◊ measured from floor to bottom of tray

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4.1.6 Conclusion

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4.2 **Test #2** - 8/C PVC Jacketed Ungrounded 120V CPT

4.2.1 Description of Test Setup and Parameters

Test 2 was the second test completed in this group of four redundant tests. The standard test setup was used. Test parameters are shown in Table 4.2-1.

Table 4.2-1: Test 2 Parameters

Parameter	Value
Power Source	120VAC CPT 150VA Secondary Ungrounded
Computer Data Cycle Time	15 seconds
Cable	8 – conductor, PVC Jacketed
Tray Fill	3 rows (Duke and fill cable used)
Tray Assembly Used	Tray B
Tray Height◊	38.75-inches (0.984-meters)
Burner Position	Center of burner offset ~6-inches (0.152-meters) from center of tray bend
HRR	350kW
Actuation Devices	Josyln-Clark NEMA 1 reversible motor starters

◊ measured from floor to bottom of tray

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4.3 **Test #3 -** 8/C PVC Jacketed Ungrounded 120V CPT

4.3.1 Description of Test Setup and Parameters

Test 3 was the third test completed in this group of four redundant tests. The standard test setup was used. Test parameters are shown in Table 4.3-1.

Table 4.3-1: Test 3 Parameters

Parameter	Value
Power Source	120VAC CPT 150VA Secondary Ungrounded
Computer Data Cycle Time	15 seconds
Cable	8 – conductor, PVC Jacketed
Tray Fill	3 rows (Duke and fill cable used)
Tray Assembly Used	Tray A
Tray Height◊	38.5-inches (0.978-meters)
Burner Position	Center of burner offset ~7-inches (0.178-meters) from center of tray bend
HRR	350kW
Actuation Devices	Josyln-Clark NEMA 1 reversible motor starters

◊ measured from floor to bottom of tray

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4.4 **Test #4** - 8/C PVC Jacketed Ungrounded 120V CPT (All Duke Cable)

4.4.1 Description of Test Setup and Parameters

Test 4 was the last test conducted from Group 1. Test 4 differed from the previous three tests, in that the tray was only filled with Duke 8/C cable and no fill cables were used. It is believed that the test was run this way to evaluate any effects that the fill cable introduced to the tests. Test parameters are shown in Table 4.4-1.

Table 4.4-1: Test 4 Parameters

Parameter	Value
Power Source	120VAC CPT 150VA Secondary Ungrounded
Computer Data Cycle Time	2 seconds (electrical), 15 seconds (thermal)
Cable	8 – conductor, PVC Jacketed
Tray Fill	3 rows (Duke cable ONLY)
Tray Assembly Used	Tray B
Tray Height◊	39-inches (0.991-meters)
Burner Position	Center of burner offset ~8.4-inches (0.213-meters) from center of tray bend
HRR	350kW
Actuation Devices	Josyln-Clark NEMA 1 reversible motor starters

◊ measured from floor to bottom of tray

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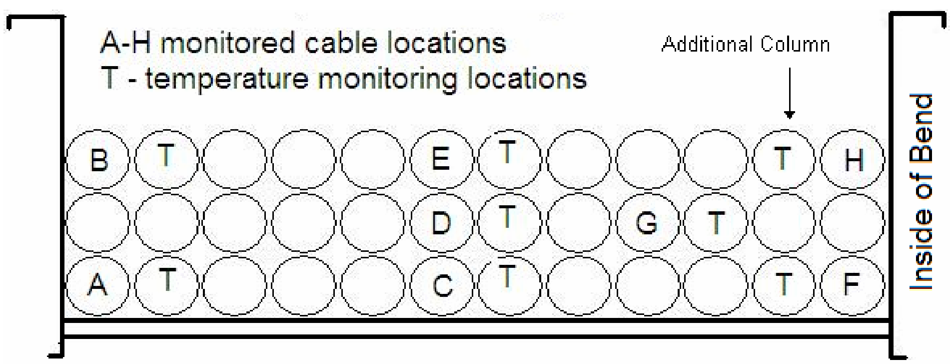
Group 2 - Bare Armor Ungrounded 120V CPT

This section provides results from tests 5-7. Test 8 was not conducted due to time constraints. Group 2 tests involve testing cable with the exterior PVC jacket removed such that the exterior cable surface is bare armor. This type of cable configuration is used extensively for indoor applications at Duke's Catawba plant (outdoor cables would have PVC jacket) and at McGuire inside containment. Dukes reason for removal of PVC jacket is to reduce the amount of combustible material within the plant. Besides having no exterior PVC Jacket, tests 5-7 deviated from the standard tray fill used in other tests by having one additional column of cables placed in the tray fill. Removal of the cables PVC jacket decreased the diameter of each cable, since Dukes test plan called for minimal air space tray fill, one extra column of cables was added for these tests. This tray fill is shown in Figure 4.1.

Figure 4.1 – 8/C Bare Armor Tray Fill



Eight 120VAC DA circuits were connected to eight 8/C bare armor Duke cables and placed among three rows of bare armor fill cable within the standard ladder-back cable tray. All Duke cables were connected to the corresponding DA circuit in the source centered configuration. The HRR was 350kW for all Group 3 tests with the cable tray bend located in the gas sand burners plume (off center).

4.5 **Test #5** - 8/C Bare Armor Ungrounded 120V CPT

4.5.1 Description of Test Setup and Parameters

Test 5 was the first test completed in this group of four redundant tests. Test parameters are shown in Table 4.5-1, on the next page.

Table 4.5-1: Test 5 Parameters

Parameter	Value
Power Source	120VAC CPT 150VA Secondary Ungrounded
Computer Data Cycle Time	15 seconds
Cable	8 – conductor, Bare Armor (no exterior PVC Jacket)
Tray Fill	3 rows; 12 columns (Duke and fill cable used)
Tray Assembly Used	Tray B
Tray Height[◊]	38.25-inches (0.971-meters)
Burner Position	Center of burner offset ~12-inches (0.305-meters) from center of tray bend
HRR	350kW
Actuation Devices	Josyln-Clark NEMA 1 reversible motor starters

◊ measured from floor to bottom of tray

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4.6 **Test #6** - 8/C Bare Armor Ungrounded 120V CPT (All Duke Cable)

4.6.1 Description of Test Setup and Parameters

Test 6 was the second test completed in this group tests. For test 6, the tray was only filled with Duke 8/C cable and no fill cables were used. The reason for conducting the test this way, was to determine if the fill cables were causing the excessive cable burning in test 5. Although not intended, the tray cable arrangement was slightly changed from the previous test. In test 6, cable D was shifted two columns towards the outside of the bend and cable G was moved 1 column away from the inside of the bend, with its corresponding thermally monitored cable moved to the opposite side of cable G. The actual cable configuration is shown below in Figure 4.2. Test parameters are shown in Table 4.6-1.

Figure 4.2 – Test 6 8/C Bare Armor Tray Fill

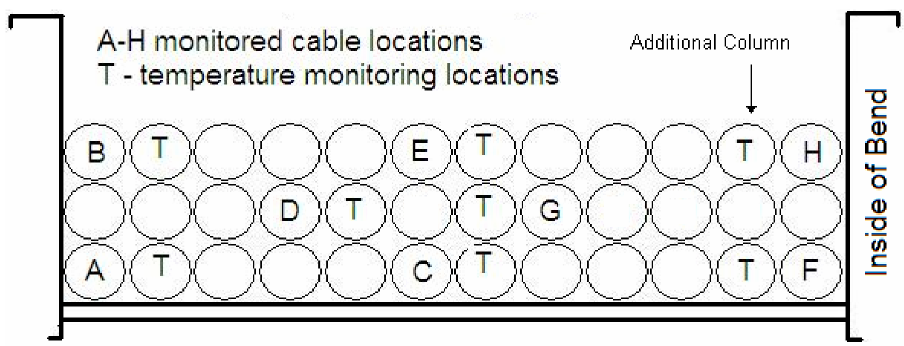

Table 4.6-1: Test 6 Parameters

Parameter	Value
Power Source	120VAC CPT 150VA Secondary Ungrounded
Computer Data Cycle Time	2 seconds (electrically); 15 seconds (thermally)
Cable	8 – conductor, Bare Armor
Tray Fill	3 rows (Duke cable ONLY)
Tray Assembly Used	Tray A
Tray Height◊	38.25-inches (0.972-meters)
Burner Position	Center of burner offset ~10-inches (0.254-meters) from center of tray bend
HRR	350kW
Actuation Devices	Josyln-Clark NEMA 1 reversible motor starters

◊ measured from floor to bottom of tray

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4.7 **Test #7** - 8/C Bare Armor Grounded 120V CPT

4.7.1 Description of Test Setup and Parameters

Test 7 was the last bare armored cable test conducted. Test 7 differed from the previous two tests in that it was conducted with the 120VAC CPT secondary **grounded**. Duke decided to change the scope of this test to evaluate the effect grounding has on spurious device actuations in a bare armor cable. See Figure 4.3, in Section 4.9, for this tests circuit grounding configuration. Test parameters are shown in Table 4.7-1.

Table 4.7-1: Test 7 Parameters

Parameter	Value
Power Source	120VAC CPT 150VA Secondary **Grounded**
Computer Data Cycle Time	2 seconds (electrically); 15 seconds (thermally)
Cable	8 – conductor, Bare Armor
Tray Fill	3 rows (Duke and fill cable used)
Tray Assembly Used	Tray A
Tray Height◊	39-inches (0.991-meters)
Burner Position	Center of burner offset ~12.80-inches (0.325-meters) from center of tray bend
HRR	350kW
Actuation Devices	Josyln-Clark NEMA 1 reversible motor starters

◊ measured from floor to bottom of tray

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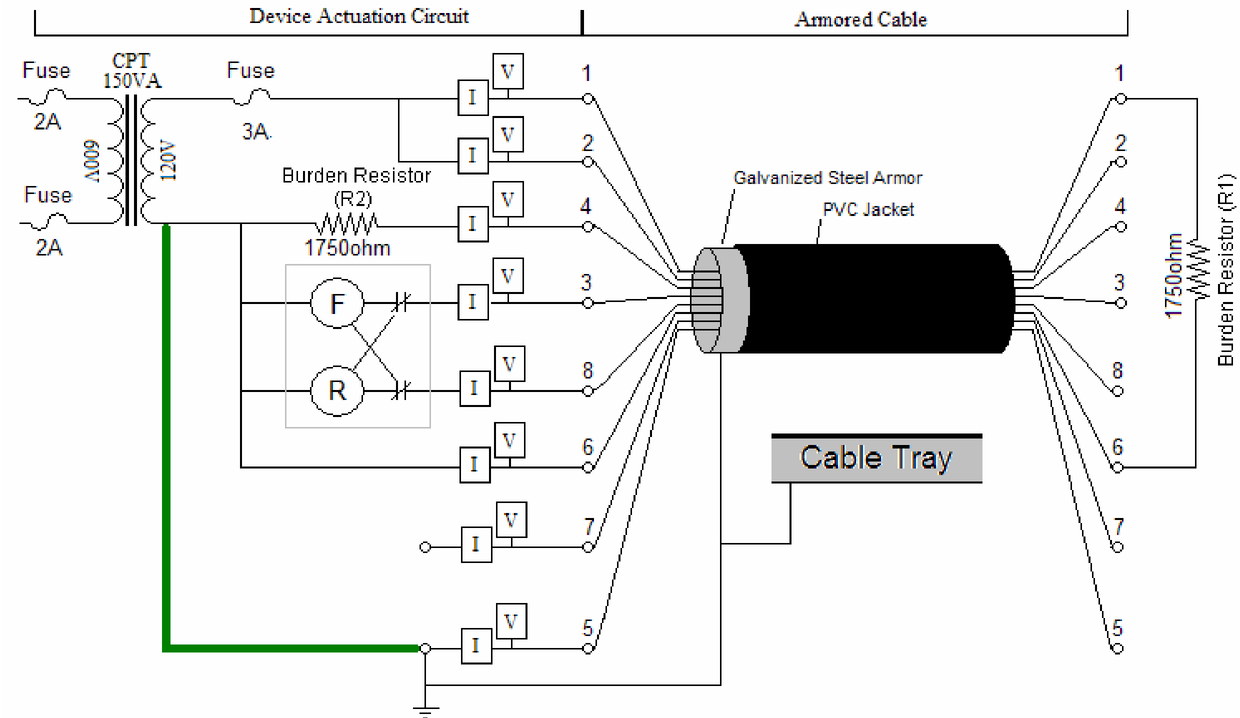
4.8 **Test #8** - 8/C Bare Armor Ungrounded 120V CPT

Test not conducted.

Group 3 - Grounded 120V CPT

This section provides the results from tests 9-12. Group 3 tests were conducted with the secondary side of the 150VA CPT grounded. This grounded configuration is limited to a small portion of Oconee installations. Duke conducted this type of testing to evaluate the effect grounding has on spurious actuations during fire conditions. Figure 4.3, shows the grounding configuration used in Group 3 tests.

Figure 4.3 - Group 3 DA Circuit Grounding



Tests 9-12 were the first tests conducted in the test program. This group of tests used the standard tray fill shown in Figure 3.3 of Section 3.3, which included eight DA circuits connected to eight 8/C Duke cables and placed among three rows of fill cable within a 12-inch horizontal steel ladder-back tray. All cables were connected to the corresponding DA circuits in the source centered configuration. The standard room configuration was used. The HRR for this test was 350kW with the cable tray bend located in the gas sand burners plume (off center).

4.9 **Test #9 -** 8/C PVC Jacketed 120V CPT Grounded

4.9.1 Description of Test Setup and Parameters

Test 9 was the first test completed in this group of redundant tests. Test parameters are shown in Table 4.9-1.

Table 4.9-1: Test 9 Parameters

Parameter	Value
Power Source	120VAC CPT 150VA Secondary **Grounded**
Computer Data Cycle Time	15 seconds
Cable	8 – conductor, PVC Jacketed
Tray Fill	3 rows (Duke and fill cable used)
Tray Assembly Used	Tray A
Tray Height◊	38-inches (0.965-meters)
Burner Position	Center of burner offset ~8.25-inches (0.210-meters) from center of tray bend
HRR	350kW
Actuation Devices	Josyln-Clark NEMA 1 reversible motor starters

◊ measured from floor to bottom of tray

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4.10 **Test #10** - 8/C PVC Jacketed 120V CPT Grounded

4.10.1 Description of Test Setup and Parameters

Test 10 was the second test completed in this group of four redundant tests. The standard test setup was used, except the computer cycle time was increased to 6 seconds. Increasing the cycle time resulted with problems with the computer systems synchronization. One computer recorded more data points than the other, in the same time frame. The results shown below represent an altered data set which tried to make the computer data be in synch with each other. Test parameters are shown in Table 4.10-1.

Table 4.10-1: Test 10 Parameters

Parameter	Value
Power Source	120VAC CPT 150VA Secondary **Grounded**
Computer Data Cycle Time	6 seconds
Cable	8 – conductor, PVC Jacketed
Tray Fill	3 rows (Duke and fill cable used)
Tray Assembly Used	Tray B
Tray Height◊	40-inches (1.016-meters)
Burner Position	Center of burner offset ~10.80-inches (0.274-meters) from center of tray bend
HRR	350kW
Actuation Devices	Josyln-Clark NEMA 1 reversible motor starters

◊ measured from floor to bottom of tray

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4.11 **Test #11** - 8/C PVC Jacketed 120V CPT Grounded

4.11.1 Description of Test Setup and Parameters

Test 11 was constructed identical to tests 9 and 10, except the computer cycle time was set back to a 15 seconds. Also, one cable location was different from the standard setup. Cable G and its associated temperature cable, was positioned one column towards the inside bend of the tray. Although this was not intended, this deviation was found after the test assembly had been built and placed inside the test chamber. No other changes were noted. Test parameters are shown in Table 4.11-1.

Table 4.11-1: Test 11 Parameters

Parameter	Value
Power Source	120VAC CPT 150VA Secondary **Grounded**
Computer Data Cycle Time	15 seconds
Cable	8 – conductor, PVC Jacketed
Tray Fill	3 rows (Duke and fill cable used)
Tray Assembly Used	Tray A
Tray Height◊	38.5-inches (0.978-meters)
Burner Position	Center of burner offset ~6.30-inches (0.160-meters) from center of tray bend
HRR	350kW
Actuation Devices	Josyln-Clark NEMA 1 reversible motor starters

◊ measured from floor to bottom of tray

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4.12 **Test #12** - 8/C PVC Jacketed 120V CPT Grounded

4.12.1 Description of Test Setup and Parameters

Test 12 was the last test completed in this group of four redundant tests. Test parameters are shown in Table 4.12-1.

Table 4.12-1: Test 12 Parameters

Parameter	Value
Power Source	120VAC CPT 150VA Secondary **Grounded**
Computer Data Cycle Time	15 seconds
Cable	8 – conductor, PVC Jacketed
Tray Fill	3 rows (Duke and fill cable used)
Tray Assembly Used	Tray B
Tray Height◊	38.75-inches (0.984-meters)
Burner Position	Center of burner offset ~7.5-inches (0.191-meters) from center of tray bend
HRR	350kW
Actuation Devices	Josyln-Clark NEMA 1 reversible motor starters

◊ measured from floor to bottom of tray

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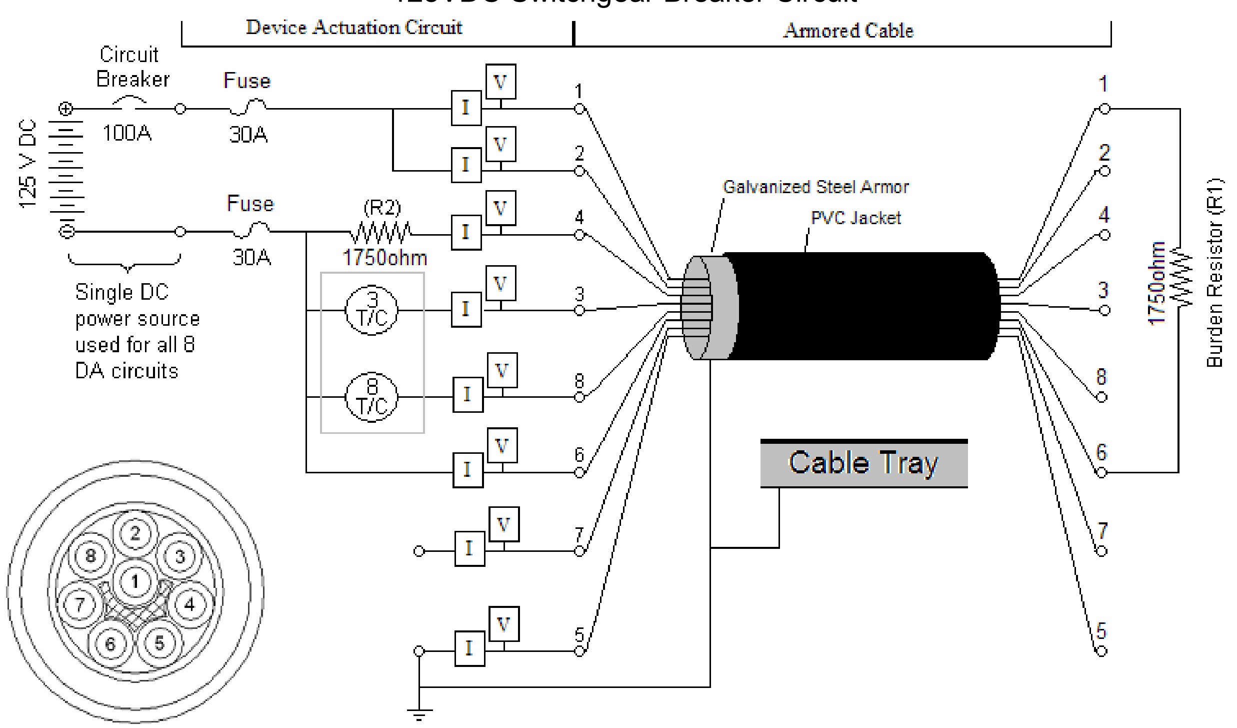
Group 4 - 125VDC Jacketed

This section provides the results from tests 13 and 14. Tests 15 and 16 from the test plan were not conducted due to problem encountered during test 14. Test 13 and 14 used the 125VDC switchgear circuit breaker device actuation circuit to monitor spurious actuations (shown above in Figure 3.8 and reprinted below). Duke conducted this type of testing to evaluate the failure probabilities of DC circuits.

Figure 3.8 – Device Actuation Circuit
125VDC Switchgear Breaker Circuit



To provide a 125VDC power source, ten 12 Volt car batteries were connected in series. The batteries were bought new and no charging was provided before, during, or after any test. A 100-Amp AC 2-pole circuit breaker was used primarily as an on/off switch, but was also sized to provide some circuit protection. The 125VDC battery bank powered all eight DA circuits during testing.

In each DA circuit, 30-Amp fuses were placed on the positive and negative power connections, to act as primary circuit protection devices. This size fuse is used in Duke installations. Duke's fuse sizing philosophy was to allow the circuit every possible change to actuate when demanded.

The actuation devices were 125VDC close and trip coils found in the switchgear breaker. Because of the coils purpose is to cause mechanical movement, the laboratory didn't have a readily available way of monitoring spurious actuations electrically. Therefore, the only way of determining spuriously actuations was to visually monitor the coils during the test and by reviewing recorded video.

The methods used for measuring conductor current and voltage profiles were also different in the 125VDC tests. No transducers were used. To measure current in a conductor, a high precision shunt resistor (0.065 ohms) was placed in series with the conductor and a voltage was measured across the shunt resistor, when a current was present. This voltage level measured can then be correlated to a current level. To measure voltage in a conductor, a resistor divider circuit was connected between the conductor being monitored and the negative terminal of the power supply. The resistor divider consisted of two resistors, with resistance values chosen to keep current through the circuit small (keeping power losses small) and to generate a voltage level across one resistor that could be measured by the computer data recording system. The voltage level recorded can then be correlated to the actual conductor voltage by a scaling factor. More information on this measurement technique is provided in Appendix A.

The burden resistors, R1 and R2 were the same used in the AC tests. In all tests the armor was grounded.

4.13 **Test #13** - 8/C 125VDC Jacketed

4.13.1 Description of Test Setup and Parameters

Test 13 was the first DC test completed. Test parameters are shown in Table 4.13-1.

Table 4.13-1: Test 13 Parameters

Parameter	Value
Power Source	125VDC Battery Bank (10 DC car batteries)
Computer Data Cycle Time	2 seconds (electrical); 15 seconds (thermal)
Cable	8 – conductor, PVC Jacketed
Tray Fill	3 rows (Duke and fill cable used)
Tray Assembly Used	Tray A
Tray Height◊	38.25-inches (0.972-meters)
Burner Position	Center of burner offset ~11.25-inches (0.286-meters) from center of tray bend
HRR	350kW
Actuation Devices	ABB 125V DC Trip Close Coils (2 per circuit)

◊ measured from floor to bottom of tray

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4.14 **Test #14** - 8/C 125VDC Jacketed

4.14.1 Description of Test Setup and Parameters

Test 14 was the second DC test completed. Shunt resistor used to measure current were removed from conductors 1 and 2 in each DA circuit, because they acted like protection devices in test 13. Test parameters are shown in Table 4.14-1.

Table 4.14-1: Test 14 Parameters

Parameter	Value
Power Source	125VDC Battery Bank (10 DC car batteries)
Computer Data Cycle Time	2 seconds (electrical); 15 seconds (thermal)
Cable	8 – conductor, PVC Jacketed
Tray Fill	3 rows (Duke and fill cable used)
Tray Assembly Used	Tray A
Tray Height◊	38.25-inches (0.972-meters)
Burner Position	Center of burner offset ~11.25-inches (0.286-meters) from center of tray bend
HRR	350kW
Actuation Devices	ABB 125V DC Trip Close Coils (2 per circuit)

◊ measured from floor to bottom of tray

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4.15 **Test #15 -** 8/C 125VDC Jacketed

Test not conducted.

4.16 **Test #16 -** 8/C 125VDC Jacketed

Test not conducted.

Group 5 - 37 Conductor Jacketed 120VAC CPT Ungrounded

This section provides the results from tests 17-20. Group 5 tests were conducted using a 37 – conductor cable. These large trunk cables are typically used near cable spreading areas to distribute a large amount of control signals to a specific area of the plant (motor control center, control distribution panel, etc.). Duke conducted this type of testing to evaluate the failure characteristics of this large trunk cable.

Tests 17-20 used the standard 37/C tray fill shown in Figure 3.4 of Section 3.3, which included two rows of 37/C Duke qualified cable within the 12-inch horizontal ladder-back cable tray. Two 37/C cables were monitored for electrical failure by four DA circuits each and placed among two rows of Duke cable. All monitored cables were connected to the corresponding DA circuits in the source centered configuration. The standard room configuration was used. The HRR for this test was 350kW with the cable tray bend located in the gas sand burners plume (off center).

4.17 **Test #17** - 37/C Jacketed 120VAC CPT Ungrounded

4.17.1 Description of Test Setup and Parameters

Test 17 was the first 37/C test completed in this group of redundant tests. The standard 37/C test setup was used. Test parameters are shown in Table 4.17-1.

Table 4.17-1: Test 17 Parameters

Parameter	Value
Power Source	120VAC CPT 150VA Secondary Ungrounded
Computer Data Cycle Time	2 seconds (electrical), 15 seconds (thermal)
Cable	37 – conductor, PVC Jacketed
Tray Fill	2 rows (Duke cable ONLY)
Tray Assembly Used	Tray A
Tray Height◊	38.5-inches (0.978-meters)
Burner Position	Center of burner offset ~7-inches (0.178-meters) from center of tray bend
HRR	350kW
Actuation Devices	Josyln-Clark NEMA 1 reversible motor starters

◊ measured from floor to bottom of tray

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4.18 **Test #18** - 37/C Jacketed 120V CPT Ungrounded

4.18.1 Description of Test Setup and Parameters

Test 18 was the second test completed in this group of redundant tests. The standard 37/C test setup was used. Test parameters are shown in Table 4.18-1.

Table 4.18-1: Test 18 Parameters

Parameter	Value
Power Source	120VAC CPT 150VA Secondary Ungrounded
Computer Data Cycle Time	2 seconds (electrical), 15 seconds (thermal)
Cable	37 – conductor, PVC Jacketed
Tray Fill	2 rows (Duke cable ONLY)
Tray Assembly Used	Tray B
Tray Height◊	38.75-inches (0.984-meters)
Burner Position	Center of burner offset ~9.7-inches (0.246-meters) from center of tray bend
HRR	350kW
Actuation Devices	Josyln-Clark NEMA 1 reversible motor starters

◊ measured from floor to bottom of tray

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4.19 **Test #19** - 37/C Jacketed 120V CPT Ungrounded

4.19.1 Description of Test Setup and Parameters

Test 19 was the third test completed in this group of redundant tests. Test parameters are shown in Table 4.19-1.

Table 4.19-1: Test 19 Parameters

Parameter	Value
Power Source	120VAC CPT 150VA Secondary Ungrounded
Computer Data Cycle Time	2 seconds (electrical), 15 seconds (thermal)
Cable	37 – conductor, PVC Jacketed
Tray Fill	2 rows (Duke cable ONLY)
Tray Assembly Used	Tray A
Tray Height◊	38-inches (0.965-meters)
Burner Position	Center of burner offset ~8-inches (0.203-meters) from center of tray bend
HRR	350kW
Actuation Devices	Josyln-Clark NEMA 1 reversible motor starters

◊ measured from floor to bottom of tray

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4.20 **Test #20** - 37/C Jacketed 120V CPT Grounded

4.20.1 Description of Test Setup and Parameters

Test 20 was the last test completed in this group of four redundant tests. Test 20 was very similar to tests 17, 18 and 19, except for this test the 120VAC CPT secondary was **grounded**. Duke decided to change the scope of this test to evaluate the effect grounding has on spurious device actuations for a trunk cable during fire exposure. Test parameters are shown in Table 4.20-1.

Table 4.20-1: Test 20 Parameters

Parameter	Value
Power Source	120VAC CPT 150VA Secondary **Grounded**
Computer Data Cycle Time	2 seconds (electrical), 15 seconds (thermal)
Cable	37 – conductor, PVC Jacketed
Tray Fill	2 rows (Duke cable ONLY)
Tray Assembly Used	Tray B
Tray Height◊	39-inches (0.991-meters)
Burner Position	Center of burner offset ~13.40-inches (0.340-meters) from center of tray bend
HRR	350kW
Actuation Devices	Josyln-Clark NEMA 1 reversible motor starters

◊ measured from floor to bottom of tray

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TEST CABLES

8/C Duke Cable
Manufacture: General Cable
Cable Marker: "GENERAL CABLE (R) (WC)8/C 12AWG 1KV 8XJ12G1/BLACK 2005 0004901"
Cable construction shown on next page.
#12 AWG Tinned Copper conductor
0.045" Extruded Flame Retardant Irradiated XLPE Insulation (White)
Flame Retardant Polypropylene Filler
Cable ID marker cord
Fiberglass Scrim Binder Tapes
0.025" Galvanized steel Square interlocking armor
Jacket removal rip cord
0.050" Extruded Black PVC Jacket (Black)

8/C Fill Cable
Manufacture: Basic Wire Cable
Cable Marker: "12AWG-8C XLP 1000V 90C MC TYPE SNRS D.B. CT USE"
Cable Construction (from center outward)
Copper 12AWG conductor
XLPE Insulation (Black)
Synthetic Filler cord
Mylar Wrap
PVC Inner Jacket (sub-armor)
Galvanized steel interlocking armor
PVC Jacket (Black)

37/C Duke Cables
Manufacture: BICC BRAND-REX
Cable Marker: "37/C #12 AWG 1KV 27XJ12G1/BLACK 1999"
Cable Construction shown on following pages.
#12 AWG Tinned Copper conductor
0.045" Extruded Flame Retardant Irfradiated XLPE Insulation (White)
Flame Retardant Polypropylene Filler
Cable ID marker cord
Fiberglass Scrim Binder Tapes
0.025" Galvanized steel Square interlocking armor
Jacket removal rip cord
0.050" Extruded Black PVC Jacket (Black)

The following two pages show cable specifications for the 8/C and 37/C Duke cable used in this testing program. These are UNCONTROLLED documents.

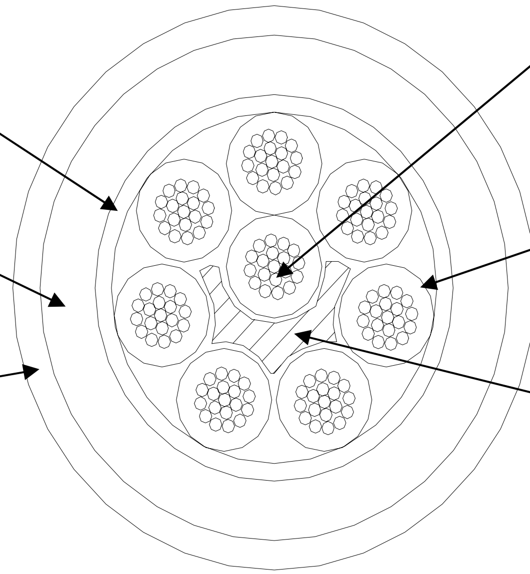
Glass Scrim Binder Tapes
Applied Over Assembly

0.025" Galvanized Steel
Square locked Interlocked
Armor
Nominal Diameter: 0.85"

0.050" Extruded Black
Polyvinyl Chloride Jacket
Nominal Diameter: 0.96""

Nominal Weight: 659 Lbs/M'

Dimensions are Nominal and
Subject to Normal Manufacturing
Tolerances



#12 AWG (19/.0185) Tinned
Class C Strand, Soft Drawn
Copper Conductor
Nominal Diameter: 0.0888"

0.045" Extruded Flame
Retardant Irradiated Cross-
linked
Polyethylene Insulation
Nominal Diameter: 0.185"

Flame Retardant
Polypropylene Fillers
(As Necessary)

Circuit Identification:
White Pigmented Insulation
with
ICEA Method 3 Type E1 Print

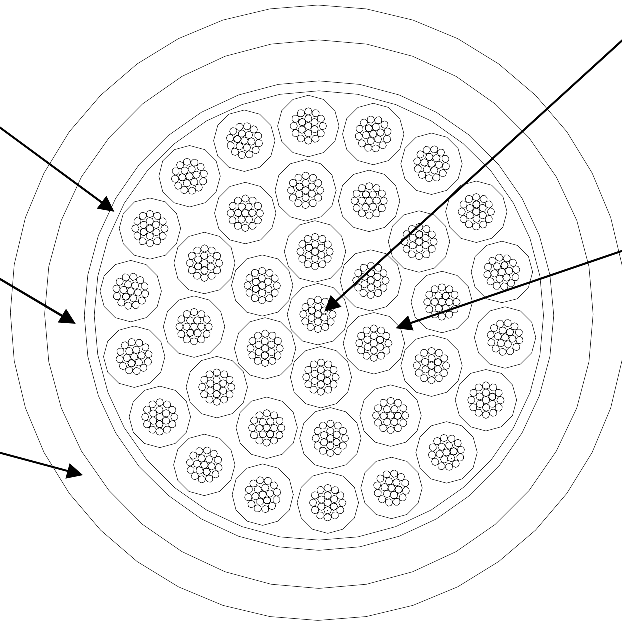
EIGHT CONDUCTOR 12 AWG 1000 VOLT STATION CONTROL CABLE MANUFACTURED IN ACCORDANCE WITH DUKE ENERGY SPECIFICATION # CNS-1354.02-00-0001 REVISION 6 DATED 2/1/82	**Duke Energy Corporation** **Catawaba Nuclear Power Station**	General Cable
	Spec #: CNS-1354.02-00-0001 **Mark Number: 8XJ12G1/BLACK**	Drawn By: DGM. Dept: Eng. Approved By: MN. Scale: None Date: 4/12/05 No.: **M-0653R1**

Glass Scrim Binder Tapes Applied Over Assembly

0.025” Galvanized Steel Square locked Interlocked Armor
Nominal Diameter: 1.55”

0.060” Extruded Black Polyvinyl Chloride Jacket
Nominal Diameter: 1.68”

Nominal Weight: 2228 Lbs/M’



#12 AWG (19/.0185) Tinned Class C Strand, Soft Drawn Copper Conductor
Nominal Diameter: 0.0888”

0.045” Extruded Flame Retardant Irradiated Cross-linked
Polyethylene Insulation
Nominal Diameter: 0.185”

Circuit Identification:
White Pigmented Insulation with
ICEA Method 3 Type E1 Print

Dimensions are Nominal and Subject to Normal Manufacturing Tolerances

THIRTY SEVEN CONDUCTOR 12 AWG 1000 VOLT STATION CONTROL CABLE MANUFACTURED IN ACCORDANCE WITH DUKE ENERGY SPECIFICATION # CNS-1354.02-00-0001 REVISION 6 DATED 2/1/82	**Duke Energy Corporation** **Catawaba Nuclear Power Station**	General Cable
	Spec #: CNS-1354.02-00-0001 **Mark Number: 37XJ12G1/BLACK**	Drawn By: DGM. Dept: Eng. Approved By: MN. Scale: None Date: 4/12/05 No.: **M-0654R1**

120VAC DA Circuit Components

Single phase step up transformer		
	Hammond Power Solutions Inc	
	Single Phase Dry Type Transformer	
	Part No. 181640	
	25 kVA rated	
	Aluminum windings	
3 – Amp Fuses	Copper Bussman Model	BAF-3
	For 250Volts or less a.c.	
Control Power Transformers		
	EGS Electrical Group	
	Industrial Control Transformer	
	Model	E150JN
	Insulation Class	105
2 – Amp Fuses	LIMITRON Model	KTK-2
	Fast acting fuse	
	A BUSS Quality Fuse	
Current Transducers	Ohio Semitronics Model	MCT-005A
	Input Range:	0 – 5 A
	Output Range:	0 – 1 mA
	Accuracy:	0.25% of span
	Burden:	0.175 VA @ rated load
Voltage Transducers:	Ohio Semitronics Model	MVT-150A
	Input Range:	0 – 150 VAC
	Output Range:	0 – 5 V DC
	Accuracy:	0.25% of span
	Burden:	1.0 VA @ rated voltage
MOV Starters	Joslyn Clark Model	
	Reversible	
	Catalog Number	T30U031
	Rating	27 Amps
	Classification	NEMA 1
	Bulletin 6013 Type TM	
Burden Resistor	OHMITE Model	B12J1K75
	Resistance	1750
	Power Rating	12 Watts
	Tolerance	5%

120VDC DA Circuit Components

Trip/Close Coils	ABB Model	191920T14
	Voltage	125V DC
Shunt Resistor	EGB Model	PCS-100
	Resistance Value	0.065 Ω
	Tolerance	1%
	Power Rating	100 Watt (at 70°C case temperature)
		50 Amp permanent
Resistive Voltage divider	Ra	
	Resistance Value	20 kΩ
	Tolerance	5%
	Power Rating	1 Watt
	Rb, Rd	
	Resistance Value	4.7 kΩ
	Tolerance	5%
	Power Rating	1 Watt
	Rc	
	Resistance Value	100 kΩ
	Tolerance	5%
	Power Rating	1 Watt
Individual Battery	Car Quest Model	65
	Type	24-6
	CA	660 Amps
	CCA	530 Amps
	RC	90

General Testing Components

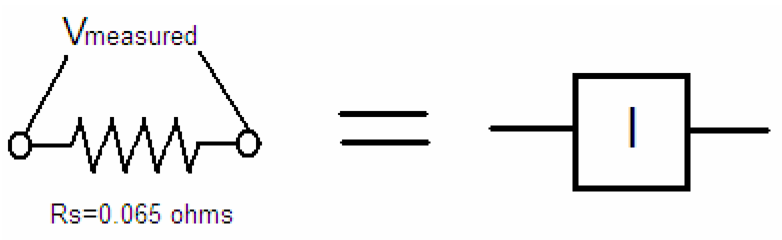
Fiberglass tape (used to secure TC to exterior of jacket)

Scotch 27
Glass Cloth Electrical Tape
Class “B” Insulation
3M ¾” (19mm)

Cable Tray

Husky
12-inch wide
Ladder-back Tray

DC Current Measurement Techniques



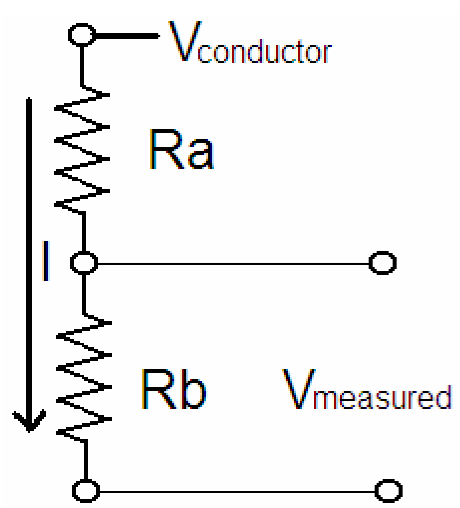
To measure current in a conductor, a high precision (low tolerance) shunt resistor was placed in series with the conductor. Any current flowing through the conductor would flow through the shunt resistor and cause a voltage drop across the resistor. This voltage drop is what was measured by the data recording system. The equations that follow show the scaling factor that was applied to the raw data to arrive at actual current levels in the conductor.

$V_{measured} = I \times Rs$ (ohms law)

$$I = \frac{V_{measured}}{Rs} = \frac{V_{measured}}{0.065} = 15.3846 \times V_{measured}$$

Scaling Factor = <u>15.3846</u>

DC Voltage Measurement Techniques



For conductors C-1 to C-4 and C-6 through C-8
Ra = 20kΩ ±5%
Rb = 4.7kΩ ± 5%

For conductors C-5
Ra = 100kΩ ±5%
Rb = 4.7k Ω ±5%

To measure voltage on a conductor, a resistor divider network was constructed and placed in parallel with the conductor to be monitored. This placed a 0.63W load (at rated power) onto the battery circuit for all conductors, except C-5. This configuration caused a 0.15W load for monitored conductor C-5. The equations that follow show the scaling factors that was applied to the raw data to arrived at actual voltage levels on the conductor.

$V_{conductor} = I(R_a + R_b)$ (ohms law) $i = \frac{V_{measured}}{R_b}$

$V_{conductor} = V_{measured}\frac{R_a + R_b}{R_b}$ $\frac{R_a + R_b}{R_b} =$ **Scaling factor** = <u>5.2553</u> (for C-1,2,3,4,6,7,8)

= <u>22.2766</u> (for C-5)

APPENDIX - B
NEMA 1 STARTER PICK-UP AND DROP-OUT CHARACTERISTICS

Duke chose to determine pick-up and drop-out voltages for each coil of every starter before any testing began and after every test that resulted in spurious actuations. The intent to measure these parameters after a spurious was to evaluate if any degradation occurred. The following tables show the associated pick-up and drop-out values for the starters.

The first time the starters were run though this evaluation, a manually controlled variac applied a ramp like voltage to the starter. The voltage at which starter chatter occurred was noted. The following table shows the initial starter evaluations.

Pick-up (P/U) and Drop-out (DO) evaluations for BRAND NEW Starters

Starter	Coil	Pick-up (volts)	Comment	Drop-Out (volts)
A	Fwd	119	56v chatter	89
	Rev	89	55v chatter	87
B	Fwd	108[1]	54v chatter	103
	Rev	79	54v chatter	73
C	Fwd	80	55v chatter	78
	Rev	85	54v chatter	82
D	Fwd	81	52v chatter	61
	Rev	89	54v chatter	86
E	Fwd	79	51v chatter	75
	Rev	76	53v chatter	72
F	Fwd	79	56v chatter	70
	Rev	80	53v chatter	72
G	Fwd	78	52v chatter	75
	Rev	90	56v chatter	87
H	Fwd	81	60v chatter	72
	Rev	78	56v chatter	73

[1] Lamp fully lit at 102V ac with ramp input, there was a high freq. hum up until 108V

For all evaluations after a test with spurious actuations occurred, a step like voltage signal was applied to determine full lock-in voltage. For this method of evaluation, a voltage level was applied to a starter coil, if full lock-in was not achieved, the voltage was removed from the starter and a new voltage level was applied until the starter locked-in. For these tests, the value recorded is lock-in voltage. Drop-out was not tested.

Pick-up evaluations after Test 1 and before Test 2.

Starter	Coil	Pick-up (volts)	Starter	Coil	Pick-up (volts)
A	Fwd	81	E	Fwd	81
	Rev	81		Rev	81
B	Fwd	77	F	Fwd	72
	Rev	77		Rev	85
C	Fwd	79	G	Fwd	71
	Rev	83		Rev	77
D	Fwd	68	H	Fwd	79
	Rev	87		Rev	81

Pick-up evaluations after Test 6 and before Test 4

Starter	Coil	Pick-up (volts)	Starter	Coil	Pick-up (volts)
A	Fwd	N/A	E	Fwd	77
	Rev	N/A		Rev	78
B	Fwd	N/A	F	Fwd	80
	Rev	N/A		Rev	80
C	Fwd	80	G	Fwd	80
	Rev	N/A		Rev	84
D	Fwd	78	H	Fwd	76
	Rev	83.6		Rev	80

Note: N/A = data not available

Pick-up evaluations after Test 5 and before Test 6

Starter	Coil	Pick-up (volts)	Starter	Coil	Pick-up (volts)
A	Fwd	91	E	Fwd	80
	Rev	84		Rev	82
B	Fwd	97	F	Fwd	78
	Rev	78		Rev	81
C	Fwd	78	G	Fwd	80
	Rev	88		Rev	85
D	Fwd	76	H	Fwd	77
	Rev	81		Rev	88

Pick-up evaluations before Test 20

Starter	Coil	Pick-up (volts)	Starter	Coil	Pick-up (volts)
A	Fwd	91	E	Fwd	79
	Rev	80		Rev	79
B	Fwd	93	F	Fwd	85
	Rev	76		Rev	79
C	Fwd	71	G	Fwd	74
	Rev	89		Rev	82
D	Fwd	74	H	Fwd	77
	Rev	81		Rev	81

For DC coil testing, 4 batteries were connected in series to generate 50 volts. This 50 volt potential was enough to cause all coils to actuate. This testing was done prior to test 13 and 14.

ATTACHMENT 1

To

RES Letter Report on Results and Observations from Duke Armored Control Cable Fire-Induced Spurious Operation Testing

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Duke Test Plan for Evaluation of Fire Induced Spurious Actuations in Armored-Cable Control Circuits

ADAMS Accession No. ML052900252

ATTACHMENT 2

To

RES Letter Report on Results and Observations from Duke Armored Control Cable Fire-Induced Spurious Operation Testing

NRC Transmittal Letter of NRC Comments on Duke Power Armored-Cable Test Plan

ADAMS Accession No. ML052910084

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ATTACHMENT 3

To

RES Letter Report on Results and Observations from Duke Armored Control Cable Fire-Induced Spurious Operation Testing

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ATTACHMENT 4

To

RES Letter Report on Results and Observations from Duke Armored Control Cable Fire-Induced Spurious Operation Testing

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ATTACHMENT 5

To

RES Letter Report on Results and Observations from Duke Armored Control Cable Fire-Induced Spurious Operation Testing

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ATTACHMENT 6

To

RES Letter Report on Results and Observations from Duke Armored Control Cable Fire-Induced Spurious Operation Testing

Resolution of Two Concerns Regarding Conservatism of Duke Armored-Cable Fire Tests