Duke Power Nuclear Generation Test Plan
For Evaluation of
Fire-Induced Spurious Actuations in Armored-Cable Control Circuits

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1.0 SCOPE

This test plan describes the methods for evaluating spurious actuation and other fire-induced failure effects on armored electrical cables and their contained control circuits used in Duke Power Company's nuclear plants. The tests will develop experimental information to better understand fire-induced circuit-failures and their probabilities as they apply to these cables. This plan intends to help address NRC staff technical concerns of the potential for fire-induced spurious operation of equipment, including that for safe-shutdown functions. Accordingly, the test results are expected to provide relevant information in the following inputs to these issues for armored multi-conductor control cable:

- Likelihood of spurious actuations from hot shorts within the cable
- Likelihood of multiple spurious actuations
- Likelihood of shorts-to-ground versus hot shorts
- Likelihood of open circuits
- Insulation resistance in damaged cable
- Voltage and current values in damaged cable
- Variance in the number of conductors per cable

Table 1 in Section 6.1 provides information on parameters considered by the referenced Sandia National Laboratory report to be important to the circuit failure modes being evaluated in these tests. These factors and the observations for them in the EPRI / NEI tests report, Ref. 9.1, were considered to develop this test plan and the selected test configurations to be evaluated. This plan was developed from the larger-scoped EPRI / NEI test plan (Appendix B in Ref. 9.1) and information provided by members of the Duke Power NGDept. Appendix R Working Group, Duke nuclear plant circuit experts, industry consultants, a representative from the contracted test laboratory, and NRC staff and contractors.

2.0 OBJECTIVE

Expand upon previous EPRI / NEI fire-induced circuit-failures tests to better understand the electrical response of Duke Power Company's nuclear plant armored control cables and circuits to fires. Responses will be measured as actuations of control devices (NEMA starters) in these circuits and by measurements of voltage and current in monitored conductors leading to the calculation of Insulation Resistance in fire-damaged cables. The results should provide a basis for determining probabilities of spurious device actuations and failures for risk-based analyses.

3.0 TEST CRITERIA

Each test will apply heat from a sandbox-type burner to a test apparatus as detailed later. This fire exposure will continue until one of the following criteria is met. These criteria are intended only to determine at what point each test will be terminated, not to assess the "success" or "failure" of the test.

3.1 At least one hour has elapsed without adverse response, as defined below in Sections 4.1 and 4.3. An additional 30 minutes beyond the hour criteria can also allow time to gather useful data on fire effects, such as changes in conductor insulation resistance values, even if adverse effects have not occurred. (Exception: A test may be terminated prior to 60 minutes if all circuits have failed, and little or no data remains to be obtained.)

3.2 If all fuses in the control circuits (Figure 2) of all monitored Device-Actuation cables or bundles have blown, the ability to monitor voltage and current will be removed and the test will be terminated.

4.0 DEFINITIONS

4.1 ADVERSE RESPONSE

An adverse response consists of one or more fire-induced spurious device actuations, or one or more fire-induced circuit failures.

4.2 CIRCUIT

A circuit is a conductor or system of conductors through which an electric current is intended to flow. [Note: Fire effects on control circuits are evaluated in this test program.]

4.3 CIRCUIT FAILURE

A circuit failure consists of a hot short, a short to ground, or a change to an open circuit.

4.4 DATA ACQUISITION SYSTEM

A data acquisition system is a computer-based system for monitoring voltage and current in selected circuits, as well as temperature in selected locations. Further information will be provided as necessary in the test lab's final report.

4.5 HOT SHORT

A hot short is a fire-induced insulation breakdown between conductors of the same cable, between conductors of different cables, or from some other external source resulting in a compatible but undesired impressed voltage on a specific conductor.

4.6 INSULATION RESISTANCE

Insulation resistance is the calculated resistance of intact or damaged insulation between conductors or a conductor to ground, based on measurements of voltage and current.

4.7 OPEN CIRCUIT

An open circuit is a fire-induced break in a conductor resulting in a loss of electrical continuity. (This open-circuit failure category does not include blown fuses.)

4.8 SHORT TO GROUND

A short to ground is a fire-induced breakdown of a cable's insulation system resulting in the potential on the conductor being applied to ground potential.

4.9 TEST ASSEMBLY

A test assembly is an assembly of horizontally run ladder-back galvanized steel cable tray (see Figure 1). The tray will contain cables as specified later.

4.10 TEST FRAME

The tests will be conducted in a 10' x 10' test chamber 8' in height. The test chamber has a standard-size single door with no windows except a small video-camera port, and except that a small aperture will be cut near the bottom of the test chamber for connecting the cables to the test monitoring equipment outside the chamber. The chamber is ¼" steel plate with a concrete floor. Cables will be mounted on a horizontal 12"-wide ladder-back tray with a 90^{o} bend.

4.11 THERMOCOUPLE

A thermocouple is a fast-response electrical assembly used to measure temperature, consisting of an electrically welded fused junction of dissimilar metals, and their respective leads to the data acquisition system.

5.0 RESPONSIBILITIES

5.1 DUKE POWER COMPANY

Duke Power Company (Duke), via its Appendix R Working Group, will assume total management responsibility for this testing. Duke will provide, as needed, the actual materials to be tested, including cable, actuation devices (NEMA starters and switchgear breaker close and trip coils), and 600v / 120v control power transformers. Duke also reserves the right to inspect test circuits before each test is initiated.

5.2 NRC

The Nuclear Regulatory Commission (NRC) will be asked to provide input prior to, during, and following the test program as may be arranged through Duke. All NRC input (NRR, RES, or contractor) will be coordinated through a single point of contact. A limited number of NRC personnel or contractors representing the Offices of Research and Nuclear Reactor Regulation will be provided the opportunity to observe the actual testing. Duke will provide the NRC with test results and data, as may be requested, and by appropriate mutual agreement.

5.3 TEST LABORATORY

The test laboratory will provide the necessary facilities and data acquisition system, prepare the test assemblies and data acquisition system for each test, and conduct the actual tests. It will provide timely input to Duke on changes needed during the testing program to optimize the usefulness of the results or to address unforeseen contingencies. In addition, the test lab will provide DVD video and digital color photographic coverage of each test as requested by Duke. It will provide test reports and assist interpreting the results, as may be arranged in the final contract with Duke.

Although full 10 CFR 50 Appendix B Quality Assurance (QA) is not required, the testing shall be conducted under the test laboratory's standard QA program.

6.0 TEST PARAMETERS AND CONFIGURATION INPUTS

6.1 PARAMETERS CONSIDERED

In their report "Circuit Analysis – Failure Mode and Likelihood Analysis," (Ref. 9.2) Sandia National Laboratory identified parameters for consideration during testing of the type to be performed under this plan. Subsequently, the EPRI / NEI tests documented in Ref. 9.1

determined the actual significance of some key parameters. Table 1 below summarizes the parameters, their potential significance as identified by Sandia, the EPRI / NEI tests actual significance for likelihood of spurious actuation (when the Sandia parameter was identified as a key parameter in the EPRI / NEI tests), and the proposed Duke application to the testing.

Table 1: Application of Sandia Parameters to Armored-Cable Control Circuits Fire Testing

Parameter	Significance	EPRI / NEI Conclusions & Proposed Application in Duke Tests
Insulation Type	Expected weak, Actual moderate	Spurious actuations are less probable in thermoset insulated cables than in thermoplastic insulated cables. All of the armored cables in the Duke tests will be thermoset insulated (XLPE = cross-linked polyethylene or EPRubber, reflecting actual installations).
Jacket properties	Expected weak	Not specifically evaluated. Some cable tested will have a (thermo-plastic) jacket over the armor, and some will have un-jacketed armor.
Number of conductors	Expected significant, Actual strong	Proximity of source and target conductors drives failure rates. For cables containing circuits of more than one device, multiple spurious actions could be possible. 8-conductor and 37-conductor QA cables will be tested (reflecting both single and multiple MOVs or switchgear breakers control-circuits within a cable). The EPRI / NEI specified configuration will reflect typical nuclear plant control cable circuits (Fig. 7).
Armoring	Expected significant, Actual strong	Armor decreases susceptibility to hot-shorts. All cables evaluated in the Duke tests will have galvanized steel interlocked armor.
Cable age	Expected weak	Not specifically evaluated. The tested 8-conductor QA and fill cables will be new; the 37-conductor QA cables will be from existing unused inventory (at least five years storage).
Cable size	Expected significant	Conductor sizes of tested cable will be #12 AWG, typical for Duke. Outer jacketed diameters: ~ 1.1" for 8/c and ~ 1.8" for 37/c.
Cable qualification status	Expected weak	Not specifically evaluated. All evaluated cables will meet IEEE 383-1974 (& QA) requirements per latest Duke plant (Catawba) specification. Fill cables will be non-QA 'commercial-grade' with similar construction: thermoset insulation, interlocked armor, and thermoplastic jacket (which will be removed for some tests).
Cable tray type	Expected significant, Actual moderate	Overall failure rates for tray and conduit were similar in the EPRI / NEI tests. Galvanized steel ladder-back tray will be used.
Conduit	Expected significant, Actual moderate	Only tray installations will be tested, consistent with the vast majority of Duke installations (and since using armored cables).
Raceway load (and location of monitored cables)	Expected significant, Actual strong	Sparsely-populated tray and cables in bottom row closest to the flame had the highest failure rate. However, cables above and isolated from grounded tray were more likely to have spurious actuations (not expected to be as much a differentiator for grounded armor). Trays are loaded more heavily at control-power sources and more lightly at end loads. Eight monitored 8-conductor cables or two monitored 37-conductor cables (each with four bundles of 8 control conductors) will be located within the tray fill for each test. For statistical results with consistent configurations, the tests will apply 3 and 2 rows of cable fill for the 8-conductor and 37-conductor cables, respectively. Thus all tests will have between a 3" and 4" fill depth (vs. 5" maximum).
Raceway (tray) orientation	Expected significant, Actual weak	Horizontal vs. vertical tray orientation had little impact on the likelihood of hot shorts. As with most EPRI / NEI tests, a horizontal run tray with a 90 degree horizontal bend will be consistently used.
Circuit voltage, power supply type, and grounding	Expected significant, Actual strong	Compared with lab power supply, 480V / 120V CPTs did not sustain voltage as well under hot-short conditions, thus producing fewer spurious actuations. Ungrounded sources are less quick to blow fuses

Parameter	Significance	EPRI / NEI Conclusions & Proposed Application in Duke Tests
		during faults and thus are more susceptible to spurious actuations. Ungrounded 600V / 120VAC CPTs (150VA or nearest equivalent size for NEMA 1 or 2 per Ref. 9.6) should be used for the Duke tests, consistent with actual control circuit installations. One test series may use grounded CPTs for the minority of Oconee plant exceptions. Another series of tests for switchgear breaker controls will use a 125 VDC ungrounded source.
Conductor bias, relative locations within a cable	Actual strong	Of the four conductor-connection patterns within the 7-conductor cables used in the EPRI / NEI tests, the Source-Centered (SC) arrangement produced the highest % of spurious actuations. Rather than introduce another variable to expand the number of tests, the Duke tests will consistently and conservatively use an 8-conductor pattern similar to the identified worst-case (Source-Centered).
Flame exposure type and relative fire elevation	Expected significant, Actual moderate	Varying tray heights above the flame and variable heat release rates in the EPRI / NEI tests simulated both plume and hot gas layer exposure, showing a relatively minor influence on spurious actuations. Consistent with the two EPRI / NEI tests on armored cables, the Duke tests will apply a 350 kW flame exposure, large enough that the cables not directly in the flame are still affected by it.
Exposure duration/ intensity	Expected significant	Consistent with the two EPRI / NEI tests on armored cables, the Duke tests will apply a 350 kW heat release rate (HRR), simulating a more than sufficiently severe exposure to produce circuit failures. The intent of the testing will be to simulate the temperatures associated with this constant HRR. The ability to simulate the constant heat release rate is a function of several factors including sandbox burner size and test chamber size. These factors may limit the HRR. The duration of each test may vary to prevent the temperatures from becoming excessive.
Application of suppressants	Expected significant, Actual weak	If any conductors have not failed after the nominal test duration per the section 3.0 criteria, tests may subsequently include water dousing at approximately 0.3 liter per square meter per second for 1 minute.

6.2 TRAY CONFIGURATION AND TESTING PARAMETERS

The planned tray configuration is as follows. Figure 1 reflects the planned horizontal configuration of tray and cables for all tests, consistent with the EPRI / NEI tests on armored cables. The tray is a 12" wide by 6" high galvanized steel ladder-back type in the horizontal position welded in a right angle configuration with a standard 24" radius 90degree tray bend between the two ~ 6' legs, protecting recommended cable bend radii which were problematic during one of the EPRI / NEI tests. The tray is supported on each end by concrete blocks at the desired height, and at the corner by a chain suspended from the ceiling of the 10' x 10' x 8' height steel test chamber. Cable outside the tray segment will be wrapped with a suitable fire barrier material to prevent interaction effects outside the tray.

The resolution of other testing parameter issues is as follows:

- Each AC-powered (8-conductor) test circuit will use a 600v / 120v, 150 VA (or closest larger commercially-available equivalent such as 180 VA) control power transformer (CPT) since it is the actual power source used in motor-control centers (MCCs) to feed safety-related MOV starter controls (which are all NEMA 1 or 2) at Duke nuclear plants. Thus, the fault-current capacity of the sources should represent what is installed in the field. Each DC-powered (8-conductor) test circuit will use a 125 VDC source capable of delivering at least 70A continuously at that voltage (the largest feeder breaker source to 4160 VAC switchgear breaker controls at Duke nuclear plants).

- In each test, data will be monitored for eight DA (device actuation – see Section 6.3) bundles in the tray. A bundle is either an 8-conductor cable or an 8+-conductor group of insulated wires within a 37-conductor cable. In each test, all monitored cables will be the same type; i.e., they will have the same number of conductors with thermoset insulation and overall armor, without mixing. The eight DA bundles will be used to evaluate both actuated devices and insulation resistance. The trays will be filled to a depth of three rows for the 8-conductor cables and two rows for the 37-conductor cables (between 3" and 4" depth in either case) with similar cable used only as fill, but these fill cables will not be monitored. Placement of the bundles in each fill configuration is shown in Figures 5 and 6.

- The representative HRR (heat release rate) will be 350 kW, a more than sufficiently severe exposure to produce circuit failures. The intent of the testing will be to simulate the flame temperatures associated with this HRR. The ability to simulate these constant HRRs depends upon a number of factors including sandbox burner size and test chamber dimensions. The burner size and the duration of the test should be chosen to minimize direct flame impingement.

- Before and after each test a thorough visual examination of the cables will be conducted. Both videotape and close-up color photographs will be used. Photographs will be scanned into digital format, or digital photographs will be made. All photographs will be placed onto CD-ROM discs. Voice recordings noting observations should be made, if necessary. Videotaping during the tests is also desirable to identify and record when certain visually-observed phases occur, such as when jackets are ignited or completely melted.

6.3 VOLTAGE AND CURRENT MONITORING

For the cable bundles just described, the voltage and current monitoring of the 8-conductor and 37-conductor control cable will use the scheme illustrated in Figure 2 where both device actuation and insulation resistance are evaluated. Cable bundles with this purpose are described as DA bundles in this test plan. The Figure 2 scheme applies the NEI / EPRI basis "test circuit representative of a 'typical' motor-operated valve (MOV)" 120 VAC control circuit as shown in Figure 7 (Ref. 9.1, its section 4.2.2 and its App. B test plan). For switchgear breaker control circuits, the source is changed to an ungrounded 125 VDC source and the actuating devices are changed to switchgear breaker close and trip coils.

Within the 8-conductor DA arrangements in both the 8-conductor and 37-conductor control cables (Figure 2), two conductors will be connected to two separate actuation devices (MOV starter Forward and Reverse coils or switchgear breaker close and trip coils) with no power source. Two additional conductors will be connected to the control-power source, one through a burden resistor. The purpose of the burden resistor is to simulate the load imposed by indicating lamps or any other continually energized devices. Another conductor is the return path to the source for this burden circuit. One conductor is open at both ends, simulating a connection between open contacts. Another conductor is a spare which is consistently grounded per Duke Criteria in Ref. 9.5. One conductor will be connected to a burden resistor at the CPT return point, but not connected on the load end. Voltage and current will be monitored on all conductors.

6.4 CONTROL CABLE TESTING

The control cables Device Actuation (DA) conductors configuration to be tested and monitored is represented in Figure 3 for the 8-conductor cable and in Figure 4 for the 37-conductor cable. Each monitored 37-conductor cable will contain four 8-conductor DA wire bundles (plus five additional wires), representing generic controlling circuits for four separate motor-operated valves (MOVs) or switchgear breakers.

The selected Source Centered conductor arrangement for the 8-conductor DA cable is shown in Figure 3. As noted previously, this Source-Centered arrangement was the worst-case wire configuration in the EPRI / NEI tests in terms of the resulting spurious actuations. Likewise, the conductor configuration for the 37-conductor DA cable is shown in Figure 4 to include a similar Source Centered arrangement for the center bundle. Because the center, middle, and outer layers of this larger cable are twisted in successive opposite directions, the relative position between the 3 layers is continuously changing with cable length. Therefore, the conductor arrangements for the three 8-conductor bundles in the middle and outer independent ‘rings’ or layers include conservatively positioning the actuation-device target conductors between the powered conductors to maximize the potential for spurious actuations from hot-shorted conductors within each ‘ring’.

Figures 5 and 6 show intended locations for monitored DA cables in each test. Variations in cable type, jacketing, and power sources are also summarized in Table 2.

6.5 TEST APPARATUS

The tests shall be conducted using a sandbox-type flame source. For all tests, the size and number of the burner(s) will be governed by the HRR of 350 KW (as described in section 6.2) such that this specific HRR is maintained at a level that minimizes direct flame impingement.

The straight horizontal segments of ladder-back tray, shown in Figure 1, shall be approximately 6 feet in length, or that which is sufficient to minimize the amount of cable outside the tray but inside the 10’ x 10’ (x 8’ high) test chamber. The burner should be located such that the tray in the hot gas layer is approximately 2 feet from the plume centerline. This location can be optimized after the first one or two tests.

6.6 Other Test Specifications

6.6.1 Cable

Cable length (estimated ~ 25 feet each) for all test samples will be sufficient to allow a single pass through the tray segments with enough cable to allow connections to measurement instrumentation and data acquisition systems outside the test chamber. The monitored armored thermoset insulated control cable will be 8-conductor #12 AWG and 37-conductor #12 AWG types. Per Ref. 9.8 and its sub-referenced NEMA / ICEA standards, the insulation for these 10CFR50 App. B QA / Class 1E cables can be either flame-retardant EPR or XLPE materials, but will most likely be the flame-retardant XLPE at a thickness of 45 mils for the 1KV rating. Both of these monitored control cable types have a strippable thermoplastic jacket extruded over the galvanized steel interlocked armor. Since the 8-conductor cables have a very active inventory, they will be purchased new. The 37-conductor cables will be taken from an unused inventory which has been in outdoor but covered storage for approximately six years. To provide a practical yet suitable consistency of materials within the entire tray fill which is representative of Duke installations, the fill cables for the 8-conductor cable tests will be purchased new of standard commercial grade 7-conductor thermoset (EPR or XLPE) insulated #12 AWG copper with similar interlocked armor and strippable thermoplastic jacket.

6.6.2 Protective Devices

Sizing of the protective devices (fuses) from the power supplies should be consistent with the criteria applied in an actual Duke plant application. From review of example 120 VAC elementary diagrams for the MOV controls (Ref. 9.4), Catawba and McGuire plants use 3A fuses, while Oconee has some lower-current sizes like 1.6A or 2A. From the perspective of allowing the potential for spurious actuations to occur, the 3A fuse is the conservative size to apply in all of the AC tests. From review of example 125 VDC elementary diagrams for the switchgear breaker controls, all of the Duke plants consistently use 30A fuses, which will therefore be used in all of the DC tests.

6.6.3 Voltage and Current Monitoring

Monitoring of voltages and currents shall be of a continuous sampling type through a multi-channel event recorder or PC computer based system. Signal conditioners shall be used where necessary. Consistent with Figure 2, voltage and current monitoring points shall be located between the power source, with its burden impedances or actuation devices, and the test cable conductors. Use high-accuracy current sensors, preferably Hall based, thermally isolated and temperature stabilized.

6.6.4 Actuation Devices

Actuation devices to be used for all AC tests are the interlocked forward and reverse coils and contacts in NEMA-1 starters (the size for the vast majority of Duke plant MOVs, the few using NEMA-2 also having the same CPT source size). For the DC tests, the actuation devices are the close and trip coils from (Gould-ITE) switchgear circuit-breakers. In either the AC or DC tests, these devices shall be connected as shown in Figure 2. Device actuation will be indicated by lights and sound, as well as by voltage and current measurements. All actuation devices will be supplied by Duke for use by the test lab.

6.6.5 Temperature Monitoring

Thermocouples shall be of the rapid response design (Type K). The thermocouples should not have sleeves capable of introducing reading errors. Alternatively, the thermocouples could be compensated to null-out any such errors. The test lab will provide all of the thermocouples and their appropriate extension cabling and monitoring. Multiple thermocouples should be used to record accurate temperature profiles, including any possible hot spots, in the following general locations:

- A thermocouple will be attached to a cable adjacent to each monitored cable using fiberglass tape. This configuration should be repeated every 12 inches along the length of the cable in the tray. The amount of fiberglass tape should be minimized.

- At least one thermocouple should be placed on each of the sides and bottom of the tray being monitored (at least three altogether). This configuration should be repeated every 12 inches along the length of the cable in the tray.

- A string of thermocouples will be mounted such that they protrude through the cable bundle. The spacing of these thermocouples is approximately 9 inches on center, with a slightly increased density at the tray bend.

- *After the first few tests, the location and number of thermocouples can be adjusted, based on discussion with the test lab. For example, thermocouples located beyond a limited distance from the fire source may be of little or no value.*

7.0 TESTS TO BE CONDUCTED

Table 3 on the following page summarizes the tests to be conducted by showing the few variables that can distinguish a particular test series from the others. Each configuration will be tested up to 4 times to complete a statistical series. Recall that the constants among all the tests include: Duke specified QA armored multi-conductor 12AWG control cable within tray fill of no maintained air space between cables, 8 Device-Actuation control bundles (each with 2 actuation devices) monitored per test, the EPRI / NEI tests worst-case conductor bias of the Source-Centered wiring arrangement of each 8-conductor cable or center bundle within the 37-conductor cables (Figures 3 and 4), 350 KW heat release rate, and a horizontal tray configuration with a standard 90° turn that does not exceed cable bend radius limitations.

Table 2: Summary of Tests Variables

Variable	Base Tests 1 - 4	Tests 5 - 8	* *Tests 9 - 12*	Tests 13 - 16	Tests 17 - 20
Cable type (# of conductors)	8/c	8/c	8/c	8/c	**37/c**
Cable armor overall Jacketed or Un-jacketed	Jacketed	**Unjacketed**	Jacketed	Jacketed	Jacketed
# of rows of fill within the tray	3	3	3	3	2
# of monitored cables in rows 1, 2, and 3	3, 2, 3	3, 2, 3	3, 2, 3	3, 2, 3	1, 1
Control power source description	120 VAC CPT secondary winding, Ungrounded	120 VAC CPT secondary winding, Ungrounded	120 VAC CPT secondary winding, **Grounded**	**125 VDC Source**	120 VAC CPT secondary winding, Ungrounded

** Tests 9 through 12 shall be* ***performed first before the other tests****, since this configuration is the closest confirmation of the couple of armored-cable tests performed in the previous and referenced EPRI / NEI effort.*

7.1 GENERIC DESCRIPTION

Eight (8) device actuation (DA) cables or bundles are monitored within the un-spaced cable fill in each test. To avoid cable manufacturers minimum bend radius violations, the inside bend of any of these interlocked armored cables should typically be greater than 8 to 12 times the outer diameter (OD) of the cables (recall from section 6.1 that the jacketed ODs are ~ 1.1" for the 8/c and ~ 1.8" for 37/c cables, respectively). The tray is a 12" wide by 6" high galvanized steel ladder-back type in the horizontal position welded in a right angle configuration with a standard 24" radius 90degree tray bend between the two ~ 6' legs, thus protecting the above recommended cable bend radii. The tray is supported on each end by concrete blocks at the desired height, and at the corner by a chain suspended from the ceiling of the 10' x 10' x 8' height steel test chamber.

Each 8-conductor DA cable or bundle within a 37-conductor cable will be connected to both actuation devices (NEMA-1 starter or switchgear breaker open coil and close coil) and voltage and current monitors, as described earlier and shown in Figure 2. For the eight monitored 8-conductor DA cables per corresponding test, the sixteen actuation devices (two for each cable) are denoted DA 1-1 & 1-2, 2-1 & 2-2, 3-1 & 3-2, 4-1 & 4-2, 5-1 & 5-2, 6-1 and 6-2, 7-1 & 7-2, and 8-1 & 8-2. For the two monitored 37-conductor DA cables per corresponding test, the sixteen actuation devices (two for each of the four 8-conductor groups or bundles within each cable) use the same denotations with the first eight (1-1 through 4-2) being used in one cable and the second eight (5-1 through 8-2) in the other cable. As noted previously and consistent with Figure 2, two conductors in each 8-conductor cable (or in each 8-conductor group within the 37-conductor cables) are powered from a 120 VAC control power transformer or a 125 VDC source. All of the other conductors, including those connected to actuation devices, are potential targets of hot-shorts.

Numerous thermocouples are used to monitor temperature in the test chamber, as described in section 6.6.5: thermocouple strings in the center, left, and right side of the trays (12" spacing along the tray length), and thermocouples attached to fill cables adjacent to each DA cable to monitor the temperature seen by each DA cable (12" spacing along the cable length). In the tray configuration Figures 5 and 6, these thermocouples on adjacent fill cables are denoted T_X, with X being the adjacent DA cable designation (A through H).

Each test is intended to run for one hour. The test will be shorter if all the circuits fail prior to an hour, but may be extended for ½ hour beyond the last device actuation. Tests may conclude with a one-minute spray unless all conductors have already failed.

The test will help determine the likelihood that the starter or breaker coils can actuate spuriously from either conductor-to-conductor interactions within the same multi-conductor cable, or from cable-to-cable interactions (conductors in different cables). The latter is not expected since the cables are separated from each other by their respective grounded armor. Voltage and current measurements will be used to calculate insulation resistance between conductors subject to hot shorts.

After the test, voltage will be calculated and plotted, and correlated with any device actuations. If there are no actuations, insulation resistance will be plotted to determine how close the devices might have come to actuation. Voltage and current data can also be compared with the pickup voltage and current values for other actuation devices that are not simulated directly in this test.

7.2 TESTS 1 THROUGH 4

Base Tests 1 through 4 (all identical) include eight jacketed 8-conductor DA cables in **three rows** of fill. Two DA cables are located in the middle row and three DA cables are located in each of the bottom row and top row such that two vertically separated DA cables in the top and bottom rows are at both edges of the tray and three vertically adjacent DA cables are located at the center. The remaining DA cable is located in the middle row between the center and the outside edge which is on the inside of the tray bend. This arrangement will show any relative differences in results between rows for otherwise similar locations. The configuration for Tests 1 through 4 is shown in Figure 5.

7.3 TESTS 5 THROUGH 8

Tests 5 through 8 (all identical) are the same as Base Tests 1 through 4 except that the DA and fill cables are **unjacketed** (i.e., no jacket over the armor). Because the removed jackets are the only differences from the base tests, the configuration for Tests 5 through 8 is also represented by Figure 5. It is expected that the primary effect of un-jacketed versus jacketed cables is in the time required for failures to occur.

7.4 TESTS 9 THROUGH 12

Tests 9 through 12 (all identical) are the same as Base Tests 1 through 4 except that the control power transformer (**CPT**) 120 VAC secondary-winding sources are **grounded**. Because the grounded power source is the only difference from the base tests, the configuration for Tests 9 through 12 is also represented by Figure 5. This test will help determine the relative effects of a grounded source reflected in some limited Oconee installations. (For example, fuse blowing might be expected to be more likely.) *Tests 9 through 12 shall be **performed first before the other tests**, since this configuration is the closest confirmation of the couple of armored-cable tests performed in the previous and referenced EPRI / NEI effort.*

7.5 TESTS 13 THROUGH 16

Tests 13 through 16 (all identical) are similar to Base Tests 1 through 4 except that the control power source is changed to a **125 VDC source** (ungrounded) and the target actuating devices are changed to the **switchgear circuit-breaker close coil and trip coil**. The configuration for Tests 13 through 16 is also represented by Figure 5.

7.6 TESTS 17 THROUGH 20

Tests 17 through 20 include two jacketed **37-conductor DA cables** (each with 4 eight-conductor DA circuit bundles) within **two rows** of fill. One DA cable is located in each row such that they are vertically adjacent **in the approximate center** (erring on the inside-bend side) of the tray width. Depending on previous tests results that may show a relative worst-case location along the tray width for spurious actuations, the DA cables position could change accordingly. The configuration for these tests, shown in Figure 6, will show any relative differences in results between rows at the otherwise similar location.

8.0 TESTS RESULTS

8.1 TEST RESULTS

The test results will include the following data recorded over the duration of each test:

- Actuation data from the starter or breaker coils
- Voltage and current data
- Plots of insulation resistance
- Temperatures at each monitored location in the test apparatus
- Timing associated with this data

8.2 USE OF TEST RESULTS

The failure data from each test will be used to derive a spurious operation probability given fire damage for each tested condition as described in Table 2. The mean spurious operation probability is basically the number of recorded spurious operations for each contact divided by the number of contacts. The variance (uncertainty) will be calculated, based on standard statistical methods.

For the 37 conductor tests, statistical analysis will be used to determine if the conditional probability for a second spurious operation in the cable is higher than the random spurious operation probability. If the second spurious actuation is shown to be non-random, then a statistical model of the second, third and forth spurious operation in a cable will be derived.

8.3 TEST REPORTS

The test laboratory will prepare appropriate reports describing each test and its results. These reports will be available within one month following the completion of each test.

9.0 REFERENCES LIST

9.1 EPRI Final Report # 1003326, "Characterization of Fire-Induced Circuit Faults – Results of Cable Fire Testing", December 2002. (Its Appendix B is the EPRI/NEI Cable Fire Test Plan.)

9.2 J. LaChance, V. Dandini, et al, "Circuit Analysis – Failure Mode and Likelihood Analysis", Sandia National Laboratories, Albuquerque, NM, 2002.

9.3 Duke Design Engineering Data Base (DEDB) for cable types, example installed cable and routing data, and McGuire & Catawba 600VAC and 125VDC load list spreadsheets.

9.4 Sampled Duke safety-related motor-operated valves elementary diagrams such as Oconee O EE-151- series from one-line O-703-K, McGuire MCEE-0157- series from one-line MCCD-1703-06.11, and Catawba CNEE-0157-02. series from the 600V MCC 1EMXS load-list spreadsheet.

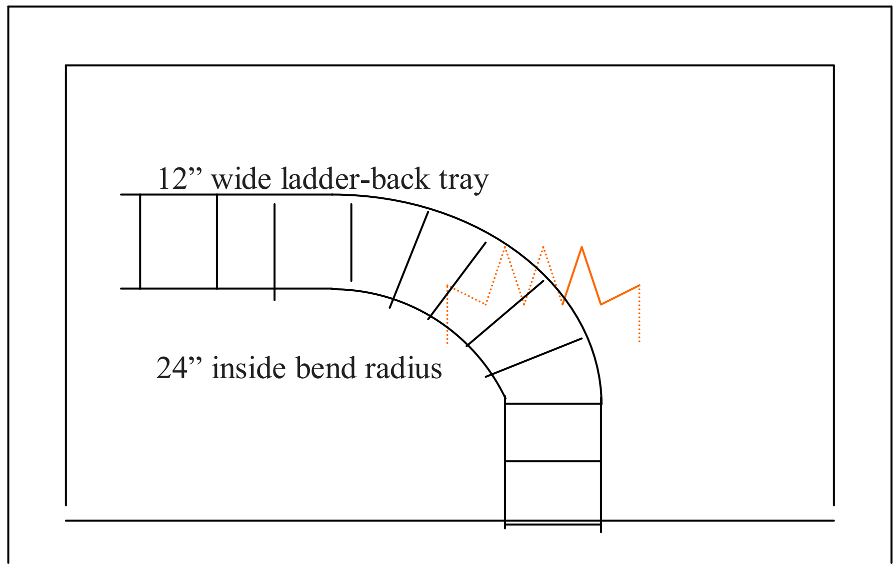
9.5 Duke spare-wire grounding design criteria and installation specifications: DC-4.05 Grounding – Instrumentation – Catawba (section 5.3.2), DC-4.09 Grounding – Instrumentation – Oconee SSF (section 5.3.2), OEE-15 Oconee Instrumentation and Control Cables Installation Procedures, MCS-1390.01-00-0043 (McGuire) Interlocked Armor Control Cable Grounding and Termination Details (sheet 1).

9.6 Duke safety-related 600V motor-control centers bills-of-materials: OM-(0, 1, or 2)308-series, MCM-1(or2)314.01- series, and CNM-1(or2)314.01- series.

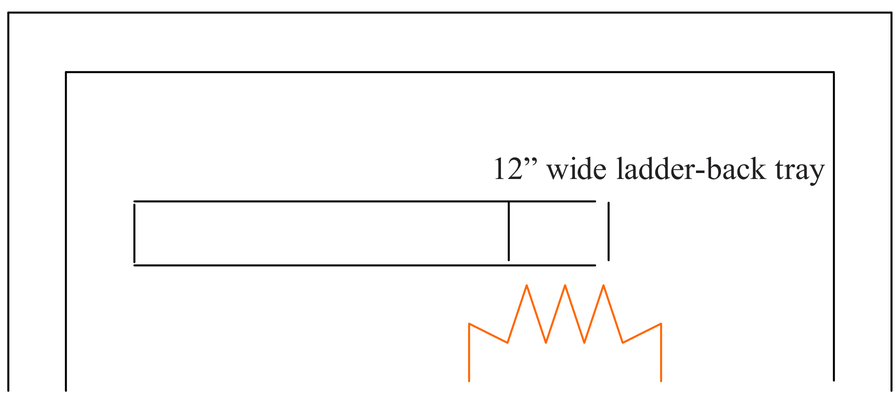
9.7 General Cable drawing (#M-0653R1) of Duke cable type 8XJ12G1 cross-section and drawing (#M-0654R1) of Duke cable type 37XJ12G1 cross-section, plus actual samples of these 10CFR50-App.B supplied QA 1KV multi-conductor control cables.

9.8 Duke Catawba Nuclear Station procurement specification CNS-1354.02-00-0001 for 1KV multi-conductor control cable. During and after construction of Catawba, the cable types from this specification have been used at all three of Duke's nuclear stations. Earlier corresponding Oconee and McGuire procurement specifications also confirm the thermoset insulation within the cable construction.

9.9 Sampled Duke safety-related switchgear circuit-breaker controls elementary diagrams such as Oconee O EE-117(-90) - series (from O-(0,1,2)705 one-lines for 125 VDC vital buses), McGuire MCEE-0115-00(.12) - series, and Catawba CNEE-0115-01(.13) series.



Plan View



Elevation View

Figure 1: Horizontal Tray Arrangement

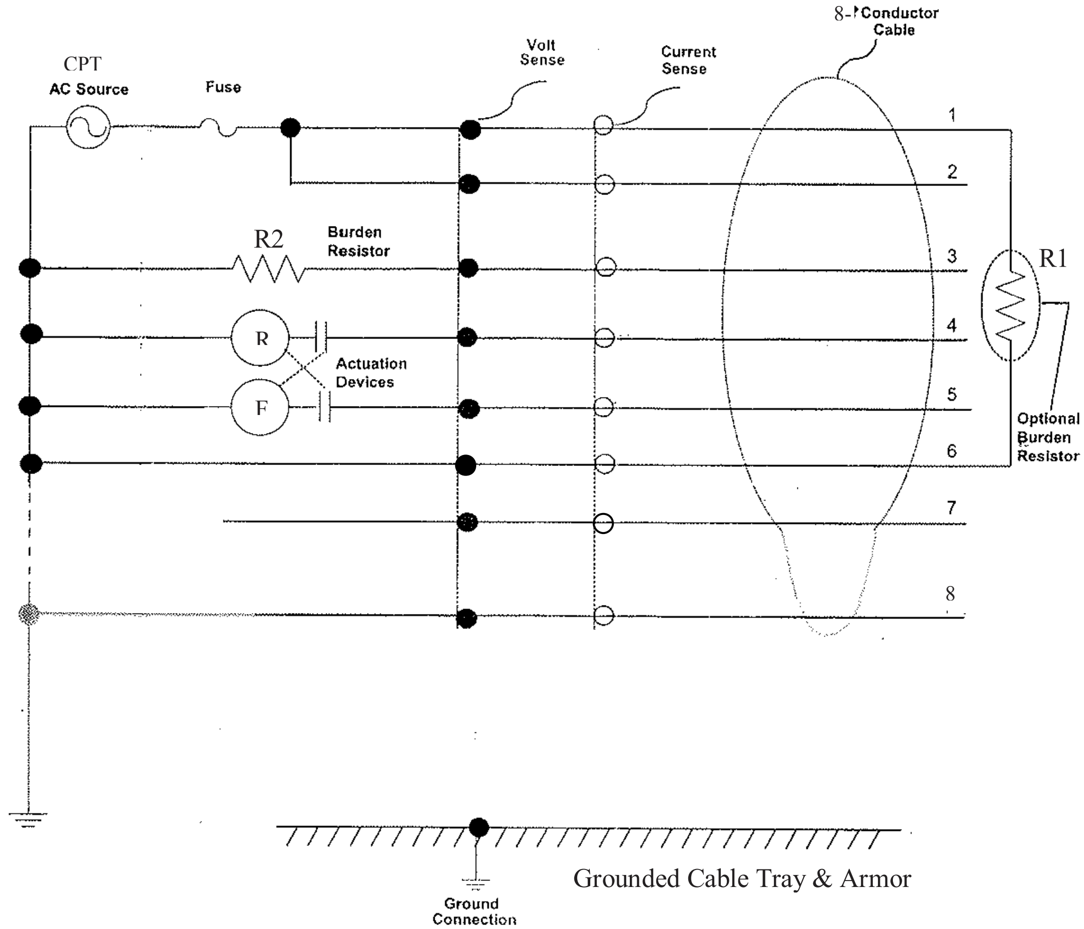
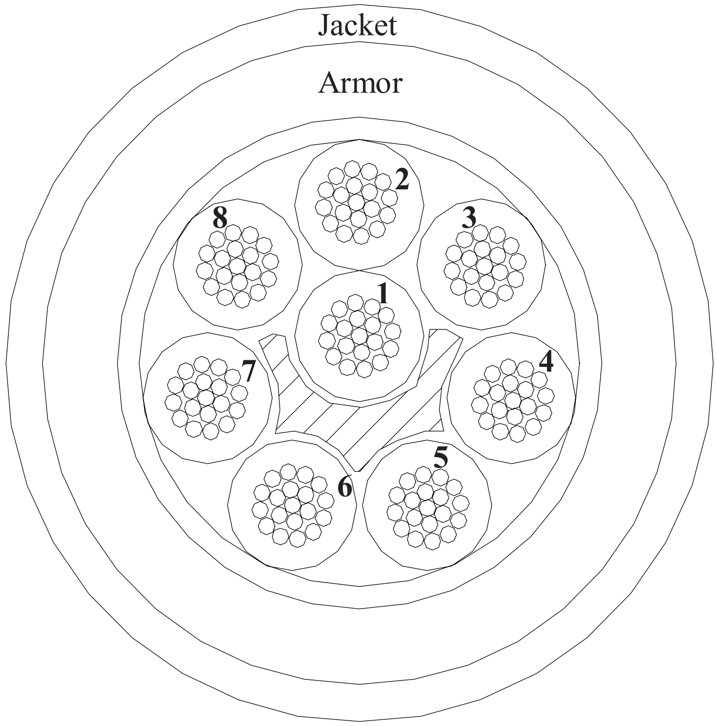


Figure 2: Monitoring and Device Connections for Cable Conductors (8/C DA Bundles)

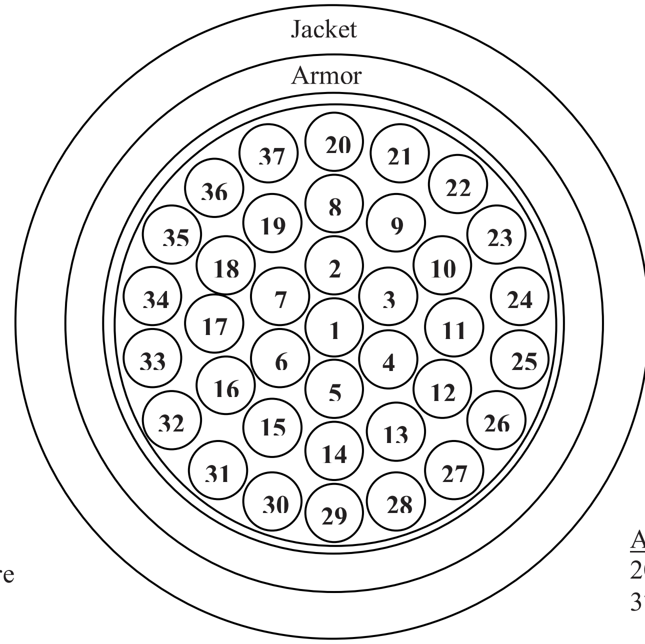
NOTE: For switchgear breaker control circuits (in Tests 13 through 16), the control power source is changed to a 125 VDC source (ungrounded) and the actuating devices are changed to switchgear breaker close and trip coils. *For the 37-conductor cable tests, the 8-conductor cable in Figure 2 is actually one of four bundles within the cable. (See also Figure 4.)*



Conductors vs. Figure 2 Configuration:

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

Figure 3: Detail of Source-Centered Conductor Arrangement for the 8-Conductor Cable



Additional Conductors
9 - Open Wire
10 - Extra CPT Power Wire
19 - Grounded Spare

Additional Conductors
20 - Open Wire
37 - Grounded Spare

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 – Burden Resistor R2-1 Load - Open
4 – Starter 1 Actuating Device (Forward)
5 – Starter 1 Actuating Device (Reverse)
6 – CPT 1 Return (from Burden R1-1)
7 – Open Wire (ex/ Open Contact)
8 – Grounded Spare

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

Figure 4: Detail of Conductor Arrangement for the 8/C Bundles in 37-Conductor Cable

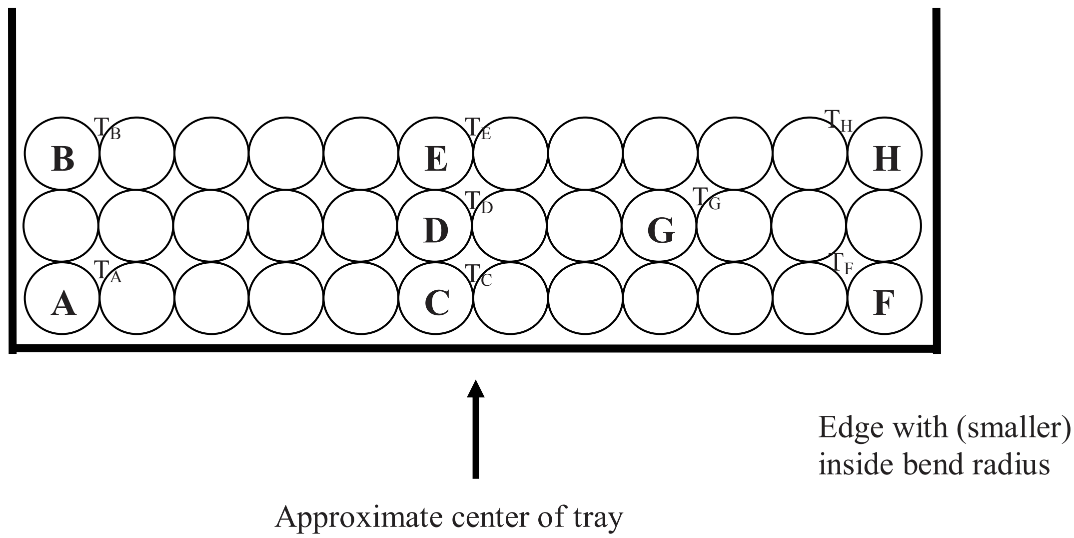


Figure 5: Three Layer Fill of 8/C Cables: Base Tests 1 - 4 (Jacketed), Tests 5 - 8 (Un-jacketed), Tests 9 - 12 (CPT grounded), Tests 13 - 16 (DC circuit)

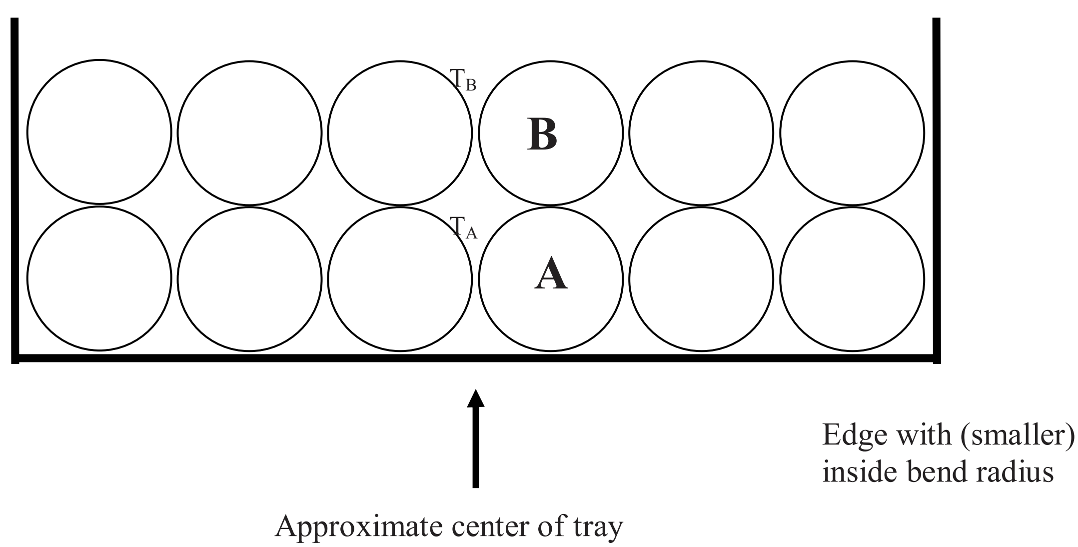


Figure 6: Two Layer Fill of 37/C Cables: Tests 17 - 20 (Jacketed)

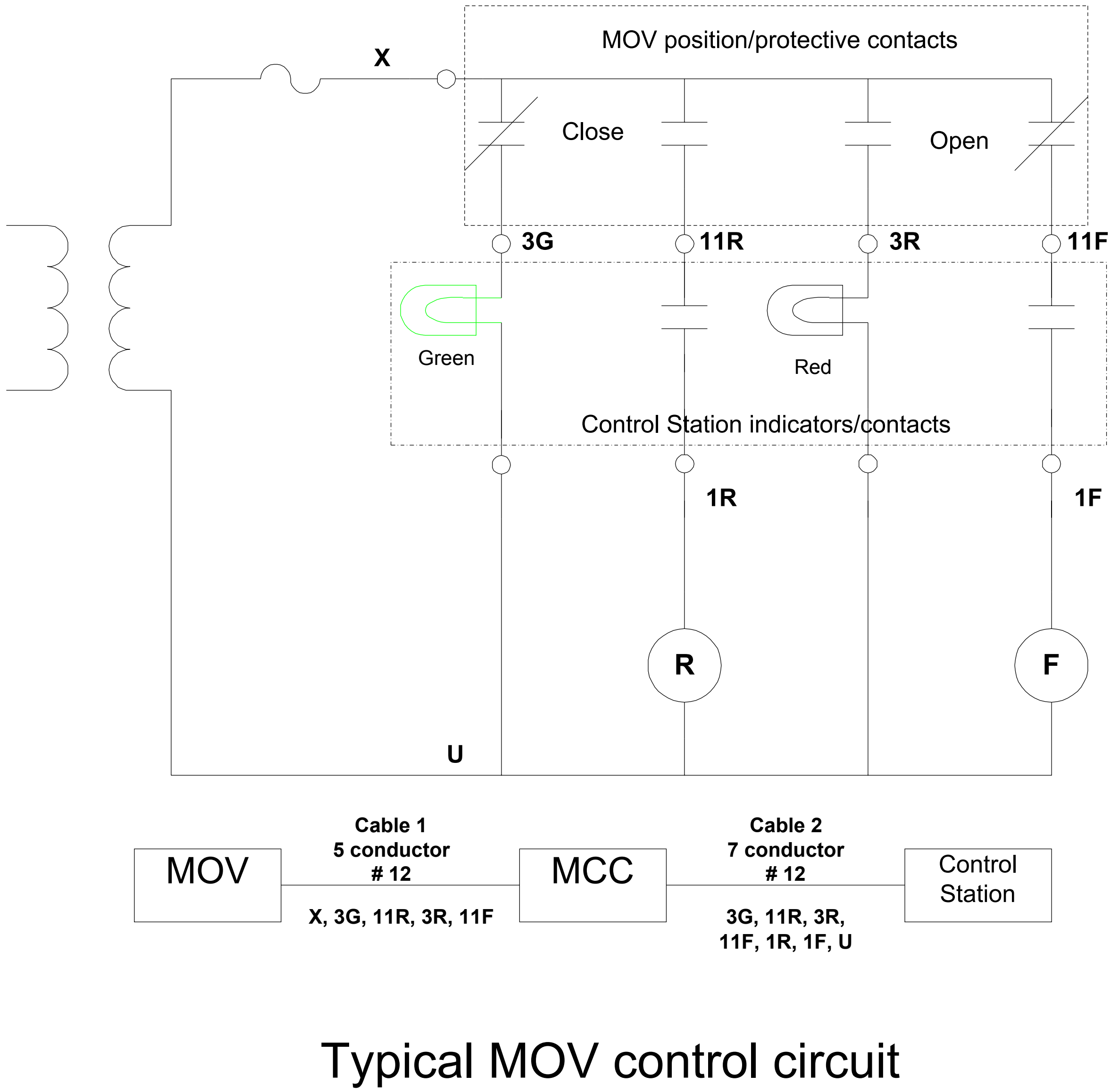


FIGURE 7

Typical Control Circuit