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Testing Korean Cables:
Electrical Degradation and Failure Associated with Radiant Heating

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Prepared by:
Francis J. Wyant, Jason W. Brown, and Steven P. Nowlen
Risk and Reliability Analysis Department 6231
Sandia National Laboratories
Albuquerque, New Mexico

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Korean Cable Fire Tests

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List of Acronyms

ac	Alternating Current
AWG	American Wire Gauge
CR	Chloroprene Rubber (Polychloroprene or Neoprene)
CSP	Chlorosulphonated Polyethylene
dc	Direct Current
EPR	Ethylene-Propylene Rubber
EPRI	Electric Power Research Institute
IRMS	Insulation Resistance Measurement System
KEPRI	Korea EPRI
MOV	Motor Operated Valve
NEI	Nuclear Energy Institute
NRC	Nuclear Regulatory Commission
RES	NRC Office of Nuclear Regulatory Research
SCDU	Surrogate Circuit Diagnostic Unit
SNL	Sandia National Laboratories

1. Introduction

Sandia National Laboratories (SNL) has conducted or participated in a number of thermal exposure tests on electric cables used in U.S. nuclear power plants beginning in early 2001. Since that time Sandia has developed a "standard" test methodology utilizing some unique diagnostic equipment to determine the onset of electrical degradation and specific failure modes of electric cables exposed to a variety of thermal conditions. The tests that have been conducted during these various test series have included a variety of cable types— thermoset, thermoplastic, and silicone rubber—as well as a variety of configurations—conductor counts of between 2 and 15, various wire gages, shielded and unshielded, armored, etc.

In 2001, Sandia was a participant in the cable fire tests sponsored by the Electric Power Research Institute (EPRI) and supported by the Nuclear Energy Institute (NEI). The purpose of these tests was to characterize fire-induced circuit faults for the U.S. nuclear industry. Sandia's participation was the first application of the Insulation Resistance Measurement System (IRMS) just developed at SNL.

Under the sponsorship of the U.S. Nuclear Regulatory Commission (NRC) Office of Nuclear Regulatory Research (RES), Sandia conducted a series of cable burn tests known as the *Cable Response to Live Fire* (CAROLFIRE) program. The purpose of the CAROLFIRE test series was two-fold: to investigate the credibility of certain cable and circuit characteristics to cause unwanted behavior as the result of fire damage and to provide the data needed to improve existing fire models. The CAROLFIRE tests were the first time the Surrogate Circuit Diagnostic Units (SCDUs) were employed to characterize the consequences of fire damage to cables on simple control circuits. CAROLFIRE was conducted in 2006.

As part of a cooperative agreement between the U.S. NRC and France, Sandia personnel participated in a five-test series of experiments involving several European cables in 2008. The PRISME tests employed both the IRMS and the SCDU to obtain data on the behavior of foreign cables in fire environments.

The NRC sponsored the *Direct Current Electrical Shorting in Response to Exposure Fire* (DESIREE-Fire) project as an effort to examine general thermoplastic and thermoset cable failure modes and effects for direct current (dc)-powered control cables. A limited number of alternating current (ac) circuits were also tested. These tests investigated the impact of cable damage for a number of different dc component control circuits including those for solenoid operated valves, dc motor operated valves (MOVs), and a large circuit breaker. A few of the test runs included the use of the SCDUs to monitor cable electrical response. The DESIREE-Fire tests were conducted in 2009 and 2010.

SNL was contacted in mid-2010 by Korea EPRI (KEPRI) to conduct a CAROLFIRE like series of tests on thirteen different Korean made cable samples. However, because of the limited

budget available to perform the tests and report on the results, it was decided to perform a very limited number of tests on six of the Korean cable types. The principal method used in this test series was to expose the cable sample to thermal environments in the Penlight test chamber and record the cable electrical responses using the IRMS and the SCDUs. These tests were conducted in the fall of 2010 at Sandia National Laboratories in accordance with the provisions of Funds-in Agreement FI 067100625 between KEPRI and SNL [1].

2. Overview of Testing Needs

2.1. Cable Failure Threshold Determination

The initial cable tests were monitored by the Sandia IRMS monitoring unit in order to determine the cable temperatures at which failure occurs. The IRMS is an ac cable monitoring unit and was used to investigate incipient current leakage between conductors within the cables. Each cable type was tested twice while connected to the IRMS. The first of these runs involved a "slow" step-wise progressive increase of the Penlight shroud temperature while recording the IRMS insulation-resistance data and cable temperature. Upon determination that electrical failure of the cable had occurred, the Penlight shroud and cable temperatures at that time were noted.

The second run for each Korean cable type was a verification of the temperature findings in the initial run for that cable type by setting the Penlight shroud temperature at or near the shroud temperature setting when failure occurred during the first threshold determination run. The expectation was that cable failure should occur within 10 to 30 minutes of the Penlight shroud stabilizing at the designated temperature. The data from both test runs formed the basis for the Penlight exposure conditions during the failure modes testing phase of the project.

2.2. AC Control Circuit Cable Failure Modes and Effects

The tests included fielding of the MOV ac control circuit simulators (the SCDUs) originally developed for the CAROLFIRE project. The threshold temperature failure modes and effects (e.g., spurious actuation) were investigated using the SCDUs. The ac equipment was deployed in a manner similar to that employed in CAROLFIRE. The intent was to conduct two to three test runs for each cable type using the SCDUs while the voltage and current characteristics of the circuit connected to the cable were being monitored and recorded. Cable temperature and Penlight shroud temperature were recorded during the test runs as well.

2.3. Cable Thermal Response Characterization

One of two major objectives of the CAROLFIRE project was to explore key behaviors associated with the thermal response of cables exposed to a fire environment. In particular, CAROLFIRE included a substantial effort to characterize cable heating behavior under a range of fire conditions and to correlate the cable thermal response to electrical performance and failure. The Korean cable testing program also included the gathering of fire exposure and cable thermal response data. With respect to cable thermal response, testing included cables

instrumented for thermal response in a manner that allows for correlation to electrical failure. Testing also included thermocouples and other instruments deployed to characterize the local thermal environment to which the cables were exposed.

3. Experimental Approach

3.1. Overview

To meet the goals of the Korean Cable Test program, six different types of Korean made cable were tested. The primary differences between the cable samples involve the number of conductors and designated function. The test matrix (provided below) includes 25 small-scale exposure tests using the Penlight test chamber.

3.2. Test Configuration

The Korean cable testing program utilized the SNL radiant heat exposure device called Penlight. This facility is described in detail in Volume 2 of NUREG/CR-6931 [2]. The planned exposure geometry is shown in Figure 1. The same general test protocol established for CAROLFIRE was followed for these tests. Essentially, two cables were used during each test: one for monitoring the thermal response, the other for monitoring the cable electrical response to determine the primary failure mechanisms. The cable heating procedure, however, conformed to the needs of this particular test series. Note that the cable lengths shown in Figure 1 have been exaggerated to illustrate positions in the tray.

One specific objective of the CAROLFIRE Penlight tests was to establish appropriate heating levels for each cable type that would induce failure within a 10-20 minute time frame. However, since the primary purpose of this testing program was to investigate the threshold failure temperature during the initial test runs, the Penlight shroud temperature was increased 25°C every 5 minutes until electrical failure (i.e., shorting to ground or hot shorts) was observed. The intent of the Penlight testing is to provide a well characterized and controlled environment in which to investigate the potential failure mechanisms of the Korean cables.

3.3. Cable Selection Criteria

In the initial contacts with SNL, KEPRI provided a list of 13 different cable types they wanted to be tested using the CAROLFIRE protocols. However, based on budget constraints, Sandia recommended a test series consisting of six of the Korean cable types. Table 1 provides the list of cables that were selected to be tested in Penlight along with basic information about the each of the cable types. All of the Korean cables insulate the individual conductors with ethylene-propylene rubber (EPR), a thermoset material. Two different jacket, or sheathing, materials were included in the Korean cable set: Chlorosulphonated Polyethylene (CSP) and Chloroprene Rubber (CR).

Table 1: Korean Cable Test List

Cable ID	Insulation / Jacket	# of conductors	Size	Minimum Sample length	Class	Rating voltage	Types	Manufacturer	Ref.
1	E P R／C S P	6	16AWG	15m	Class-1E	600	instrumentation	JS CABLE	Korean-made
3	E P R／C S P	2	16AWG	12m	Class-1E	600	instrumentation	LG CABLE	Korean-made
5	E P R／C S P	9	14AWG	12m	Class-1E	600	control	JS CABLE	Korean-made
8	E P R／C R	9	14AWG	12m	Non-1E	600	control	T A I H A N	Korean-made
10	E P R／C S P	2	16AWG	12m	Class-1E	600	power	JINRO	Korean-made
13	E P R／C S P	3	14AWG	12m	Class-1E	600	power	LS CABLE	Korean-made

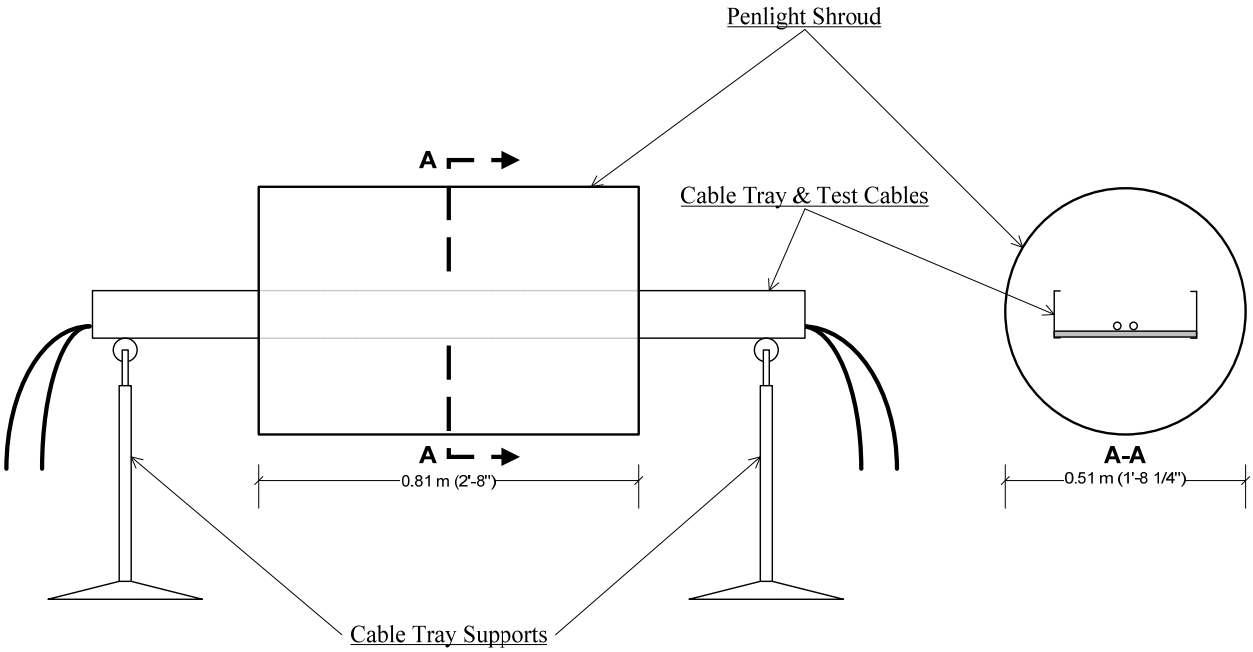


Figure 1: Penlight testing apparatus.

The cable types selected were chosen for a variety of reasons:

1. Since cable No. 5 is a 9/C, 14 AWG Class-1E control cable and cable No. 8 is a 9/C, 14 AWG non-1E control cable Sandia argued that it would be very beneficial to test them in order to compare their responses to thermal exposure and damage.
2. Since cable No. 3 is a 2/C, 16 AWG instrument cable and cable No. 10 is a 2/C, 16 AWG power cable Sandia felt the comparison of their behaviors would also be useful, additionally they are manufactured by different companies.
3. Cables No. 1 (6/C, 16 AWG) and No. 13 (3/C, 14 AWG) have constructions similar to the types of cables tested during CAROLFIRE, thus testing these cables would allow a reasonable comparison to the U.S. cable results.

KEPRI agreed with the Sandia recommendations and provided samples of each of the cable types listed in Table 1. Figure 2 provides cross-sectional views of each of the cable types tested in the Korean Cable Test Program. One unusual characteristic of the cable samples is that the total lengths of each cable type were very limited. Consequently, each of the Penlight tests was conducted with one 1-meter (3 foot) length of cable instrumented with thermocouples to provide the cable temperature measurements and one 2-meter (6 foot) length of cable connected to the electrical monitoring device, either IRMS or SCDU. Figure 3 shows the cable arrangement as installed in Penlight for testing. Connections made to the electrically monitored test cables were accomplished using standard wire nuts instead of being connected to the instrument lead cables through a junction box, as was done during the DESIREE-Fire tests.

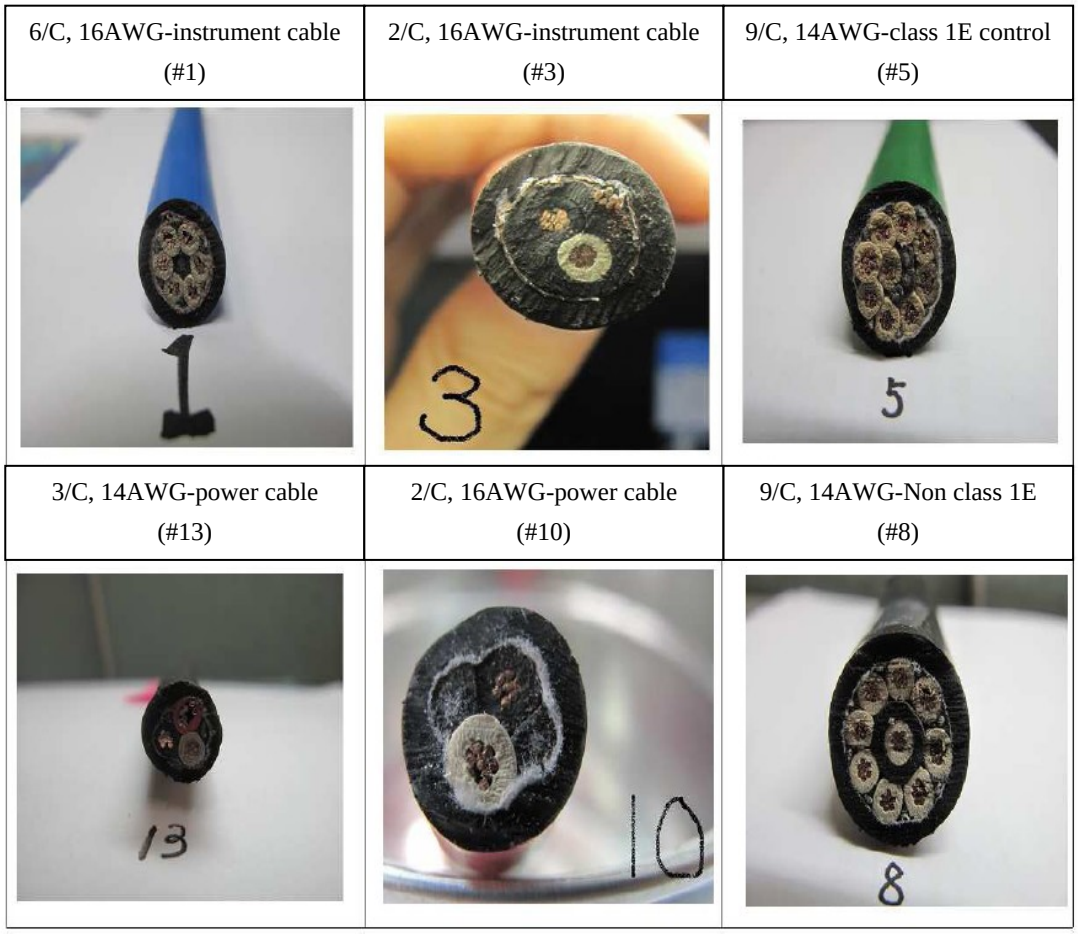


Figure 2: Cross-sectional views of the Korean test cables.

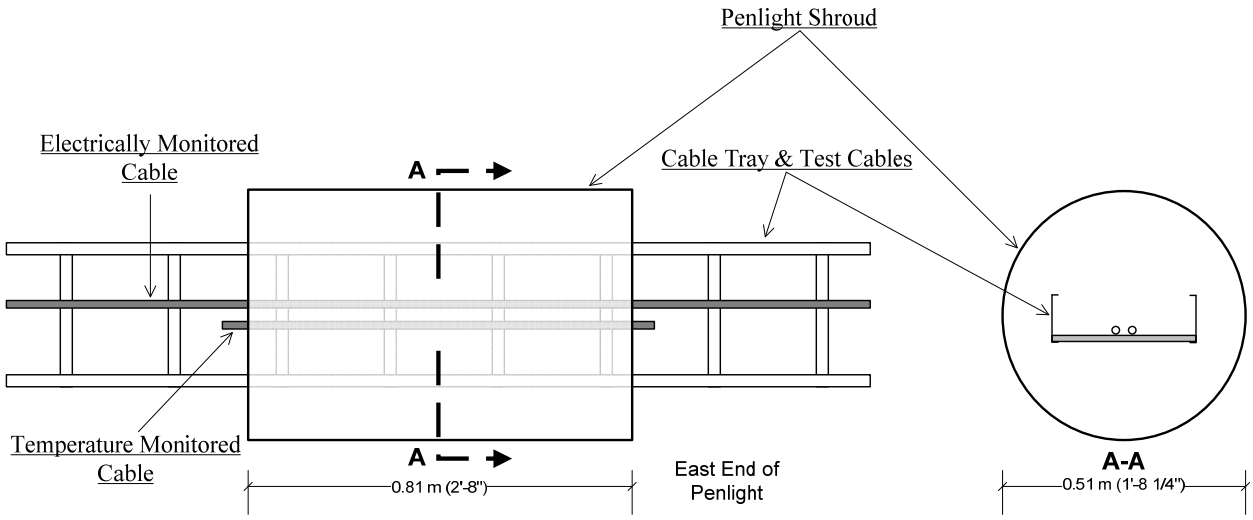


Figure 3: Penlight testing apparatus showing cable arrangement in tray

4. Primary Measurements and Performance Diagnostics

There were a number of variables that needed to be investigated in this test program. These variables will be discussed in the context of three general categories; namely, cable electrical performance and failure, exposure conditions, and cable thermal response.

4.1. Cable Electrical Performance and Failure

Cable electrical performance and failure were monitored using two general instrumentation systems.

4.1.1. The Insulation Resistance Measurement System (IRMS)

The Insulation Resistance Measurement System (IRMS) was originally developed as a part of the NRC/RES collaboration on the 2001 EPRI/NEI Fire Test Program. The system was also deployed during the CAROLFIRE testing program, and NUREG/CR-6931 provides a detailed description of the IRMS design and operation.

In CAROLFIRE, the IRMS was deployed using 120 Vac (60 Hertz) line power as the energizing source potential. In all other respects, the design, operation, and data analysis associated with the IRMS remain as described in NUREG/CR-6931.

The IRMS was the monitoring unit used to initially identify and then verify the cable failure temperature thresholds prior to investigating potential circuit failure modes.

4.1.2. The CAROLFIRE SCDUs

The other cable electrical performance and failure monitoring system deployed for these tests was the Surrogate Circuit Diagnostic Unit (SCDU) systems developed for CAROLFIRE. The

SCDUs are also described in detail in NUREG/CR-6931. Each of the four SCDU systems provides the ability to simulate one ac control circuit. For CAROLFIRE the units were generally deployed to simulate an ac motor-operated valve (MOV) control circuit. A similar approach was taken in the Korean cable tests.

It should be noted that the only design change that has been implemented relative to the SCDUs is replacement of the original motor starter relay sets at the start of DESIREE-FIRE. The motor starters used during CAROLFIRE were, in hindsight, found to require far less motive power to lock in and hold a spurious actuation signal than anticipated. As a result, CAROLFIRE was unable to resolve one of the original Regulatory Information Summary (RIS) 2004-03, "Risk-Informed Approach for Post-Fire Safe-Shutdown Circuit Inspections," [3] unresolved issues; namely, that item related to how CPT size relative to the nominal circuit required power would impact spurious actuation likelihood.

Hence, the existing motor starter contactor relays were replaced with Joslyn-Clark[1] relays of the same type used in the original 2001 EPRI/NEI Fire Test Program (current part number is T30U031). All other aspects of the SCDU deployment mirror CAROLFIRE and the ac MOV control circuits. Two motor starter relay sets were provided by EPRI via the DESIREE-FIRE collaboration, and two additional sets were procured directly from Joslyn-Clark. For the purposes of the Korean cable testing program only SCDU 1, which utilizes a 100VA CPT and mechanical interlocks, was used.

SCDU 1 was used to help identify the potential failure mode (e.g., spurious actuation) manifested when the cable began to fail electrically due to thermal damage in Penlight. The threshold pickup voltages and currents of all the Joslyn-Clark motor starter relays were measured for the DESIREE-Fire project. Those used in SCDU 1 for the Korean Cable Test program had the electrical characteristics given in Table 2.

Table 2: SCDU 1 Target MOV Relays Pickup Voltages & Currents

MOV ID	Pickup Voltage (Vac)	Pickup Current (A)
T5	93.9	0.07
T6	80.5	0.08

4.2. Thermal Exposure Conditions

The Penlight radiant heat apparatus allows heat flux exposures at virtually any exposure level up to 97 kW/m^2 (870°C shroud temperature). This is a heating level well above that typically

[1] Note that the EPRI test report (TR-1003326, page 4-13) cites "AO Smith (Clark Controls Division) Catalog #30U031" as the make and model of the motor starters used in that test program. AO Smith has since merged with Joslyn controls. The combined company is known as Joslyn-Clark Controls. The same model motor starter relays are sold under the Joslyn-Clark brand using essentially the same catalog number (T30U031).

experienced in real fires anywhere other than within the flame zone itself, or under wind-driven conditions. Given the nature of typical nuclear power plant (NPP) fires, it is desirable to monitor the degradation of cable integrity and behavior over moderately long times (nominally on the order of 10-30 minutes), thus based on previous test experience, thermoset cables will fail in the desired time frame at heat fluxes of 10 - 20 kW/m^2. This is the Penlight exposure range we began with to investigate the cable damage thresholds for the Korean cables.

Only cable tray raceways were employed during these tests. The cable tray was a 300 mm (12-inch) wide standard ladder-back tray.[2] The trays are identical to those used in CAROLFIRE as described in NUREG/CR-6931.

4.3. Cable Thermal Response

Another benefit of this test series was to provide additional cable thermal response data for the fire model improvement effort started in the CAROLFIRE test program. Measurements of the cable thermal response are important to characterize the environmental conditions leading to the failure, and additional data in this regards is considered quite valuable. Cable thermal response data was gathered during the tests in a manner similar to that employed in CAROLFIRE, albeit with somewhat less instrument density.

As noted for CAROLFIRE, it is not appropriate to instrument any single cable for both thermal and electrical response. This is because installation of a thermocouple on, or within, a cable could impact the electrical failure behavior. Instead, the approach applied involves mirroring a cable being monitored for electrical performance with a second cable (in an adjacent or symmetric location) monitored for thermal response. Figure 4 provides a graphical depiction of this dual-cable setup.

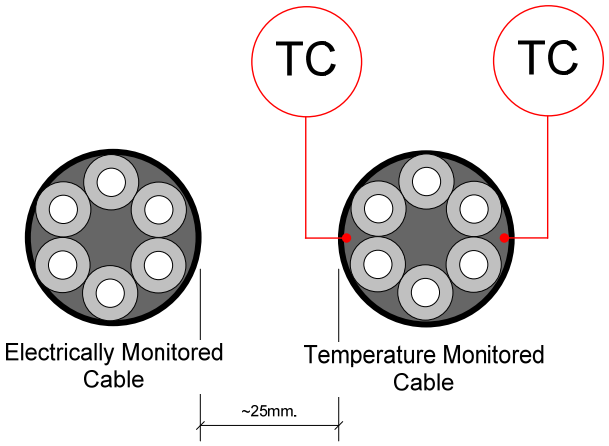


Figure 4: Example thermocouple arrangement for temperature monitoring of a 6-conductor cable located near the electrically monitored cable in tray

[2] The cable trays are B-Line7 Series 2 style steel trays with (per manufacturer specifications) a nominal 3 inch NEMA VE 1 loading depth, 4 inch side rail, and rung spacing of 9 inches. The specific part number is 248P09-12-

Thermocouples measure the thermal response of the cables upon heating. Two thermocouples were positioned at the center of the cable sample to provide redundant verification of the temperature data. Two additional thermocouples were mounted on the cable sample located along the cable length, at approximately 300 millimeters (1 foot) from the center pair of thermocouples. Type K thermocouples were used and placed just below the outer cable jacket for cable thermal response monitoring, a technique proven during the CAROLFIRE tests. A small slit is cut in the jacket allowing insertion of the thermocouple bead. The bead itself was typically be inserted into the cable for a distance of approximately 35 – 100 mm (1.4 – 4 inches) along the length of the cable placing it well away from the cut in the outer jacket. Placement distance does vary depending on the cable type. The slit was then be closed and secured with a single layer of fiberglass tape.

5. Test Matrix

Table 3 provides the test matrix for the Korean cable test program. Note that the test program was intended to allow for flexibility and for the adjustment of test configurations and goals as the program progressed. That is, each test configuration in the matrices was to be considered nominal, reflecting the overall scope and general conditions and configurations anticipated. However, it is intended that the project would maintain the option to adjust the test conditions based on insights gained as the program progressed.

The headings used in the matrix have the following meanings:

Test Run – Indicates the test run number. Data and descriptive information about the test conditions and results will be referenced to the test run number.

Cable ID – Indicates the particular cable designation originally provided by KEPRI.

Insulation/Jacket – Indicates the type of material comprising the conductor insulation and cable jacket. This information has been provided by KEPRI.

Type – Indicates the intended function of the cable under test. This information was also provided by KEPRI.

No. Cond. – Indicates the number of conductors contained within the cable under test.

Gage – Indicates the size of the conductors within the cable under test.

Electrical Diagnostics – Indicates for each test run which electrical diagnostic apparatus will be used to identify the onset of electrical failure. An “X” in a given column indicates the preferred choice of diagnostic unit: IRMS or SCDU.

Table 3: Korean Cable Test Matrix

Test Run	Cable ID	Insulation/Jacket	Type	No. Cond.	Gage	Electrical Diagnostics	
						IRMS	*SCDU*
1	1	EPR/CSP	Instr.	6	16	X	
2	3	EPR/CSP	Instr.	2	16	X	
3	5	EPR/CSP	Control	9	14	X	
4	8	EPR/CR	Control	9	14	X	
5	10	EPR/CSP	Power	2	16	X	
6	13	EPR/CSP	Power	3	14	X	
7	1	EPR/CSP	Instr.	6	16	X	
8	3	EPR/CSP	Instr.	2	16	X	
9	5	EPR/CSP	Control	9	14	X	
10	8	EPR/CR	Control	9	14	X	
11	10	EPR/CSP	Power	2	16	X	
12	13	EPR/CSP	Power	3	14	X	
13	1	EPR/CSP	Instr.	6	16		X
14	1	EPR/CSP	Instr.	6	16		X
15	1	EPR/CSP	Instr.	6	16		X
16	5	EPR/CSP	Control	9	14		X
17	5	EPR/CSP	Control	9	14		X
18	8	EPR/CR	Control	9	14		X
19	8	EPR/CR	Control	9	14		X
20	13	EPR/CSP	Power	3	14		X
21	13	EPR/CSP	Power	3	14		X
22	3	EPR/CSP	Instr.	2	16		X
23	3	EPR/CSP	Instr.	2	16		X
24	10	EPR/CSP	Power	2	16		X
25	10	EPR/CSP	Power	2	16		X

6. Analysis of the Korean Cable Tests

As previously mentioned, the scope of the Korean Cable Test Program covered the electrical monitoring of the test cables by both the IRMS and SCDU apparatuses. This section discusses the results of the cable behavior during the Penlight exposures. The results determined using the IRMS are presented first and followed by the SCDU results.

6.1. Cable Electrical Performance and Failure as Determined Using the IRMS

Cable electrical performance and failure were monitored using the IRMS during the initial test runs. The purpose of these tests was to determine the Penlight shroud temperatures (and corresponding heat flux) to employ to cause cable damage occurrence within 10 to 30 minutes from the initiation of heating. Each of the six Korean cable types was tested twice in Penlight while being monitored with the IRMS unit. These test runs covered Tests 1 through 12 in the test matrix. During each of the first six tests, the Penlight shroud temperature was initially set at 250 C and increased in 25 C increments every five minutes until ignition and cable electrical failures occurred.

The second series of six tests (7 through 12) consisted of starting the Penlight exposure at the shroud temperature setting that was in place when electrical failure of the cable occurred during the first test run. This provided verification of the appropriate Penlight shroud temperature settings to use during the failure mode assessment test runs (13-25) while employing the SCDU.

Table 4 provides a summary of the results from the IRMS diagnostic tests run in Penlight.

Table 4: Korean Cable Test IRMS Summary

IRMS Test #	Cable ID	Insulation / Jacket	No. Cond.	Cond. Size (AWG)	Tape or Shield?	Penlight Shroud Temp. (C) Setting Prior to Failure	Corresponding Heat Flux (kW/m2)	Time of 1st Failure after Penlight on (s)	Cable Temp. at Failure (C)	Initial Cable Failure Mode	Notes
1	1	EPR/CSP	6	16	YES	475	14.5	2745	421	C-G	(1)
2	3	EPR/CSP	2	16	YES	450	12.6	2501	435	C-G	(1)
3	5	EPR/CSP	9	14	NO	450	12.6	2452	404	C-C	(1)
4	8	EPR/CR	9	14	NO	375	8.1	1859	411	C-C	(1)
5	10	EPR/CSP	2	16	NO	450	12.6	2593	525	C-G	(1)
6	13	EPR/CSP	3	14	NO	450	12.6	2548	475	C-G	(1)
7	1	EPR/CSP	6	16	YES	450	12.6	639	468	C-C	(2)
8	3	EPR/CSP	2	16	YES	450	12.6	485	377	C-C	(2)
9	5	EPR/CSP	9	14	NO	450	12.6	790	492	C-C	(2)
10	8	EPR/CR	9	14	NO	450	12.6	637	442	C-C	(2)
11	10	EPR/CSP	2	16	NO	440	11.9	735	545	C-C	(2)
12	13	EPR/CSP	3	14	NO	450	12.6	485	398	C-C	(2)

(1) Penlight shroud temperature set initially to 250 C and increase by 25 C every 5 minutes until ignition.
(2) Penlight shroud temperature held at initial setting without further adjustments until after cable ignition and electrical failure.

The headings used in the IRMS summary table have the following meanings:

IRMS Test # – Indicates the test run number as indicated in the primary test matrix. Data and descriptive information about the test conditions and results are referenced to the test run number.

Cable ID – Indicates the particular cable designation originally provided by KEPRI.

Insulation/Jacket – Indicates the type of material comprising the conductor insulation and cable jacket. This information has been provided by KEPRI.

No. Cond. – Indicates the number of conductors contained within the cable under test.

Cond. Size (AWG) – Indicates the size of the conductors within the cable under test in accordance with the American Wire Gage standards.

Tape or Shield? – A "YES" indicates that the cable under test has a metal shield or tape surrounding the conductor bundle underneath the jacket. The presence of an uninsulated drain wire was not a consideration of this characteristic.

Penlight Shroud Temp. Setting Prior to Failure – Indicates the last setting of the Penlight shroud temperature achieved prior to the occurrence of cable damage and failure.

Corresponding Heat Flux – Indicates the exposure heat flux based on the Penlight shroud temperature (shroud emissivity was assumed to be 0.815).

Time of 1st Failure after Penlight on – Indicates the time it took the cable to fail electrically after Penlight heating was begun.

Cable Temp. at Failure – Provides the recorded cable temperature at its center point(s) at the first indication of electrical failure.

Initial Cable Failure Mode – Indicates the failure mechanism as indicated by the IRMS: "C-G" means one or more conductors shorted to ground, "C-C" means that two or more conductors shorted together.

Notes – Indicates the applicable note for additional information.

The results provided in Table 4 indicate that the six- and nine-conductor cables would likely fail within the desired 10-30 minute time frame if the initial Penlight shroud temperature was set at 450C. The two- and three-conductor cable responses lead the Sandia team to select a slightly lower initial shroud temperature (430-440C) for the SCDU test runs.

It is also notable that the initial failure mode during the slow step-up ramp tests (1-6) was

manifest by a conductor first shorting to ground (i.e., the cable tray) in four of the six test runs. On the other hand, conductor-to-conductor shorting was the initial failure mode observed during all of the later tests (7-12).

Additional details of the IRMS monitored tests are provided in the Appendix to this report.

6.2. Cable Electrical Performance and Failure as Determined Using the SCDU

Cable electrical performance and failure was monitored using the SCDU during the test runs following the IRMS tests. The purpose of these tests was to determine the likely failure mode occurring as the result of cable damage and the ultimate impact of those failures on a simulated motor operated valve (MOV) circuit. Each of the six Korean cable types was tested in Penlight while being monitored with the SCDU. These test runs covered Tests 13 through 25 in the test matrix. During each of these tests, the Penlight shroud temperature was initially set at the target temperature (~450 C) and was maintained at that temperature until ignition and cable electrical failure occurred.

Table 5 provides a summary of the results from the SCDU diagnostic tests run in Penlight.

Table 5: Korean Cable Test SCDU Summary

SCDU Test #	Cable ID	Insulation / Jacket	No. Cond.	Cond. Size (AWG)	Tape or Shield?	Penlight Shroud Temp. (C) Setting Prior to Failure	Corresponding Heat Flux (kW/m2)	Time of 1st Failure after Penlight on	Cable Temp. at Failure (C)	Initial Cable Failure Mode	Notes
13	1	EPR/CSP	6	16	YES	450	12.6	603	451	SA-HS	(2)
14	1	EPR/CSP	6	16	YES	450	12.6	618	451	SA-HS	(2)
15	1	EPR/CSP	6	16	YES	450	12.6	613	495	SA-HS	(2)
16	5	EPR/CSP	9	14	NO	450	12.6	738	457	SA-HS	(2)
17	5	EPR/CSP	9	14	NO	450	12.6	811	477	FC-SG	(2)
18	8	EPR/CR	9	14	NO	450	12.6	638	418	FC-SG	(2)
19	5	EPR/CSP	9	14	NO	450	12.6	743	423	FC-SG	(2, 3)
20	13	EPR/CSP	3	14	NO	440	11.9	492	438	SA-HS	(2)
21	13	EPR/CSP	3	14	NO	430	11.3	539	437	SA-HS	(2)
22	3	EPR/CSP	2	16	YES	440	11.9	506	393	SA-HS	(2)
23	3	EPR/CSP	2	16	YES	440	11.9	555	443	SA-HS	(2)
24	10	EPR/CSP	2	16	NO	440	11.9	689	588	FC-SG	(2)
25	10	EPR/CSP	2	16	NO	440	11.9	DNF	DNF	DNF	(2, 4)

(2) Penlight shroud temperature held at initial setting without further adjustments until after cable ignition and electrical failure.

(3) The cable tested during Test 19 was Cable ID 5 because there was insufficient length of Cable ID 8 to perform the test run.

(4) No electrical failures occurred during Test #25.

The headings used in the SCDU summary table have the following meanings:

SCDU Test # – Indicates the test run number as indicated in the primary test matrix. Data and descriptive information about the test conditions and results are referenced to the test run number.

Cable ID – Indicates the particular cable designation originally provided by KEPRI.

Insulation/Jacket – Indicates the type of material comprising the conductor insulation and cable jacket. This information has been provided by KEPRI.

No. Cond. – Indicates the number of conductors contained within the cable under test.

Cond. Size (AWG) – Indicates the size of the conductors within the cable under test in accordance with the American Wire Gage standards.

Tape or Shield? – A "YES" indicates that the cable under test has a metal shield or tape surrounding the conductor bundle underneath the jacket. The presence of an uninsulated drain wire was not a consideration of this characteristic.

Penlight Shroud Temp. Setting Prior to Failure – Indicates the last setting of the Penlight shroud temperature achieved prior to the occurrence of cable damage and failure.

Corresponding Heat Flux – Indicates the exposure heat flux based on the Penlight shroud temperature (shroud emissivity was assumed to be 0.815).

Time of 1st Failure after Penlight on – Indicates the time it took the cable to fail electrically after Penlight heating was begun.

Cable Temp. at Failure – Provides the recorded cable temperature at its center point(s) at the first indication of electrical failure.

Initial Cable Failure Mode – Indicates the failure mechanism as indicated by the SCDU: "SA-HS" means that a spurious actuation of one of the active target (AT) devices occurred due to a hot short from one of the energized source conductors in the test cable, "FC-SG" means that the secondary side CPT fuse cleared due to a short to ground.

Notes – Indicates the applicable note for additional information.

Table 5 indicates that the six- and nine-conductor cables did indeed fail within the desired 10-30 minute time frame with the initial Penlight shroud temperature set at 450C. This was also true for the 2-conductor Cable ID 10. The other two-conductor and the three-conductor cable responses reveal that they failed earlier than that, even with the slightly lower initial shroud temperatures (430-440C).

The initial failure mode most often observed during the SCDU tests was manifest by a spurious actuation of either active target T5 or T6 (8 cases). In four cases, the initial failure mode was by

a fuse clearing event. The test cable did not fail in one test run case (#25) although it had ignited and burned.

In a departure from the planned test matrix, it should be noted that Test #19 tested lengths of Korean Cable 5 instead of Korean Cable 8. This was done because there was not enough length of Cable 8 left over following Test #18.

Additional details of the SCDU monitored tests are provided in the Appendix to this report.

6.3. Cable Electrical Performance and Failure Summary

Given the data obtained during the IRMS and SCDU Penlight test runs, Table 6 presents a summary of the measured cable temperatures at the time of electrical failure. The results indicate that Cable 10 appears to be more rugged than the other cable types, while Cable 3 appears to be the most susceptible to cable damage.

Table 6: Korean Cable Test Failure Temperature Summary

Cable ID	Minimum Cable Failure Temperature (C)	Average Cable Temperature at Failure (C)
1	421	491
3	377	412
5	404	451
8	411	424
10	525	553
13	398	437

Regarding the spurious actuation failures occurring during eight of the SCDU tests, Table 7 presents data on the durations of the spurious actuations of the active targets (T5 and T6). The durations of the first spurious actuation occurring during each of the eight tests ranged from 1 s to 56 s with an average value of 24 s. The total time between the occurrence of the first spurious actuation until the circuit lost power because the CPT fuse cleared ranged from 12 s to 151 s with an average duration of 65 s. It is also notable that Korean Cables 8 and 10 did not exhibit the spurious actuation failure mode during these tests.

Table 7: Korean Cable Test Spurious Actuations Summary

Test #	Cable ID	Length of 1st Spurious Actuation (s)	Time period between 1st Spurious Actuation to Fuse Clear (s)
13	1	24	151
14	1	1	52
15	1	9	29
16	5	12	12
20	13	37	75

21	13	10	54
22	3	56	107
23	3	39	39

All test data and photographs taken during the Korean Cable Test program are provided on the DVD accompanying this report.

7. References

1. FUNDS-IN AGREEMENT NO. FI 067100625, Korean Cable Fire Tests, KEPRI and Sandia National Laboratories, August 2010.

2. U.S. Nuclear Regulatory Commission, "Cable Response to Live Fire (CAROLFIRE)," NUREG/CR-6931, Vol. 1 and 2, April 2008.

3. U.S. Nuclear Regulatory Commission, "Risk-informed Approach for Post-Fire Safe-Shutdown Circuit Inspections," Regulatory Issue Summary (RIS) 2004-03, Rev. 1, December 2004.

Appendix: Korean Cable Test Details and Results

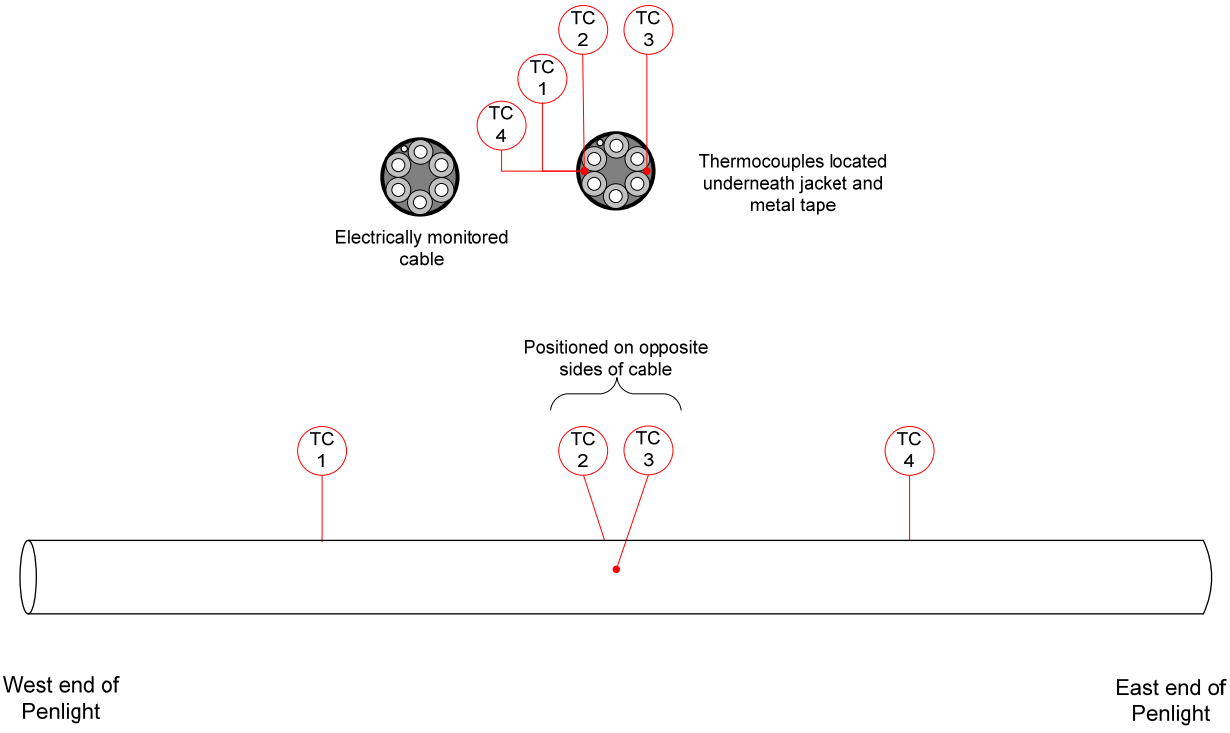
The purpose of this appendix is to provide the details for the twenty-five tests performed on the Korean supplied cables. For each test described, a nominal summary of the specific sequence of events and supporting data are provided.

Korean Cable Test #1

Test conditions:

Cable: 6-conductor, 16 AWG, EPR insulated, CSP jacketed, instrument cable (Cable ID 1).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud initially set to temperature of 250C, nominal 3.4 kW/m^2 flux from shroud, stepped-up in 25C intervals.
Electrical response monitoring: IRMS system using six channels – one for each insulated conductor, cable tray was grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see thermocouple map).

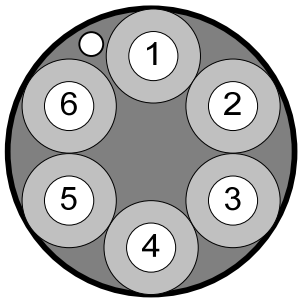
Two cables were included in Test #1, one electrically monitored, one thermally monitored. The cable had a blue jacket and white conductor insulation with printed numbers. A metal tape surrounded the conductor bundle and was grounded during the test.



Map for placement of thermocouples inserted within the thermally monitored cable during Test #1.

Thermo-couple Name	Location
TC1	Within cable just below cable jacket and metal tape, to the West of the center position
TC2	Within cable just below cable jacket and metal tape, at center position
TC3	Within cable just below cable jacket and metal tape, opposite side from Cable 2, center position
TC4	Within cable just below cable jacket and metal tape, to the East of the center position

Six of the seven available IRMS channels were connected to the electrically monitored test cable.



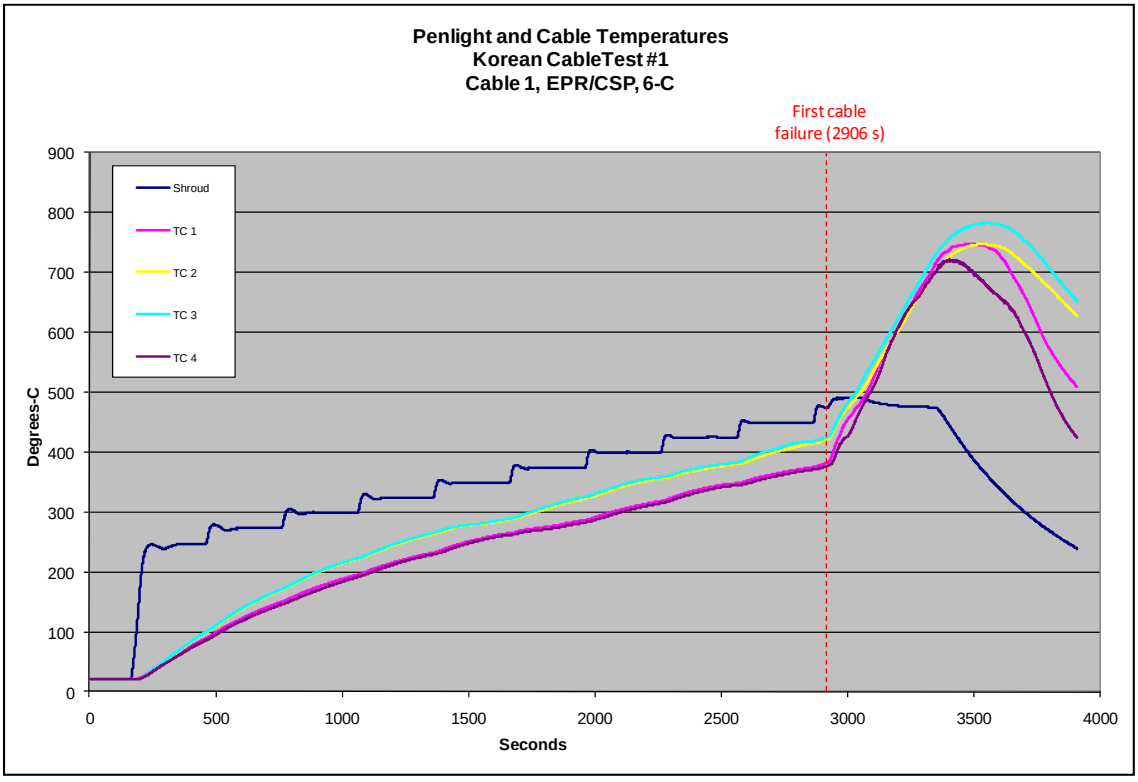
IRMS channel assignments for electrically monitored cable

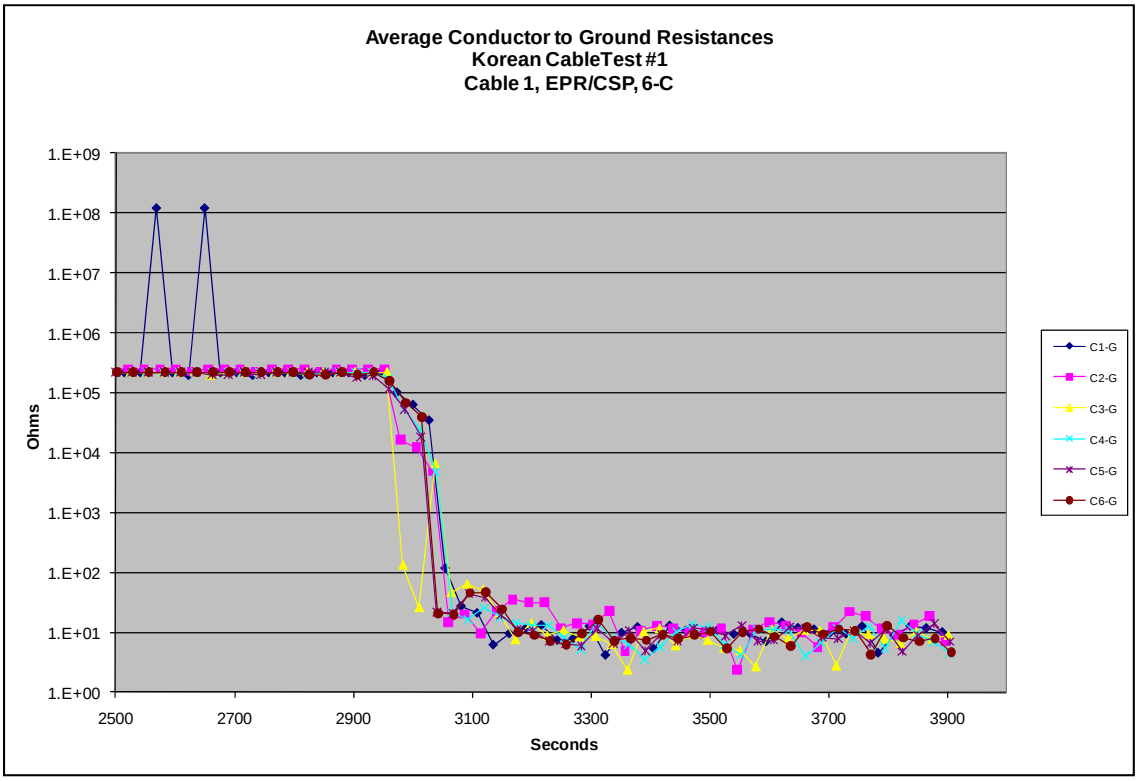
IRMS Channel	Test Cable
1	Black
2	White
3	Red
4	Green
5	Orange
6	Blue
	Drain wire grounded

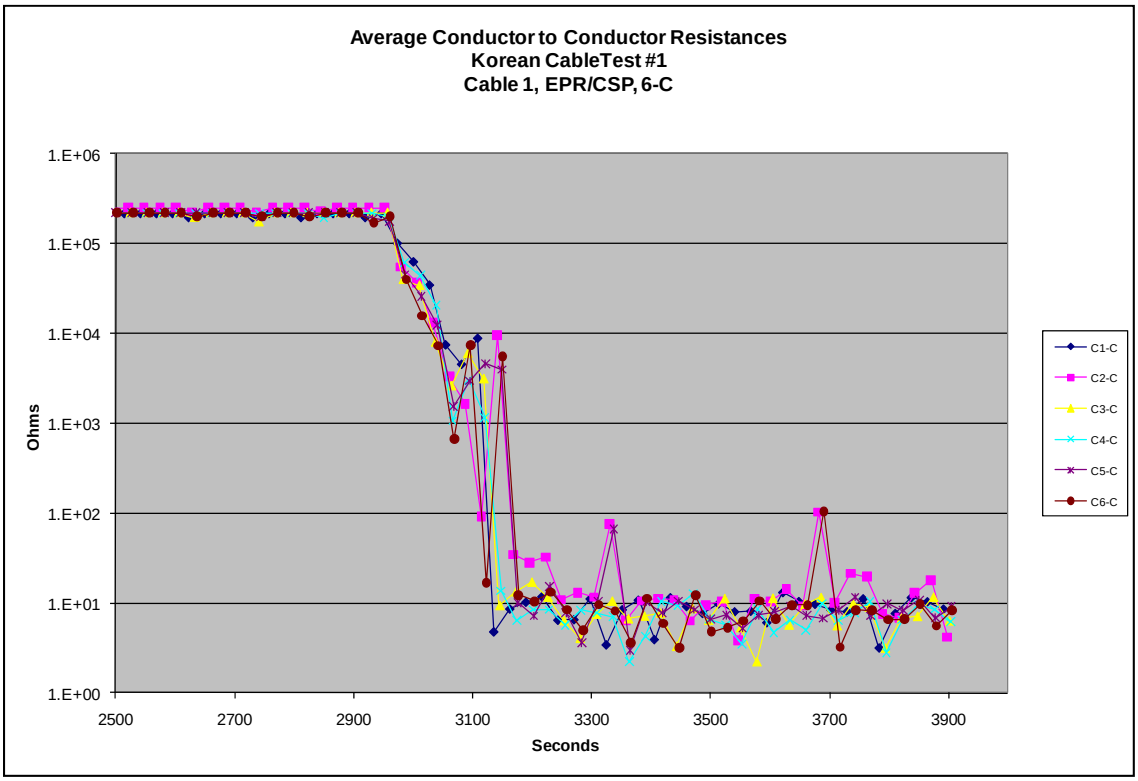
Penlight was initially set to 250C, and increased by 25C every 5 minutes until electrical failure of the cable occurred.

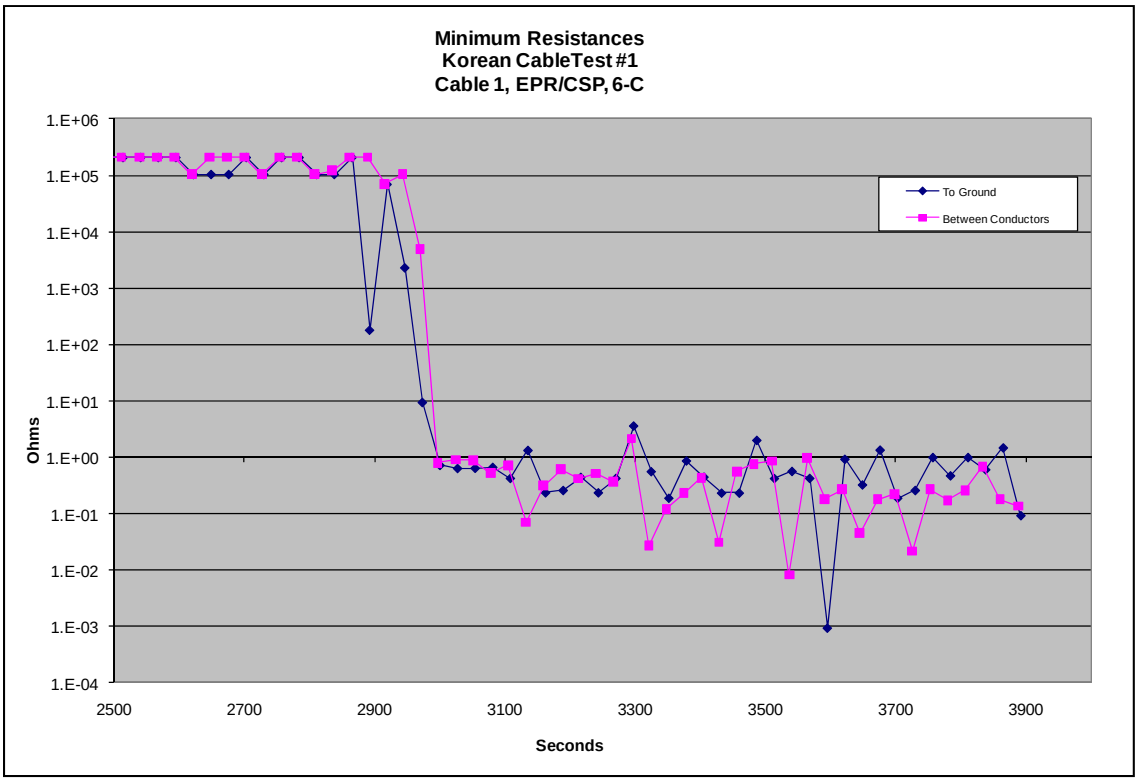
Summary of Observed Faulting Behavior for Korean Cable Test #1		
Time (s)	**Event**	**Comments**
161	Penlight On; set at 250C (3.4 kW/m2)	
2906	Conductor 5 shorts to ground at less than 1000 ohms	Initial failure is by conductor to ground shorting; average cable temperature 421C at

		center
2979-2985	Conductors 2, 3 & 4 short to ground at less than 100 ohms	
3006-3012	Conductor 2 shorts to conductors 3, 5 & 6 at less than 100 ohms	Shorting path may be through ground (tray)
3041-3042	Conductors 5 & 6 short to ground at less than 100 ohms	
3041-3050	Conductor 3 shorts to conductors 4 & 5 at less than 1000 ohms	
3055	Conductor 1 shorts to ground at less than 100 ohms	All conductors are shorted to ground
3059	Conductor 6 shorts to conductors 1, 3 & 4 at less than 100 ohms; conductor 4 shorts to conductors 2 & 5	
3080	Conductor 1 shorts to conductors 3 & 4 at less than 100 ohms	
3105	Conductor 1 shorts to conductor 2 at less than 1000 ohms	
3138	Conductor 1 shorts to conductors 2 & 5 at less than 100 ohms	




Average Conductor to Ground Resistances
Korean CableTest #1
Cable 1, EPR/CSP, 6-C
1.E+09
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
Ohms
2500
2700
2900
3100
3300
3500
3700
3900
Seconds
C1-G
C2-G
C3-G
C4-G
C5-G
C6-G


Average Conductor to Conductor Resistances
Korean CableTest #1
Cable 1, EPR/CSP, 6-C
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
Ohms
2500
2700
2900
3100
3300
3500
3700
3900
Seconds
C1-C
C2-C
C3-C
C4-C
C5-C
C6-C

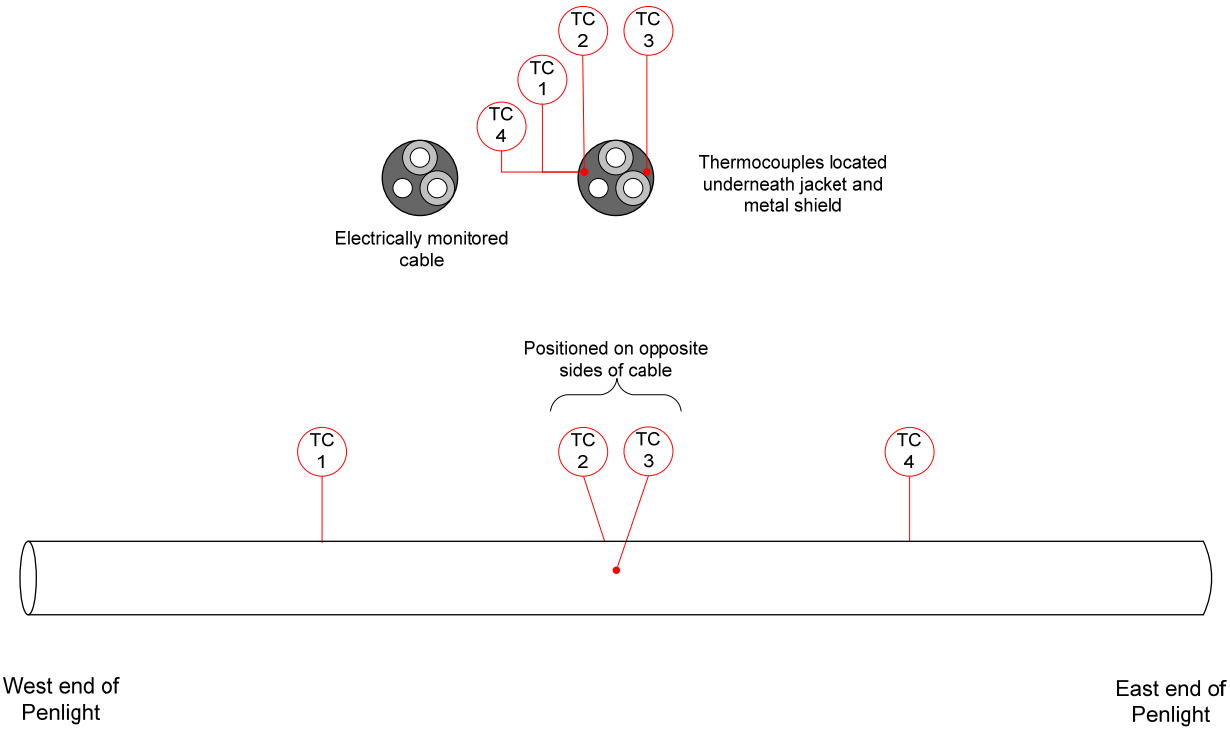


Korean Cable Test #2

Test conditions:

Cable: 2-conductor with bare drain wire, 16 AWG, EPR insulated, CSP jacketed, instrument cable (Cable ID 3).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud initially set to temperature of 250C, nominal 3.4 kW/m^2 flux from shroud, stepped-up in 25C intervals.
Electrical response monitoring: IRMS system using two channels - one for each insulated conductor, cable tray and drain wire were grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see thermocouple map).

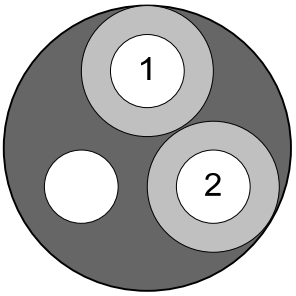
Two cables were included in Test #2, one electrically monitored, one thermally monitored. The test cables had a red jacket and black and white conductor insulation. The drain wire was not insulated and was grounded.



Map for placement of thermocouples inserted within the thermally monitored cable during Test #2.

Thermo-couple Name	Location
TC1	Within cable just below cable jacket and shield, to the West of the center position
TC2	Within cable just below cable jacket and shield, at center position
TC3	Within cable just below cable jacket and shield, opposite side from Cable 2, center position
TC4	Within cable just below cable jacket and shield, to the East of the center position

Two of the available IRMS channels were connected to the electrically monitored test cable.



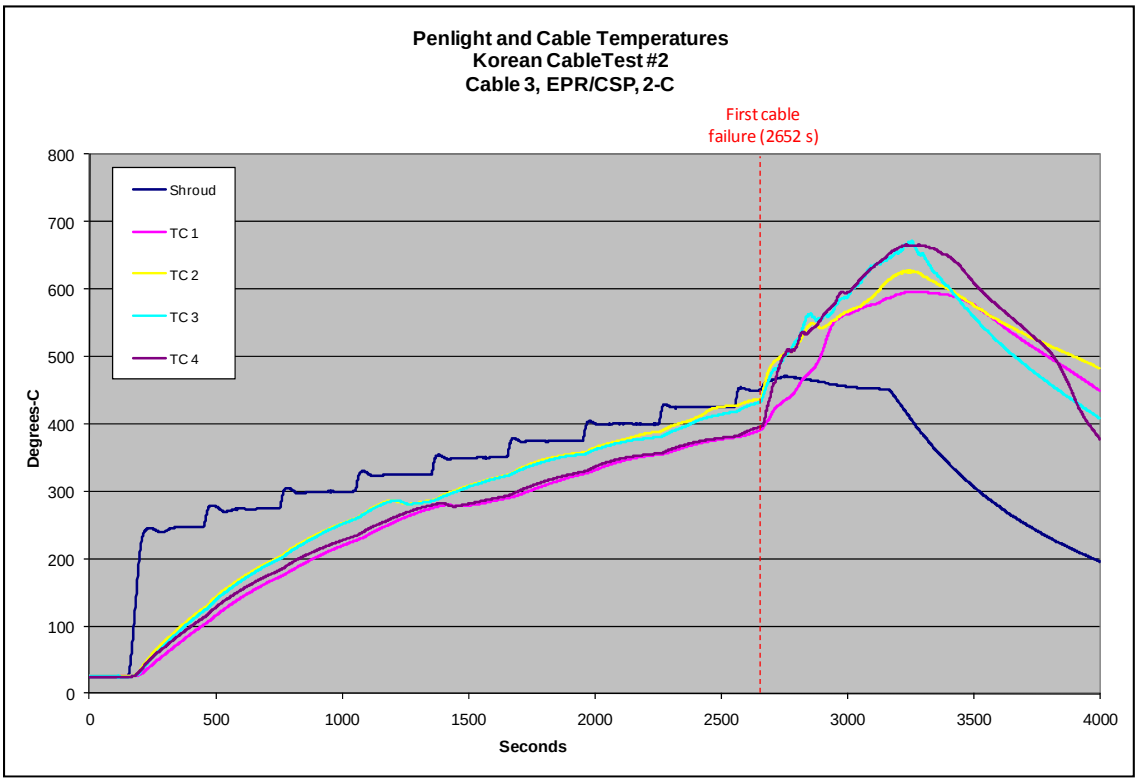
Drain wire connected to ground

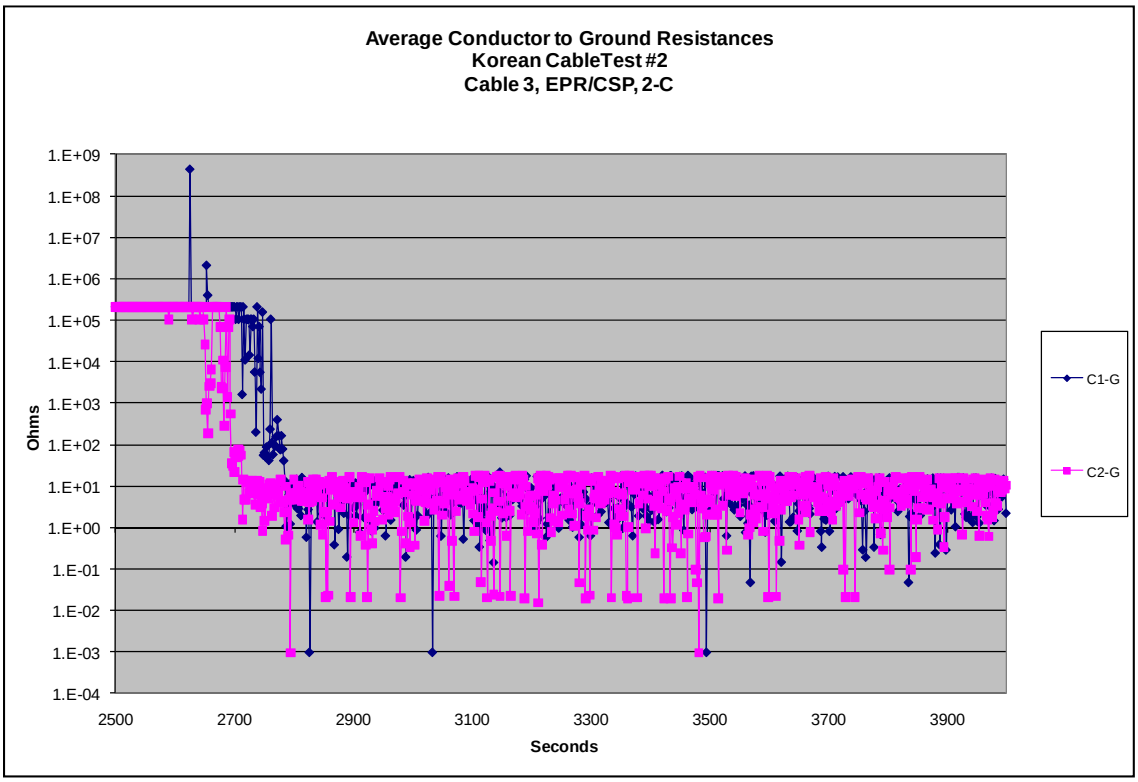
IRMS channel assignments for electrically monitored cable

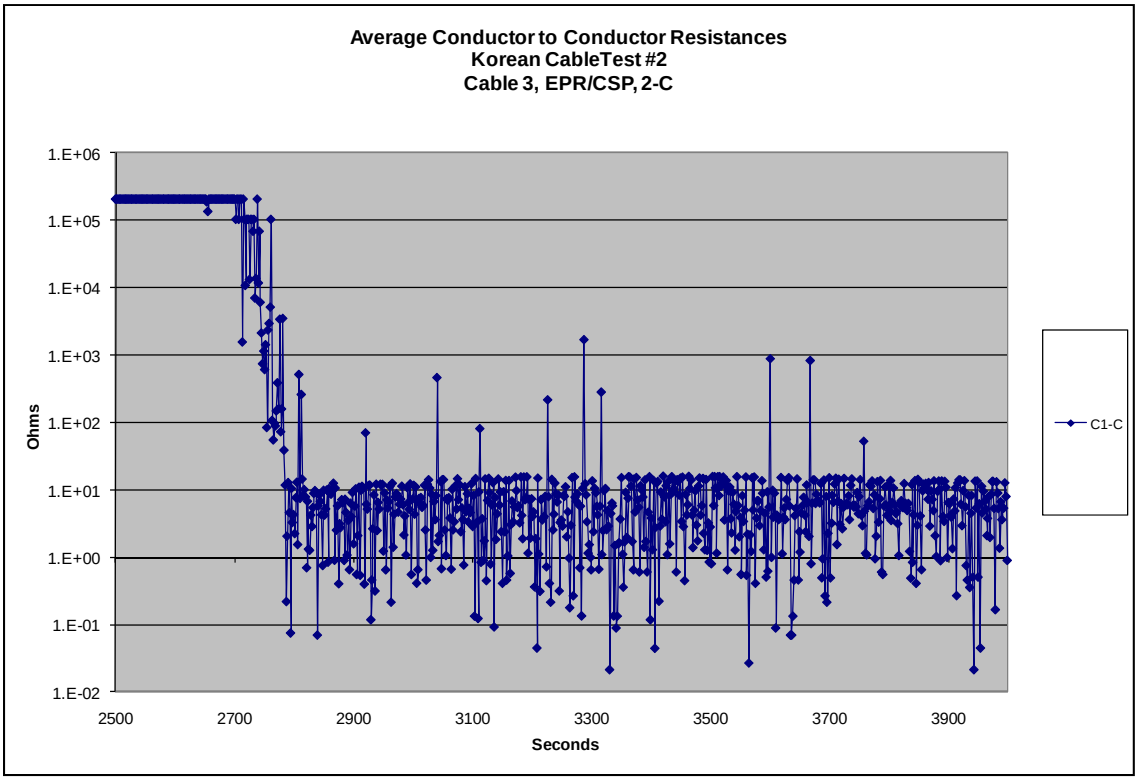
IRMS Channel	Test Cable
1	Black
2	White

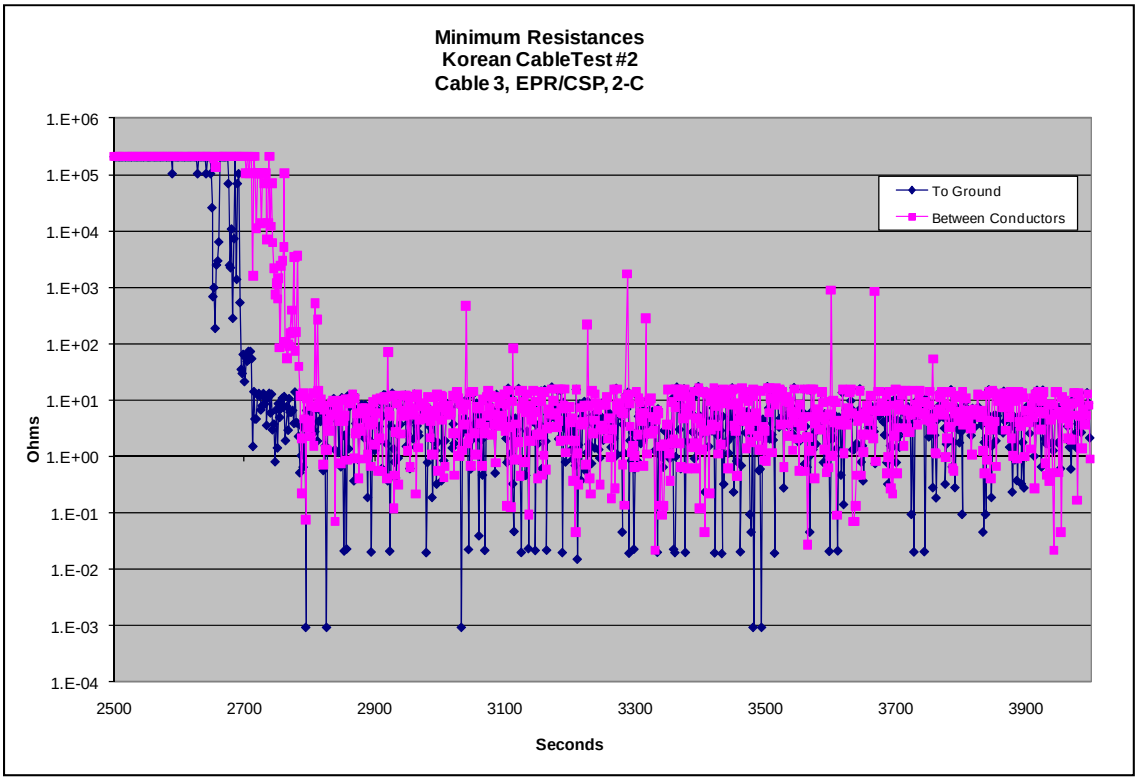
Penlight was initially set to 250C and increased by 25C every 5 minutes until electrical failure of the cable occurred.

Summary of Observed Faulting Behavior for Korean Cable Test #2		
Time (s)	**Event**	**Comments**
151	Penlight On; set at 250C (3.4 kW/m2)	
2652	Conductor 2 shorts to ground at less than 1000 ohms	Initial failure is by conductor to ground shorting; average cable temperature 435C at center
2654-2694	Intermittent conductor 2 shorting to ground	
2696	Conductor 2 shorts to ground at less than 100 ohms	
2737	Conductor 1 shorts to ground at less than 1000 ohms	
2748	Conductor 1 shorts to conductor 2 at less than 1000 ohms	
2750	Conductor 1 shorts to ground at less than 100 ohms	All conductors are shorted to ground
2755	Conductor 1 shorts to conductor 2 at less than 100 ohms	Shorting path may be through ground (tray)




Average Conductor to Ground Resistances
Korean CableTest #2
Cable 3, EPR/CSP, 2-C
Ohms
1.E+09
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
2500
2700
2900
3100
3300
3500
3700
3900
Seconds
C1-G
C2-G


Average Conductor to Conductor Resistances
Korean CableTest #2
Cable 3, EPR/CSP, 2-C
Ohms
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
2500
2700
2900
3100
3300
3500
3700
3900
Seconds
C1-C

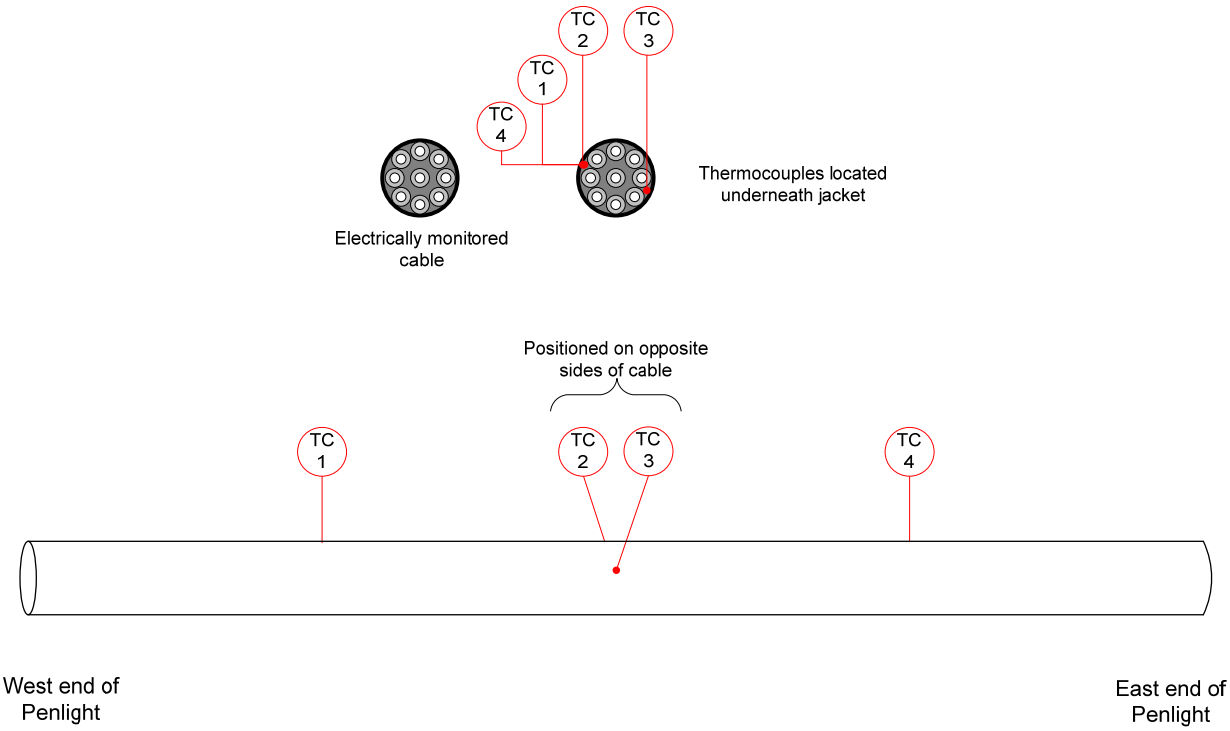


Korean Cable Test #3

Test conditions:

Cable: 9-conductor, 14 AWG, EPR insulated, CSP jacketed, control cable (Cable ID 5).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud initially set to temperature of 250C, nominal 3.4 kW/m^2 flux from shroud, stepped-up in 25C intervals.
Electrical response monitoring: IRMS system using five channels - one for center conductor, two outer conductors connected to each IRMS channel 2-5. Cable tray was grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see thermocouple map).

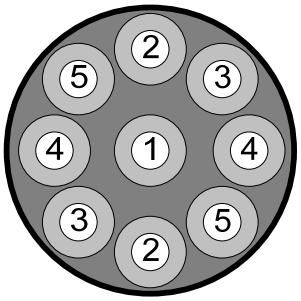
Two cables were included in Test #3, one electrically monitored, one thermally monitored. The test cables had a green jacket and white conductor insulation with printed numbers. Two conductors were connected to each of IRMS channels 2, 3, 4 & 5.



Map for placement of thermocouples inserted within the thermally monitored cable during Test #3.

Thermo-couple Name	Location
TC1	Within cable just below cable jacket, to the East of the center position
TC2	Within cable just below cable jacket, at center position
TC3	Within cable just below cable jacket, opposite side from Cable 2, center position
TC4	Within cable just below cable jacket, to the West of the center position

Five of the IRMS channels were connected to the electrically monitored test cable.



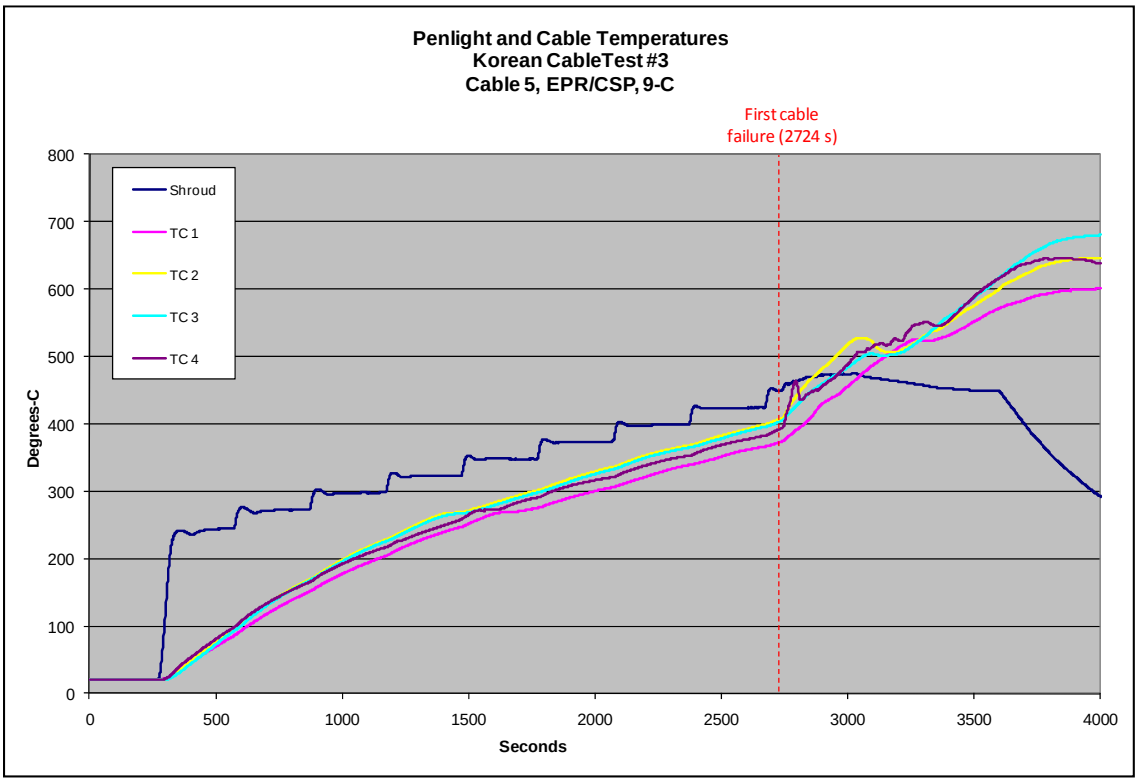
IRMS channel assignments for electrically monitored cable

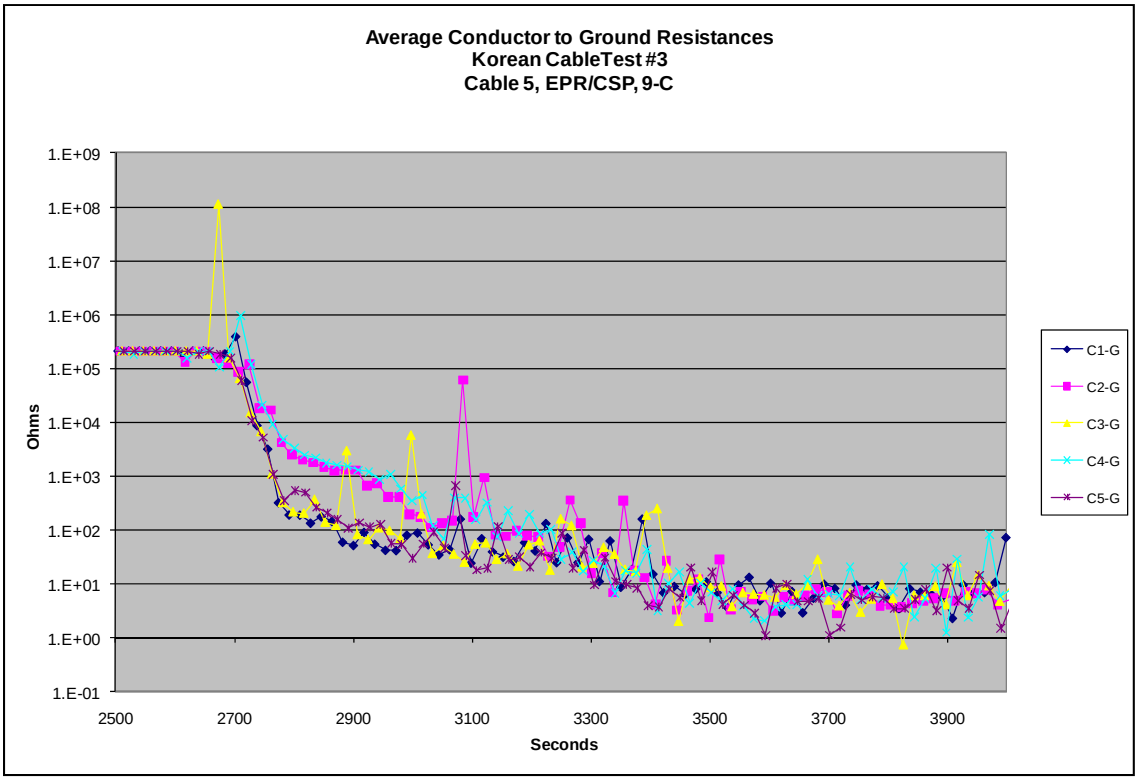
IRMS Channel	Test Cable
1	Black
2	White & Blue

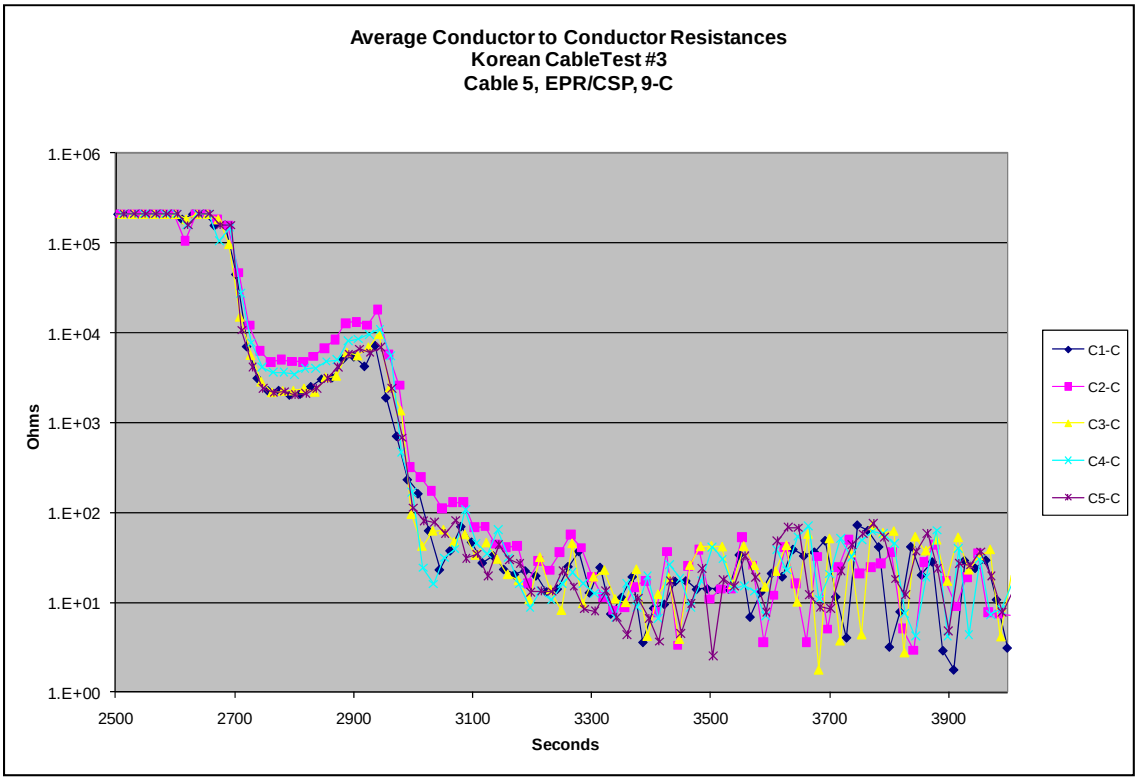
3	Red & White-Black
4	Green & Red-Black
5	Orange & Green-Black

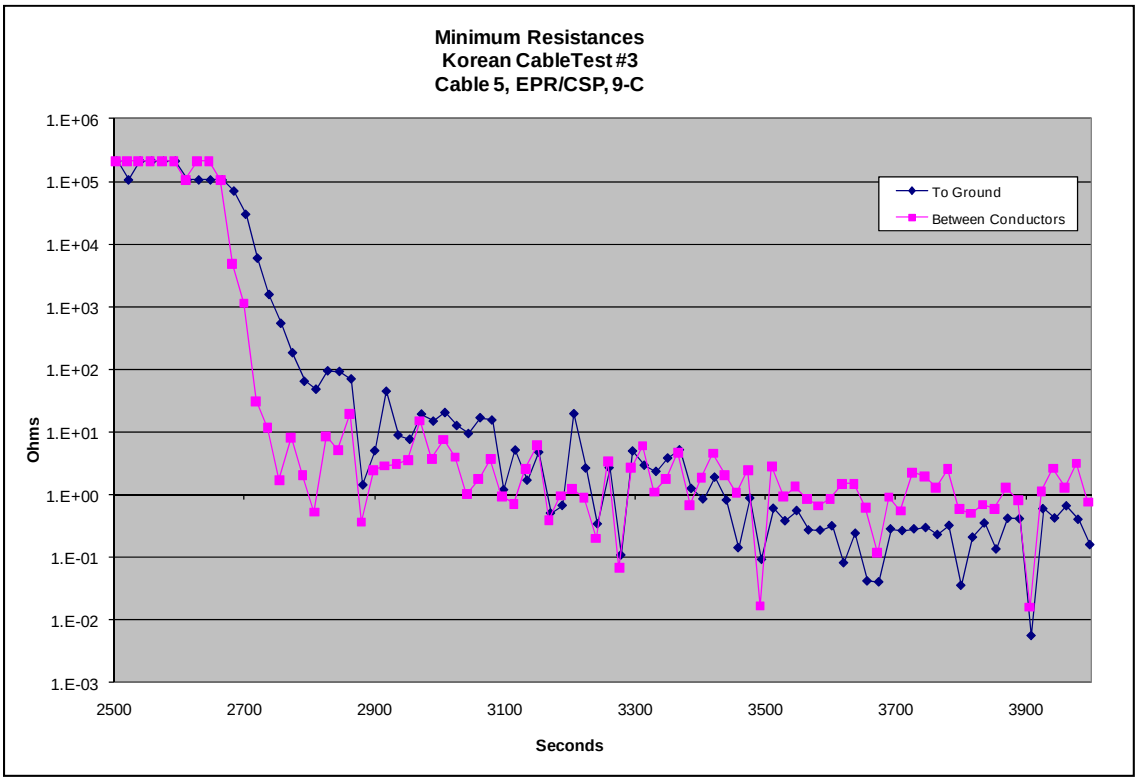
Penlight was initially set to 250C and increased by 25C every 5 minutes until electrical failure of the cable occurred.

Summary of Observed Faulting Behavior for Korean Cable Test #3		
Time (s)	**Event**	**Comments**
272	Penlight On; set at 250C (3.4 kW/m2)	
2724-2733	Conductor 5 shorts to conductors 1 & 3 at less than 1000 ohms and <100 ohm, respectively	Initial failure is by conductor to conductor shorting; average cable temperature 404C at center
2738	Conductor 1 shorts to conductor 3 at less than 100 ohms	
2761	Conductors 2, 3 & 5 short to ground at less than 1000 ohms	
2775	Conductor 1 shorts to ground at less than 1000 ohms	
2864	Conductors 1, 2, 3 & 5 short to ground at less than 100 ohms	
2944	Conductor 4 shorts to ground at less than 1000 ohms	All conductors are shorted to ground
2969	Conductor 4 shorts to conductor 5 at less than 1000 ohms	Shorting path may be through ground
2974	Conductor 4 shorts to conductors 1 & 3 at less than 100 ohms and <1000 ohms, respectively	
2988	Conductor 2 shorts to conductors 1, 3 & 5	


Penlight and Cable Temperatures
Korean CableTest #3
Cable 5, EPR/CSP, 9-C
First cable
failure (2724 s)
Shroud
TC 1
TC 2
TC 3
TC 4
Degrees-C
Seconds
0
100
200
300
400
500
600
700
800
0
500
1000
1500
2000
2500
3000
3500
4000


Average Conductor to Ground Resistances
Korean CableTest #3
Cable 5, EPR/CSP, 9-C
Ohms
Seconds
C1-G
C2-G
C3-G
C4-G
C5-G
1.E+09
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
2500
2700
2900
3100
3300
3500
3700
3900


Average Conductor to Conductor Resistances
Korean CableTest #3
Cable 5, EPR/CSP, 9-C
Ohms
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
2500
2700
2900
3100
3300
3500
3700
3900
Seconds
C1-C
C2-C
C3-C
C4-C
C5-C

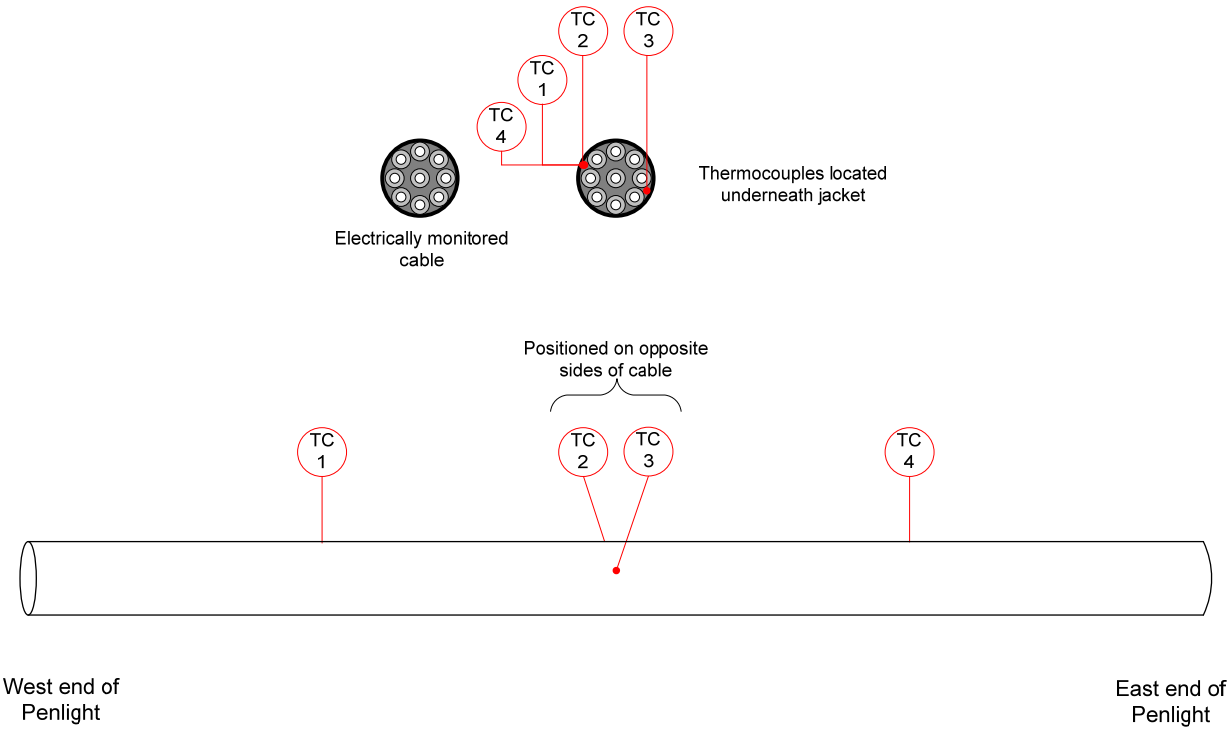

Minimum Resistances
Korean CableTest #3
Cable 5, EPR/CSP, 9-C
Ohms
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
1.E-03
2500
2700
2900
3100
3300
3500
3700
3900
Seconds
To Ground
Between Conductors

Korean Cable Test #4

Test conditions:

Cable: 9-conductor, 14 AWG, EPR insulated, CR jacketed, control cable (Cable ID 8).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud initially set to temperature of 250C, nominal 3.4 kW/m2 flux from shroud, stepped-up in 25C intervals
Electrical response monitoring: IRMS system using seven channels - one for each insulated conductor monitored by IRMS channels 1, 3, 4, 5 & 6; IRMS channels 2 & 7 monitored 2 conductors each. The cable tray was grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see thermocouple map).

Two cables were included in Test #4, one electrically monitored with the IRMS, one thermally monitored. The cable had a black CR jacket and a black insulated center conductor and eight white insulated other conductors with printed numbers.

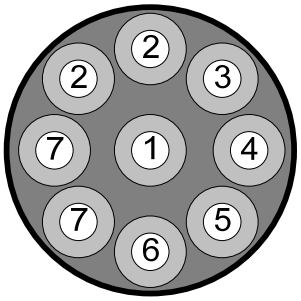


Map for placement of thermocouples inserted within the thermally monitored cable during Test #4.

Thermo-couple	Location

Name	
TC1	Within cable just below cable jacket, to the West of the center position
TC2	Within cable just below cable jacket, at center position
TC3	Within cable just below cable jacket, opposite side from Cable 2, center position
TC4	Within cable just below cable jacket, to the East of the center position

All seven of the available IRMS channels were connected to the electrically monitored test cable.



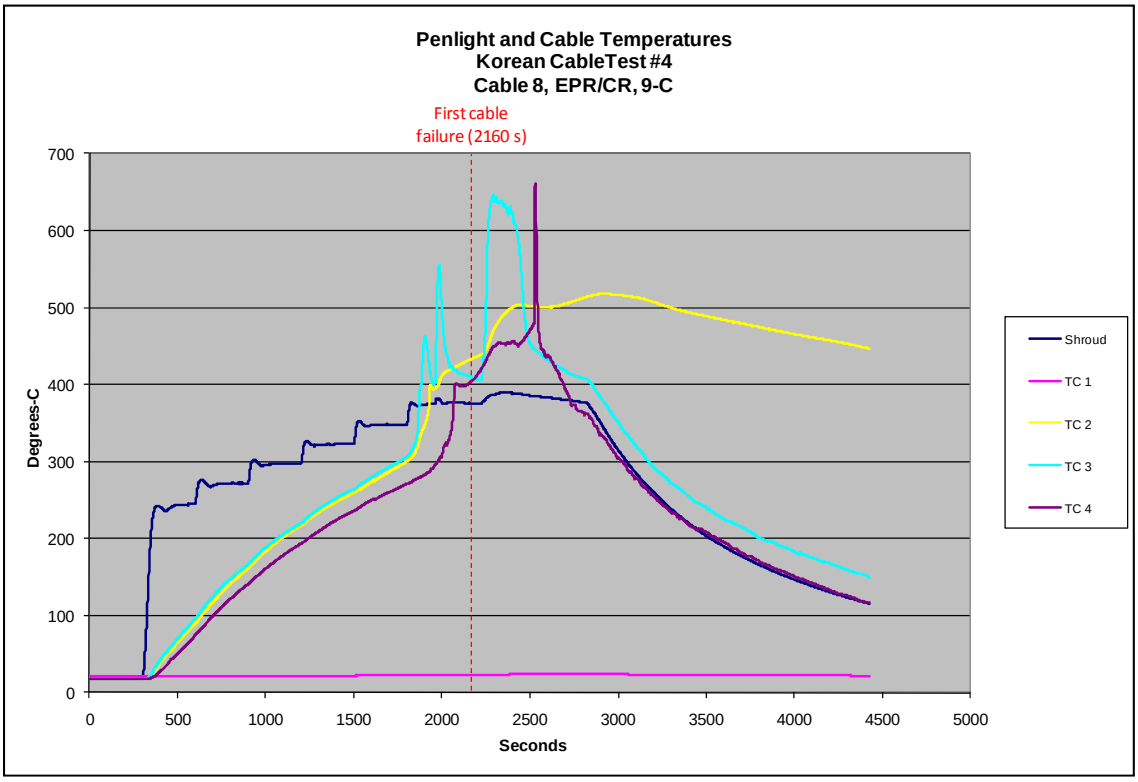
IRMS channel assignments for electrically monitored cable

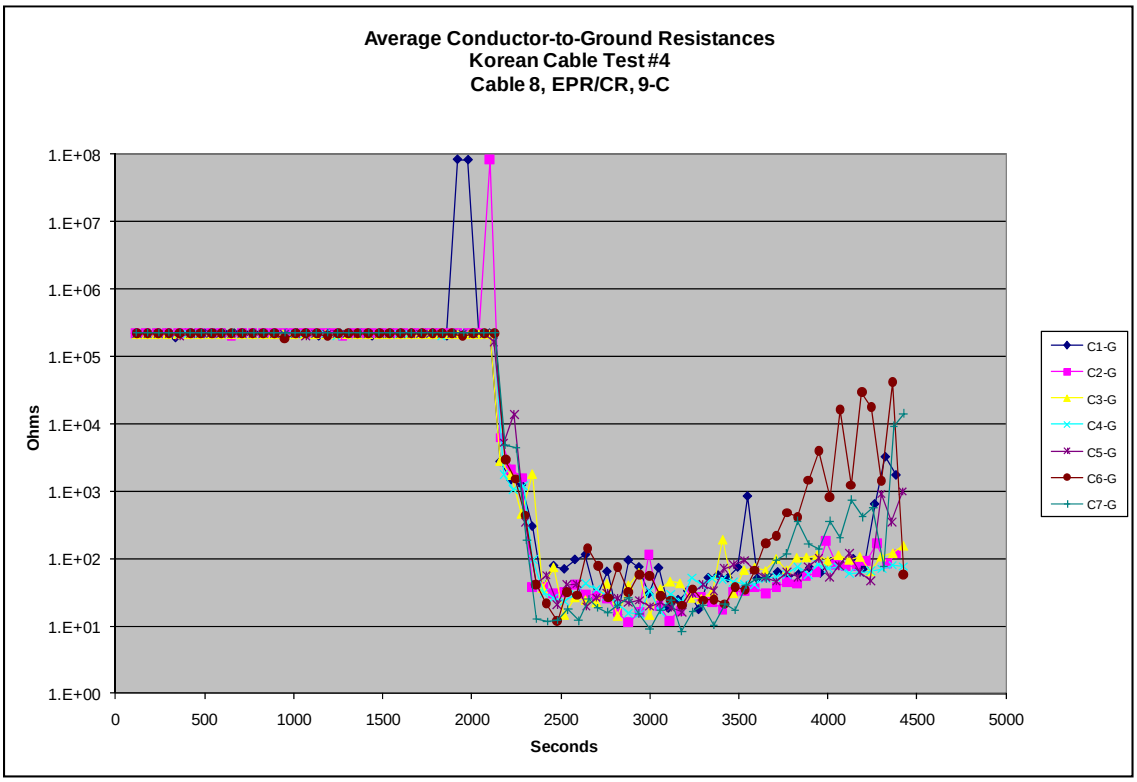
IRMS Channel	Test Cable
1	Black
2	White & Green-Black
3	Red
4	Green
5	Orange
6	Blue
7	White-Black & Red-Black

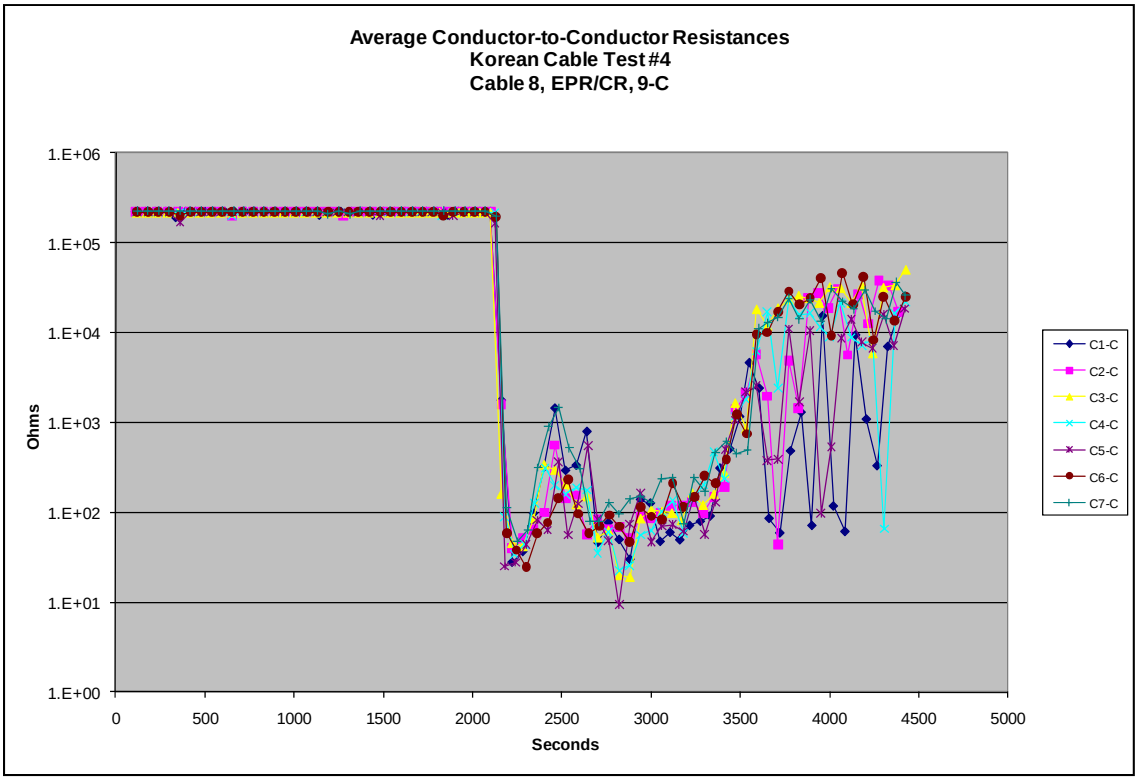
Penlight was initially set to 250C and increased by 25C every 5 minutes until electrical failure of the cable occurred.

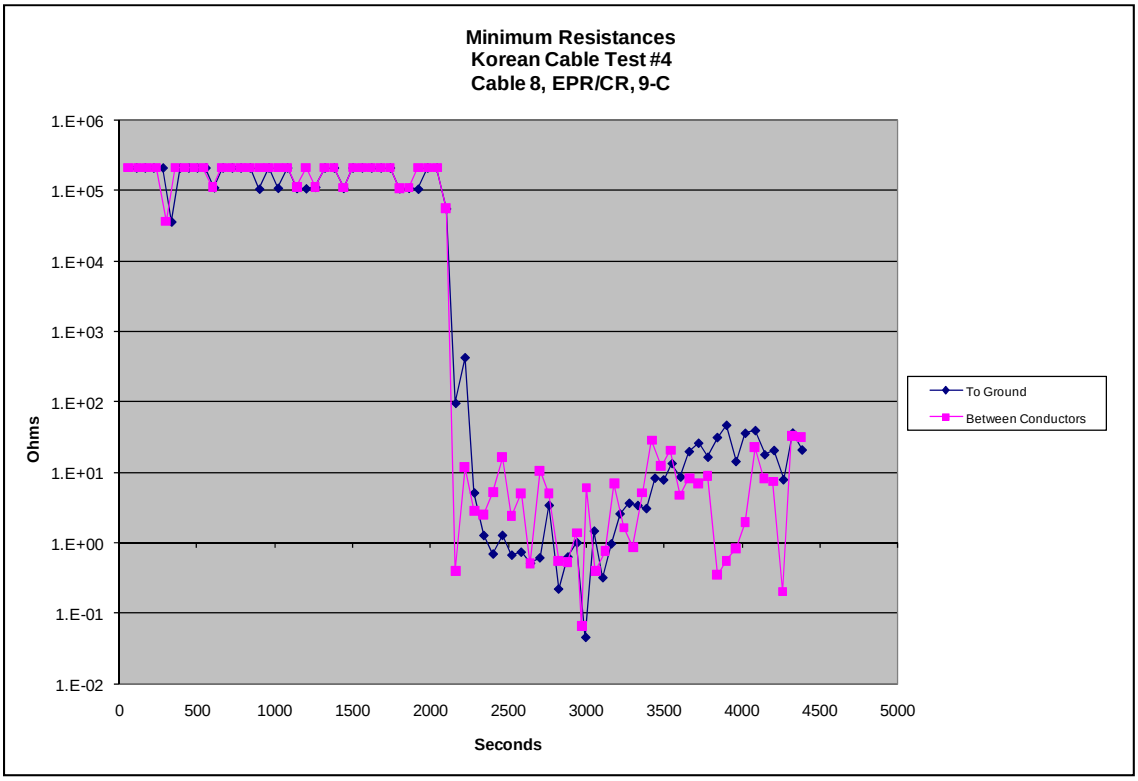
Summary of Observed Faulting Behavior for Korean Cable Test #4		
Time (s)	**Event**	**Comments**
301	Penlight On; set at 250C (3.4 kW/m2)	
2160	Almost all conductors short together except conductors 1 & 2	Initial failures are by conductor-to-conductor shorting; cable temperature 411C (TC3).
2160	Conductors 1, 4 & 5 short to ground	
2220	Conductors 1 & 2 short together	

2220	Conductors 2, 3, 6 & 7 short to ground	All conductors are shorted to ground
Additional Observations		
Observation 1	The progression of failure modes for this cable followed that expected for a typical thermoset-insulated cable: conductor-to-conductor shorts followed by shorting to ground.	
Observation 2	Cable thermocouple TC-1 did not perform as expected.	




Average Conductor-to-Ground Resistances
Korean Cable Test #4
Cable 8, EPR/CR, 9-C
Ohms
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Seconds
C1-G
C2-G
C3-G
C4-G
C5-G
C6-G
C7-G


Average Conductor-to-Conductor Resistances
Korean Cable Test #4
Cable 8, EPR/CR, 9-C
Ohms
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Seconds
C1-C
C2-C
C3-C
C4-C
C5-C
C6-C
C7-C

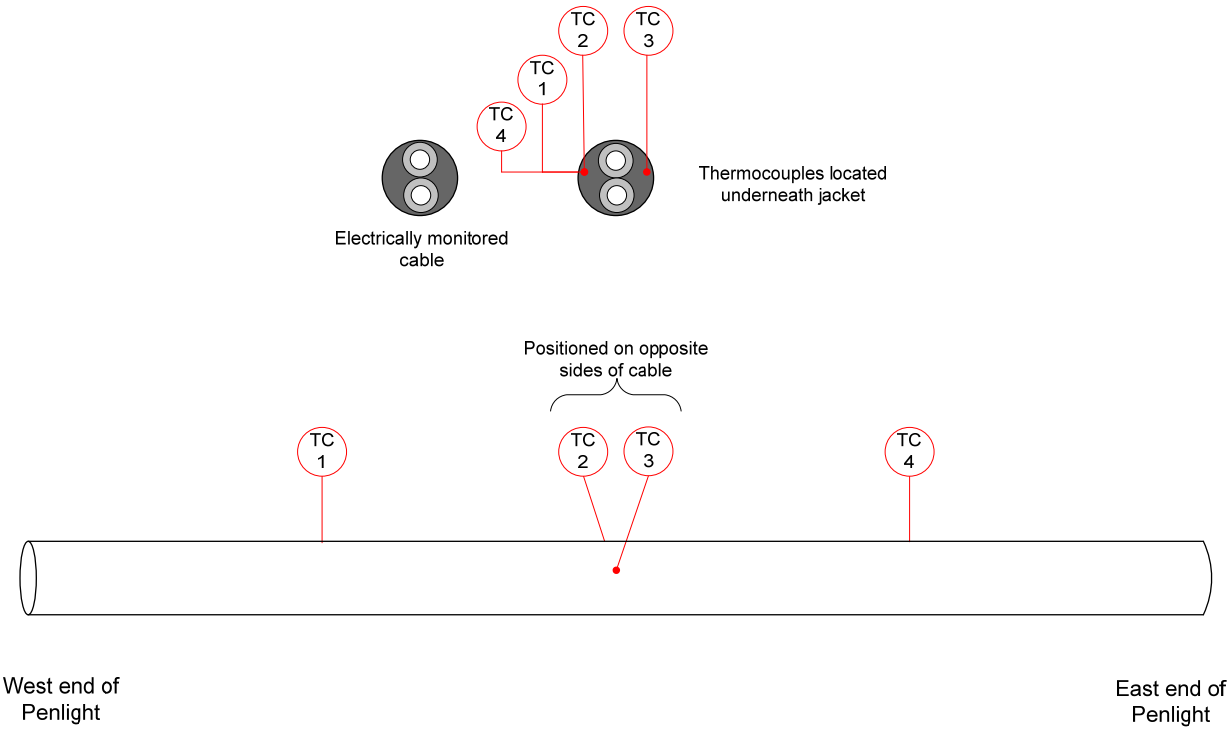


Korean Cable Test #5

Test conditions:

Cable: 2-conductor without drain wire or shield, 16 AWG, EPR insulated, CSP jacketed, power cable (Cable ID 10).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud initially set to temperature of 250C, nominal 3.4 kW/m^2 flux from shroud, stepped-up in 25C intervals.
Electrical response monitoring: IRMS system using two channels - one for each insulated conductor, cable tray was grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see thermocouple map).

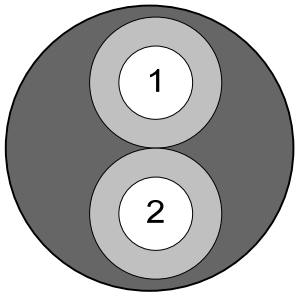
Two cables were included in Test #5, one electrically monitored, one thermally monitored. The cables had red jackets and black and white conductor insulation. This type of cable did not have a metal shield or drain wire.



Map for placement of thermocouples inserted within the thermally monitored cable during Test #5.

Thermo-couple Name	Location
TC1	Within cable just below cable jacket, to the West of the center position
TC2	Within cable just below cable jacket, at center position
TC3	Within cable just below cable jacket, opposite side from Cable 2, center position
TC4	Within cable just below cable jacket, to the East of the center position

Two IRMS channels were connected to the electrically monitored test cable.

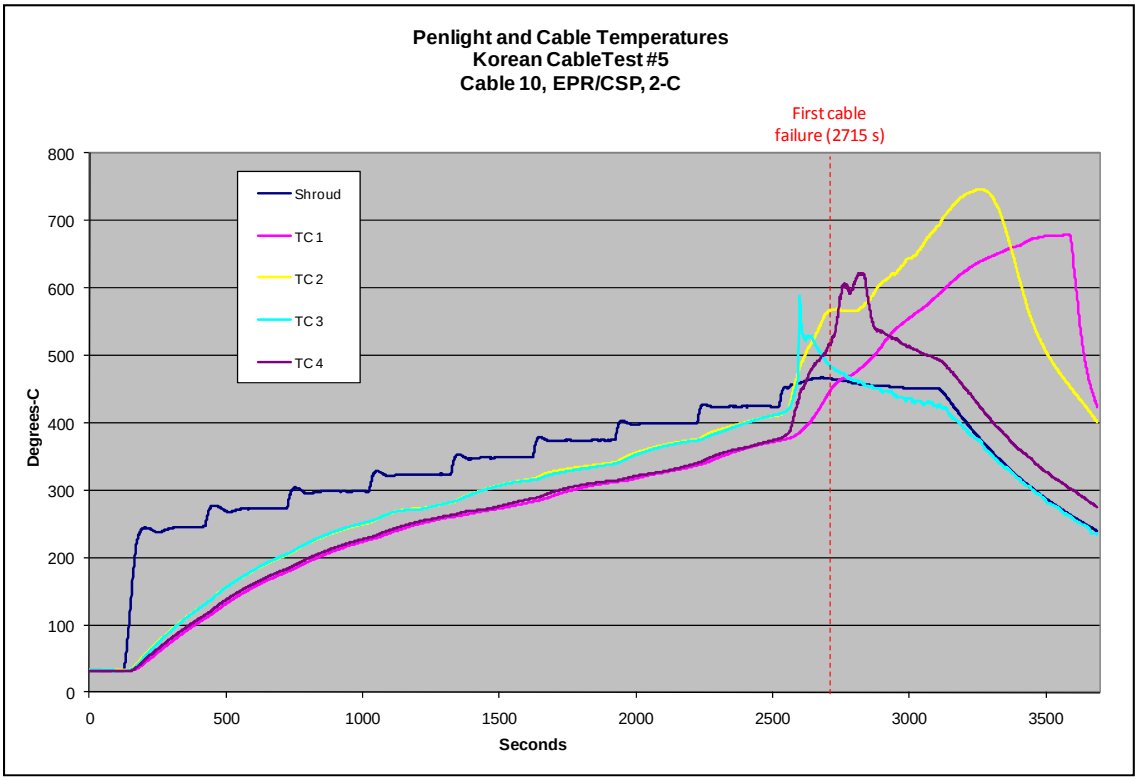


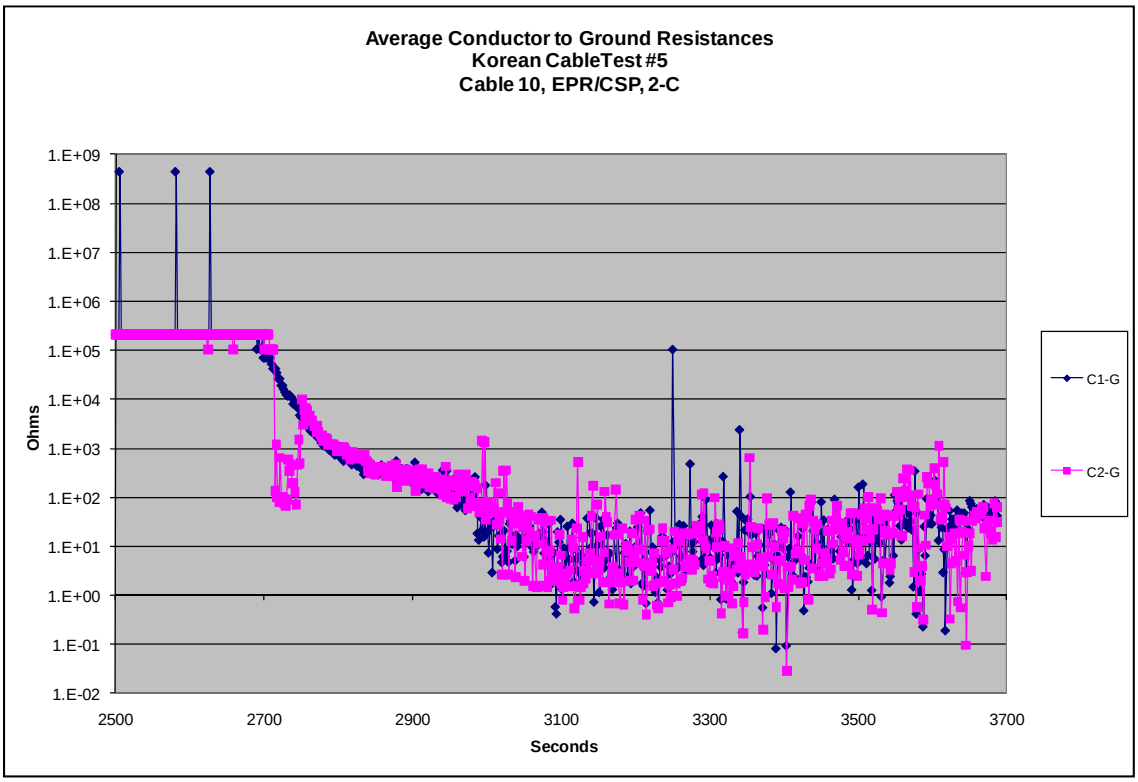
IRMS channel assignments for electrically monitored cable

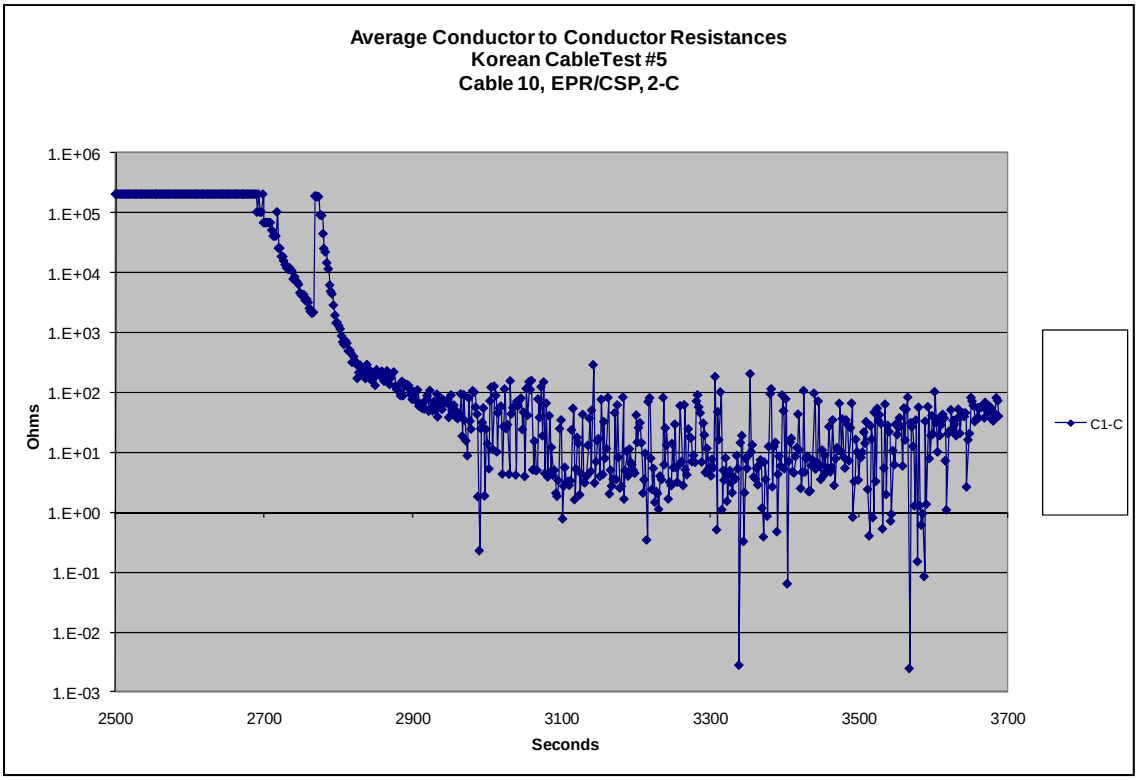
IRMS Channel	Test Cable
1	Black
2	White

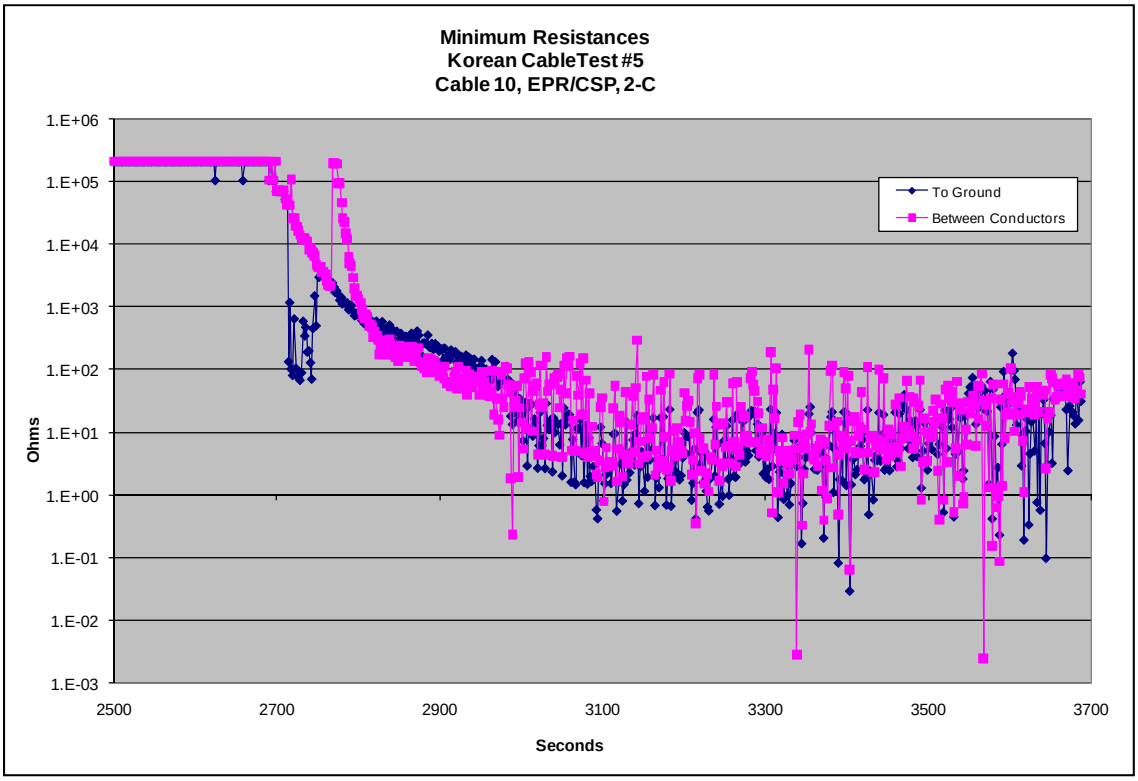
Penlight was initially set to 250C and increased by 25C every 5 minutes until electrical failure of the cable occurred.

Summary of Observed Faulting Behavior for Korean Cable Test #5		
Time (s)	**Event**	**Comments**
122	Penlight On; set at 250C (3.4 kW/m2)	
2715	Conductor 2 shorts to ground at less than 1000 ohms	Initial failure is by conductor to ground shorting; average cable temperature 525C at center
2751	Conductor 2 shorting to ground but at >1000 ohms	
2789	Conductor 1shorts to ground at less than 1000 ohms	
2797	Conductor 2 shorts to ground at less than 1000 ohms	
2805	Conductor 1 shorts to conductor 2 at less than 1000 ohms	Shorting path may be through ground (tray)
2884	Conductor 1 shorts to conductor 2 at less than 100 ohms	
2947	Conductor 2 shorts to ground at less than 100 ohms	
2959	Conductor 1 shorts to ground at less than 100 ohms	All conductors are shorted to ground




Average Conductor to Ground Resistances
Korean CableTest #5
Cable 10, EPR/CSP, 2-C
Ohms
1.E+09
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
2500
2700
2900
3100
3300
3500
3700
Seconds
C1-G
C2-G


Average Conductor to Conductor Resistances
Korean CableTest #5
Cable 10, EPR/CSP, 2-C
Ohms
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
1.E-03
2500
2700
2900
3100
3300
3500
3700
Seconds
C1-C

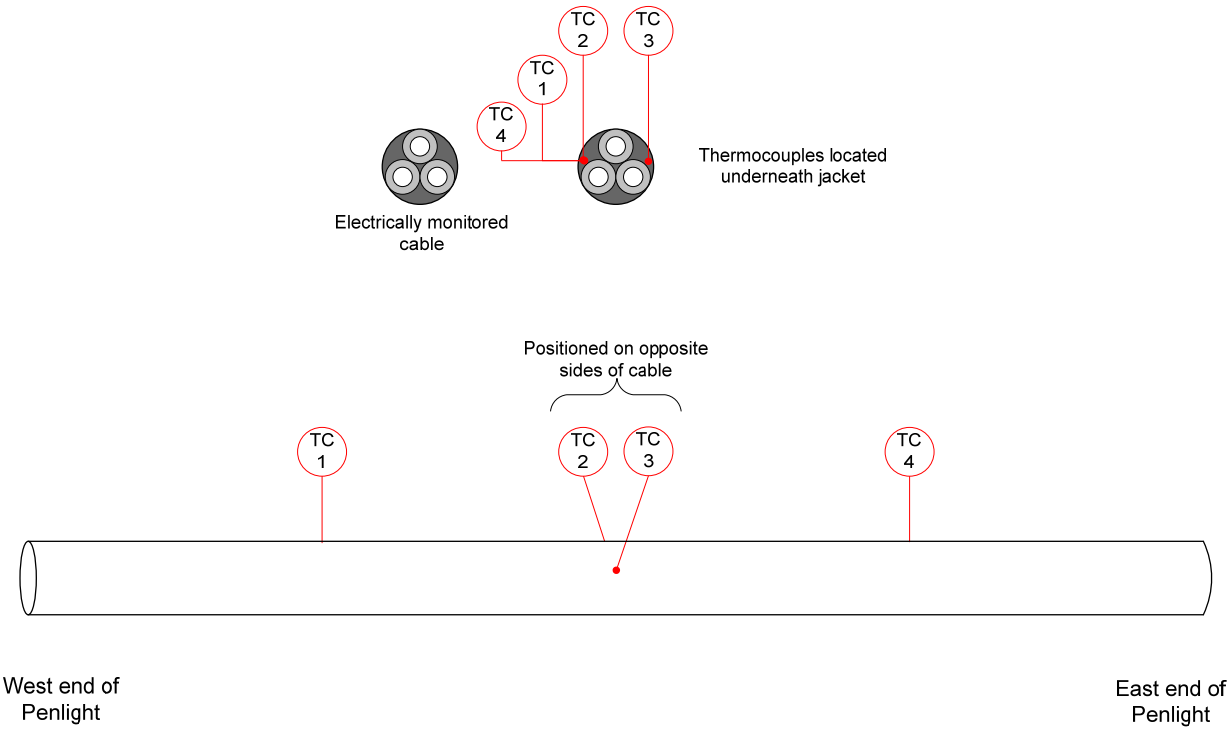


Korean Cable Test #6

Test conditions:

Cable: 3-conductor, 14 AWG, EPR insulated, CSP jacketed, power cable (Cable ID 13).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud set to temperature of 250C, nominal 3.4 kW/m^2 flux from shroud, stepped-up in 25C intervals.
Electrical response monitoring: IRMS system using three channels - one for each insulated conductor. The cable tray was grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see maps).

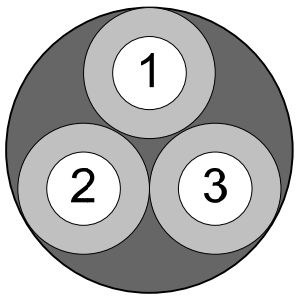
Two cables were included in Test #6, one electrically monitored, one thermally monitored. The test cables had a black jacket and black, white, and red conductor insulation.



Map for placement of thermocouples inserted within the thermally monitored cable during Test #6.

Thermo-couple Name	Location
TC1	Within cable just below cable jacket, to the West of the center position
TC2	Within cable just below cable jacket, at center position
TC3	Within cable just below cable jacket, opposite side from Cable 2, center position
TC4	Within cable just below cable jacket, to the East of the center position

Three of the IRMS channels were connected to the electrically monitored test cable.

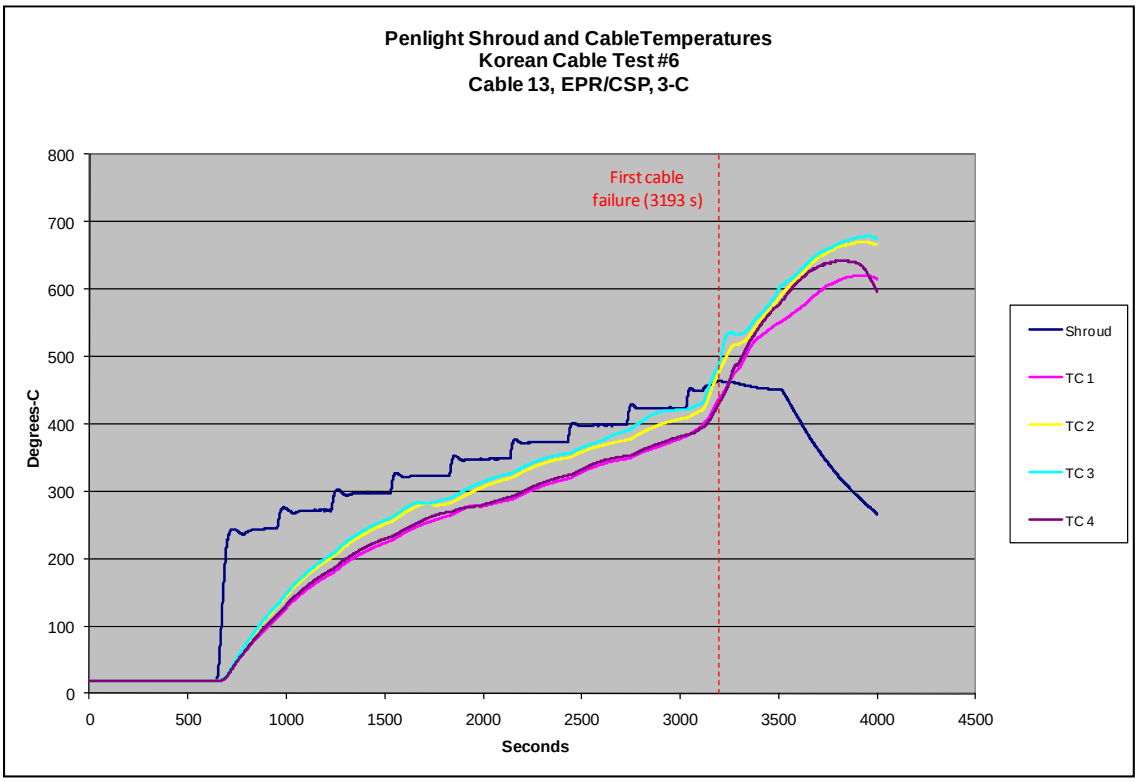


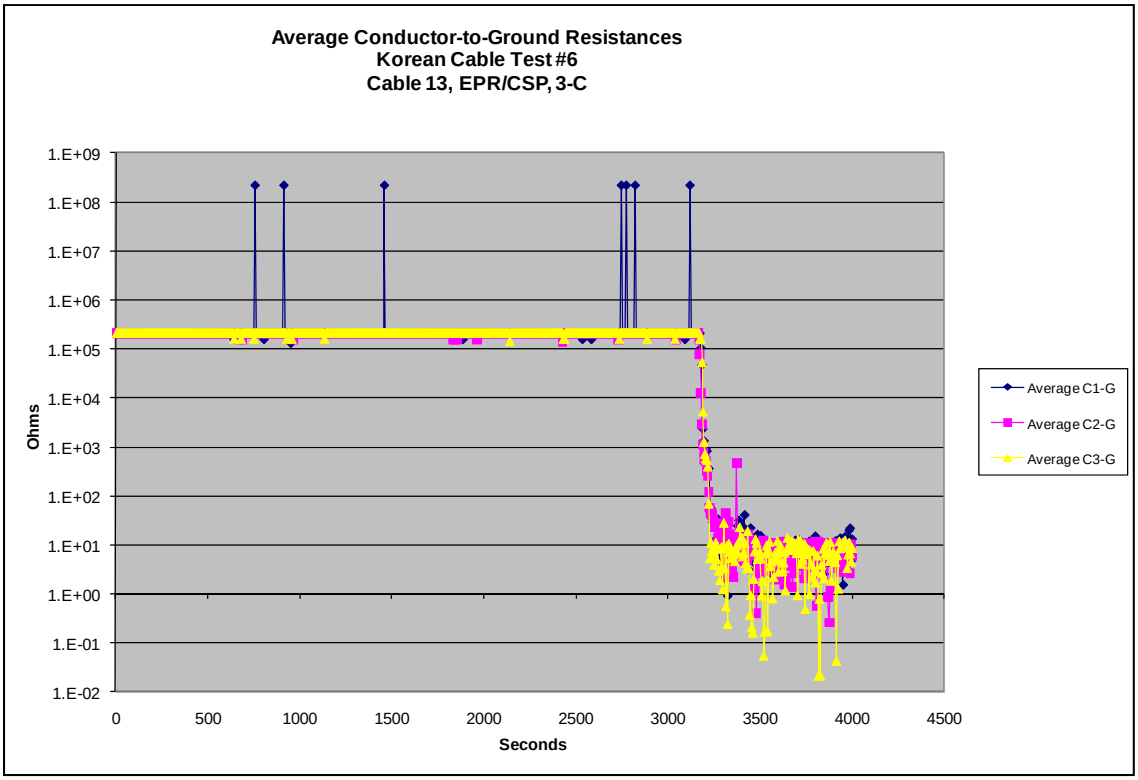
IRMS channel assignments for electrically monitored cable

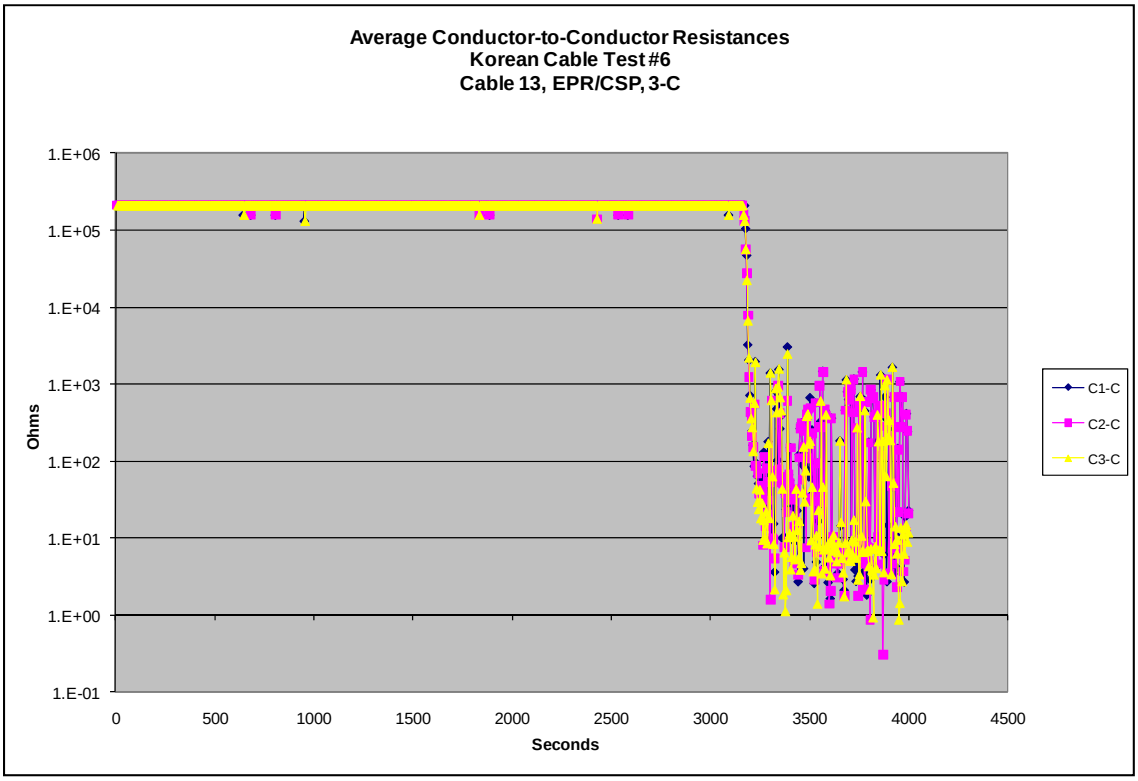
IRMS Channel	Test Cable
1	Black
2	White
3	Red

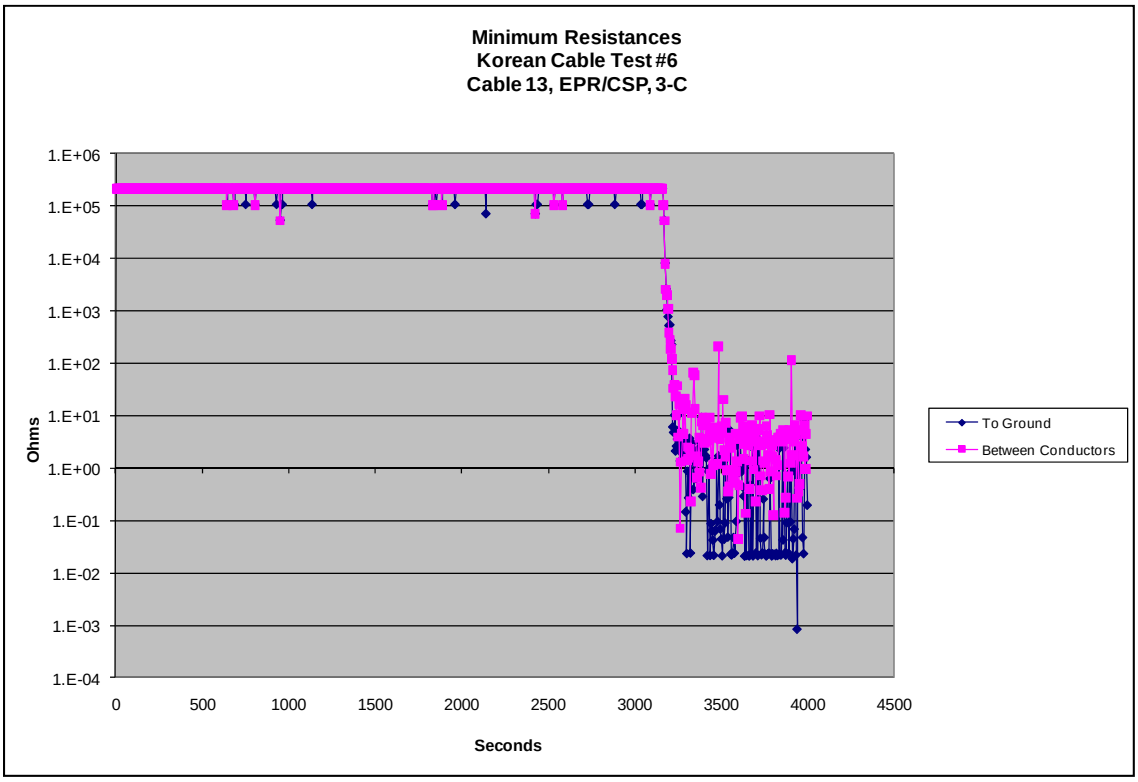
Penlight was initially set to 250C and increased by 25C every 5 minutes until electrical failure of the cable occurred.

Summary of Observed Faulting Behavior for Korean Cable Test #6		
Time (s)	**Event**	**Comments**
645	Penlight On; set at 250C (3.4 kW/m2)	
3193	Conductor 2 shorts to ground at less than 1000 ohms	Initial failure is by conductor-to-ground shorting; cable temperature is 475C.
3197	All three conductors short together at less than 1000 ohms	
3200	Conductors 1 & 3 short to ground at less than 1000 ohms	All conductors are shorted to ground
3218	Conductor 1 shorts to conductors 2 & 3 at less than 100 ohms	
3220	Conductors 2 & 3 short to ground at less than 100 ohms	
3225	Conductor 1 shorts to ground at less than 100 ohms	
3228	Conductor 2 shorts to conductor 3 at less than 100 ohms	


Penlight Shroud and CableTemperatures
Korean Cable Test #6
Cable 13, EPR/CSP, 3-C
First cable failure (3193 s)
Degrees-C
Seconds
Shroud
TC 1
TC 2
TC 3
TC 4


Average Conductor-to-Ground Resistances
Korean Cable Test #6
Cable 13, EPR/CSP, 3-C
Ohms
Seconds
Average C1-G
Average C2-G
Average C3-G


Average Conductor-to-Conductor Resistances
Korean Cable Test #6
Cable 13, EPR/CSP, 3-C
Ohms
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Seconds
C1-C
C2-C
C3-C

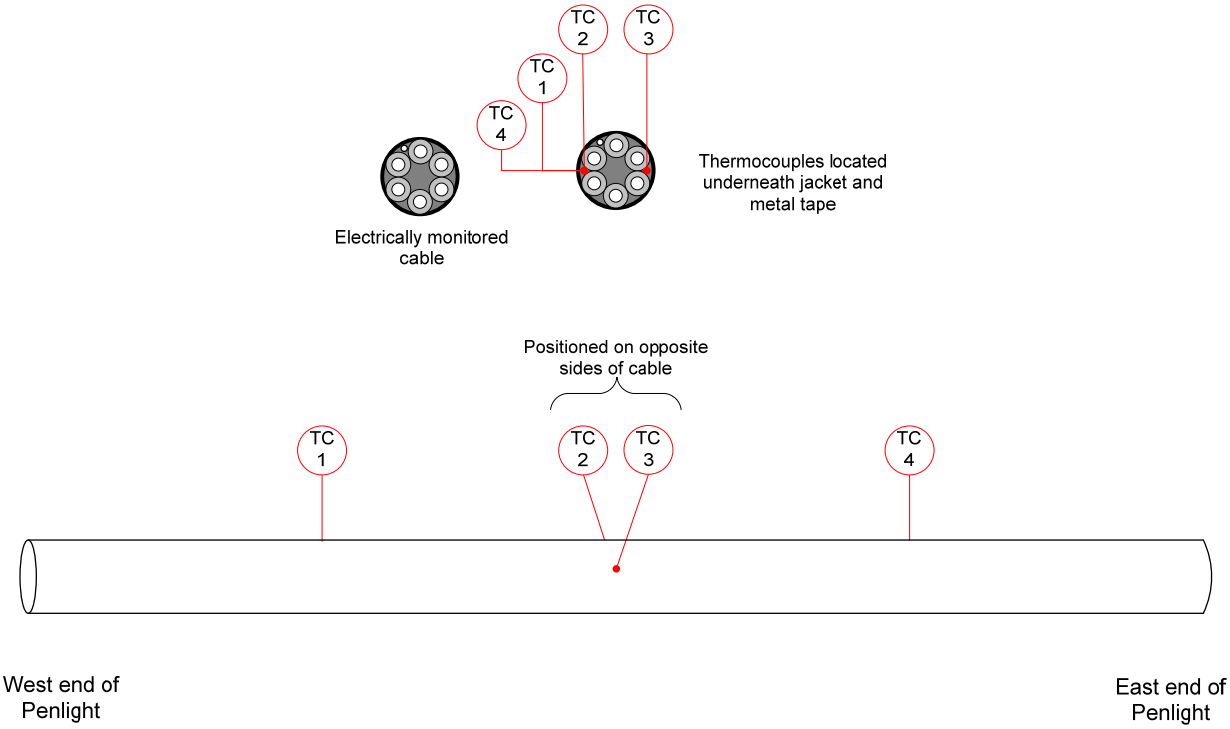

Minimum Resistances
Korean Cable Test #6
Cable 13, EPR/CSP, 3-C
Ohms
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Seconds
To Ground
Between Conductors

Korean Cable Test #7

Test conditions:

Cable: 6-conductor, 16 AWG, EPR insulated, CSP jacketed, instrument cable (Cable ID 1).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud initially set to temperature of 450C, nominal 12.6 kW/m^2 flux from shroud.
Electrical response monitoring: IRMS system using six channels - one for each insulated conductor, cable tray and drain wire grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see thermocouple map).

Two cables were included in Test #7, one electrically monitored, one thermally monitored. The cable had a blue jacket and white conductor insulation with printed numbers. A metal tape surrounded the conductor bundle and was grounded during the test.

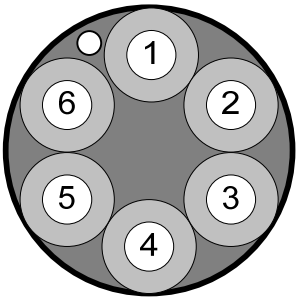


Map for placement of thermocouples inserted within the thermally monitored cable during Test #7.

Thermo-couple Name	Location

TC1	Within cable just below cable jacket and metal tape, to the West of the center position
TC2	Within cable just below cable jacket and metal tape, at center position
TC3	Within cable just below cable jacket and metal tape, opposite side from Cable 2, center position
TC4	Within cable just below cable jacket and metal tape, to the East of the center position

Six of the seven available IRMS channels were connected to the electrically monitored test cable.



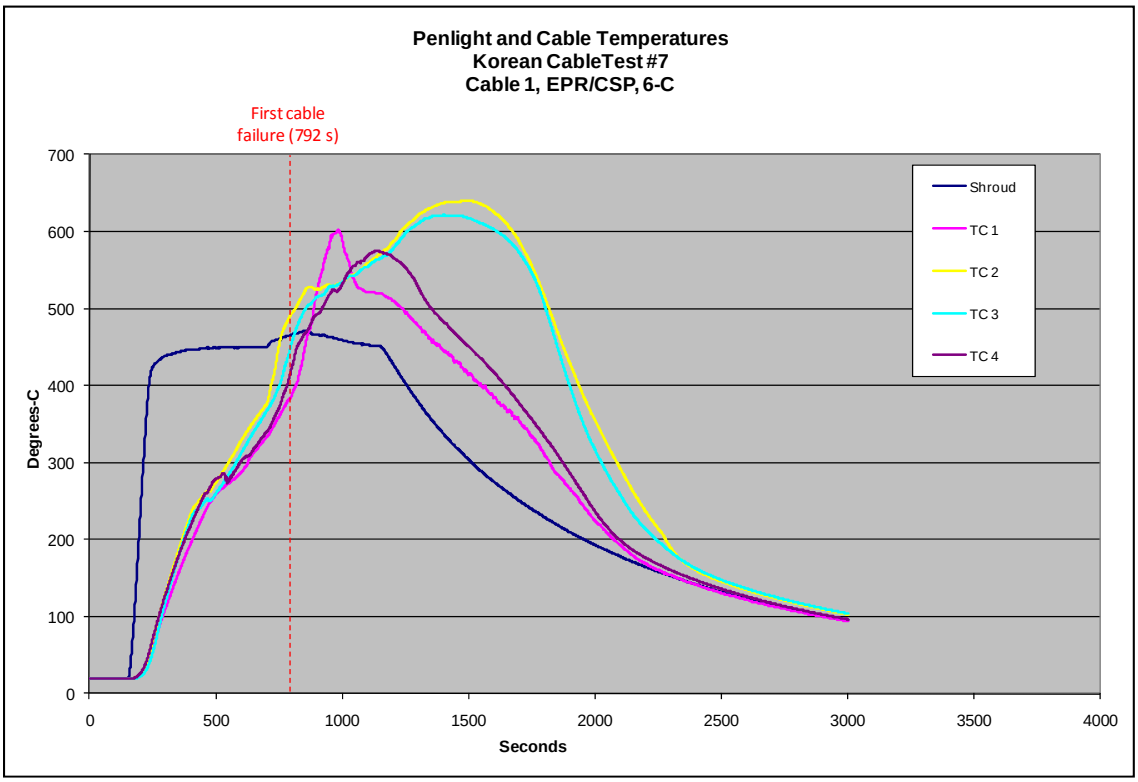
IRMS channel assignments for electrically monitored cable

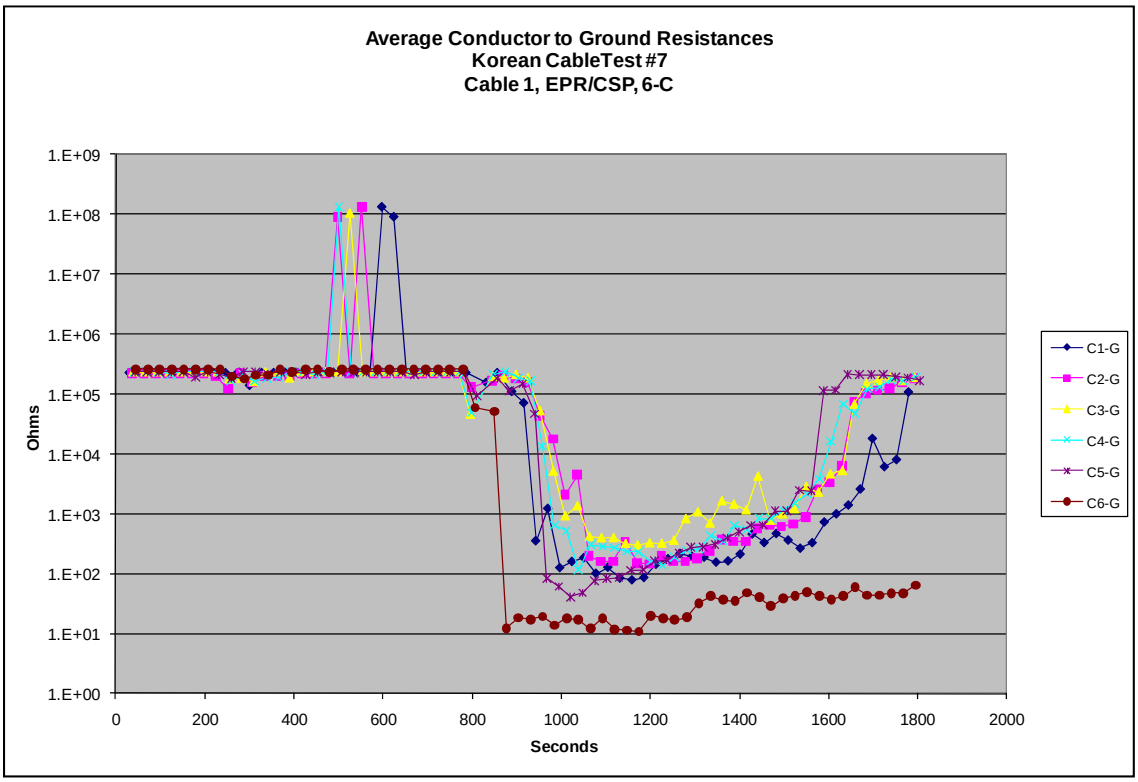
IRMS Channel	Test Cable
1	Black
2	White
3	Red
4	Green
5	Orange
6	Blue
	Drain wire grounded

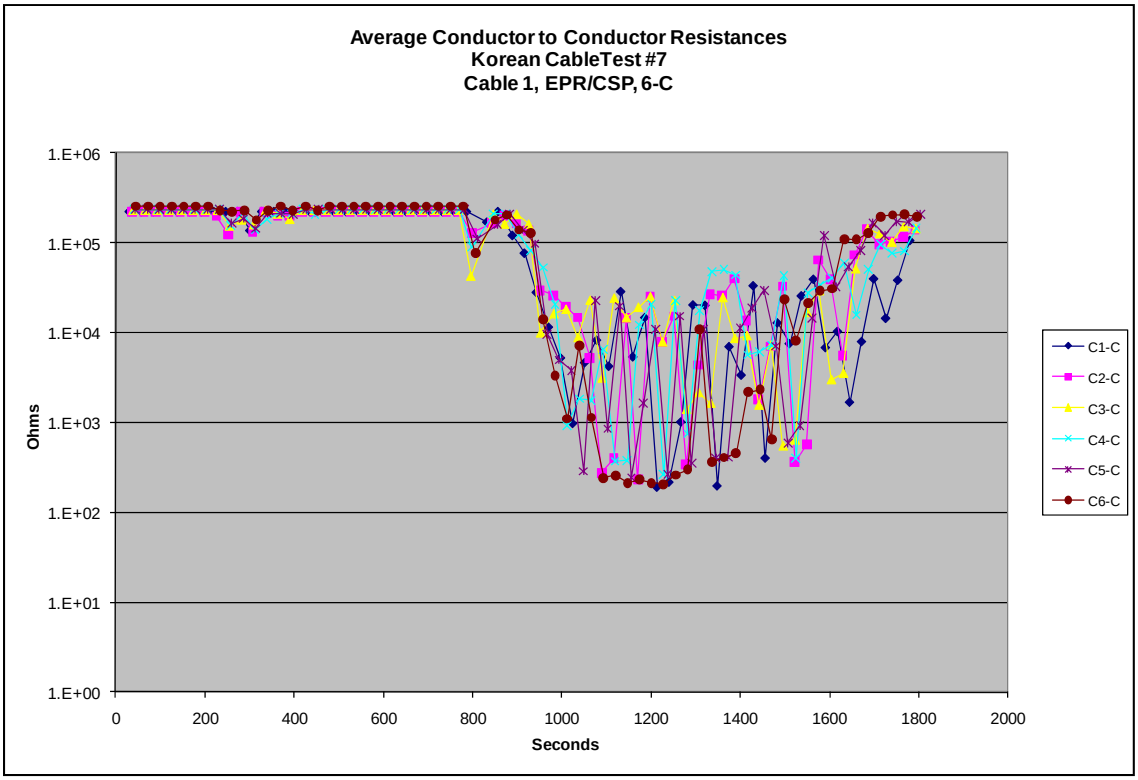
The Penlight shroud temperature was initially set at 450C and held at that value until electrical failure of the cable occurred.

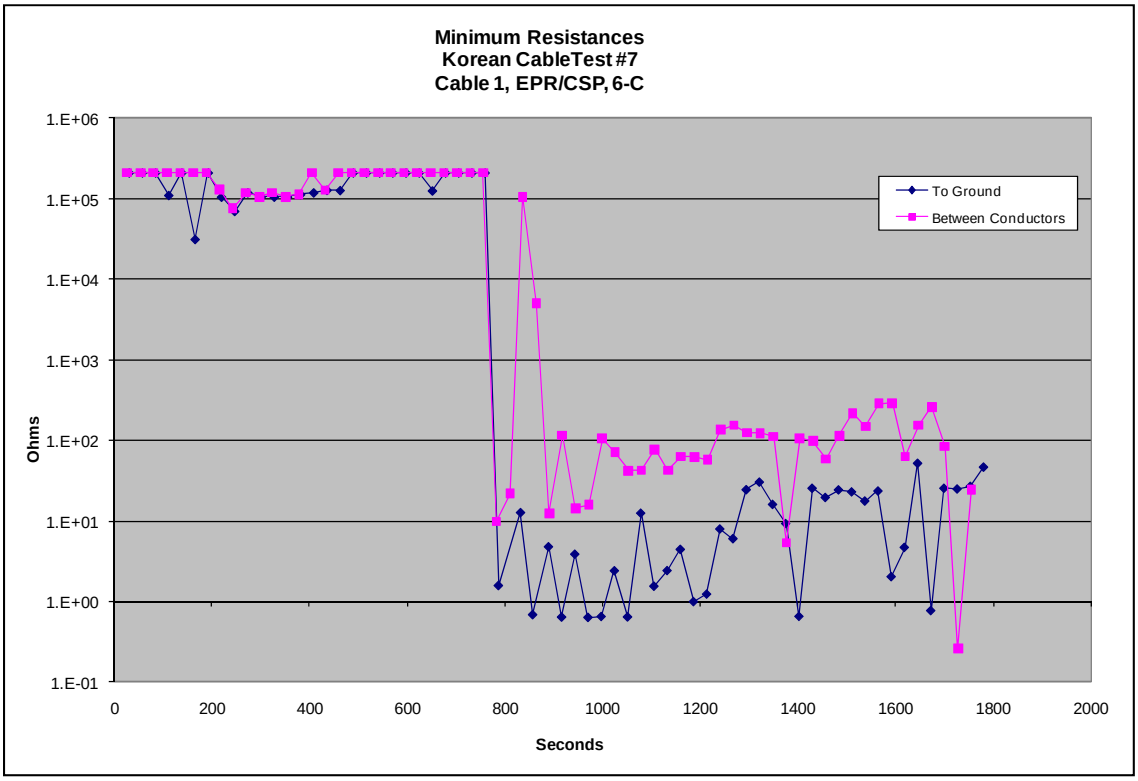
Summary of Observed Faulting Behavior for Korean Cable Test #7		
Time (s)	**Event**	**Comments**
153	Penlight On; set at 450C (12.6 kW/m2)	
792-807	Conductor 2 shorts to conductor 3 at less than 100 ohms; conductor 2 shorts to conductor 6 at less than 1000 ohms. Conductor 3 shorts to conductors 4, 5 & 6 at less than 1000 ohms. Conductor 4 shorts to conductors 5 & 6 at less than 1000 ohms.	Initial failure is by conductor to conductor shorting; average cable temperature 468C at center
798-807	Conductors 2, 3, 4 & 6 short to ground at less than 1000 ohms. Conductor 5 shorts to ground at less than 100 ohms.	
850	Conductor 6 shorts to ground at less than 100 ohms.	Shorting path may be through ground (tray)
889-898	Conductor 1 shorts to ground at less than 1000 ohms. Conductor 2 shorts to ground at less than 100 ohms.	All conductors are shorted to ground

916	Conductor 1 shorts to ground at less and 100 ohms	
964	Conductor 1 shorts to conductor 5 at less than 1000 ohms	
989	Conductor 1 shorts to conductors 4 & 6 at less than 100 ohms	




Average Conductor to Ground Resistances
Korean CableTest #7
Cable 1, EPR/CSP, 6-C
Ohms
1.E+09
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Seconds
C1-G
C2-G
C3-G
C4-G
C5-G
C6-G


Average Conductor to Conductor Resistances
Korean CableTest #7
Cable 1, EPR/CSP, 6-C
Ohms
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Seconds
C1-C
C2-C
C3-C
C4-C
C5-C
C6-C

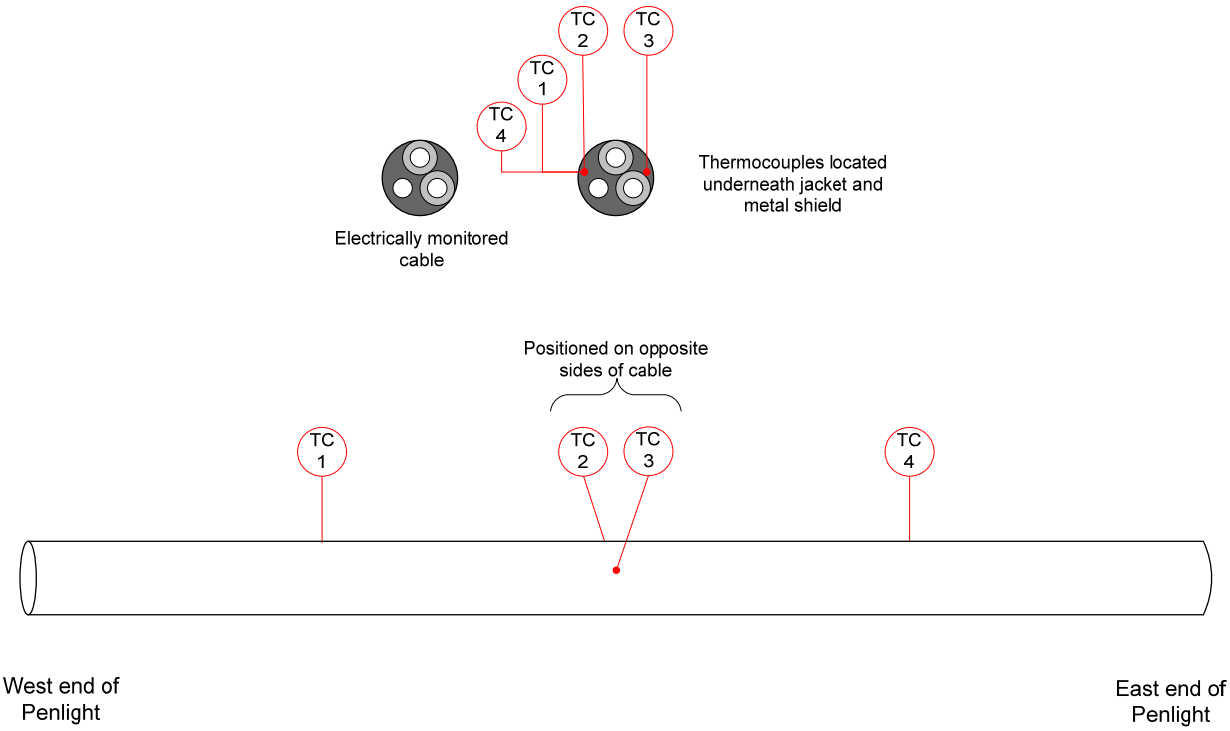


Korean Cable Test #8

Test conditions:

Cable: 2-conductor with bare drain wire, 16 AWG, EPR insulated, CSP jacketed, instrument cable (Cable ID 3).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud initially set to temperature of 450C, nominal 12.6 kW/m^2 flux from shroud.
Electrical response monitoring: IRMS system using two channels - one for each insulated conductor, cable tray and drain wire were grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see thermocouple map).

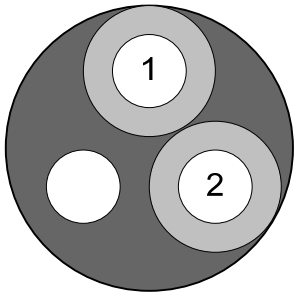
Two cables were included in Test #8, one electrically monitored, one thermally monitored. The test cables had a red jacket and black and white conductor insulation. The drain wire was not insulated and was grounded.



Map for placement of thermocouples inserted within the thermally monitored cable during Test #8.

Thermo-couple Name	Location
TC1	Within cable just below cable jacket and shield, to the West of the center position
TC2	Within cable just below cable jacket and shield, at center position
TC3	Within cable just below cable jacket and shield, opposite side from Cable 2, center position
TC4	Within cable just below cable jacket and shield, to the East of the center position

Two of the available IRMS channels were connected to the electrically monitored test cable.



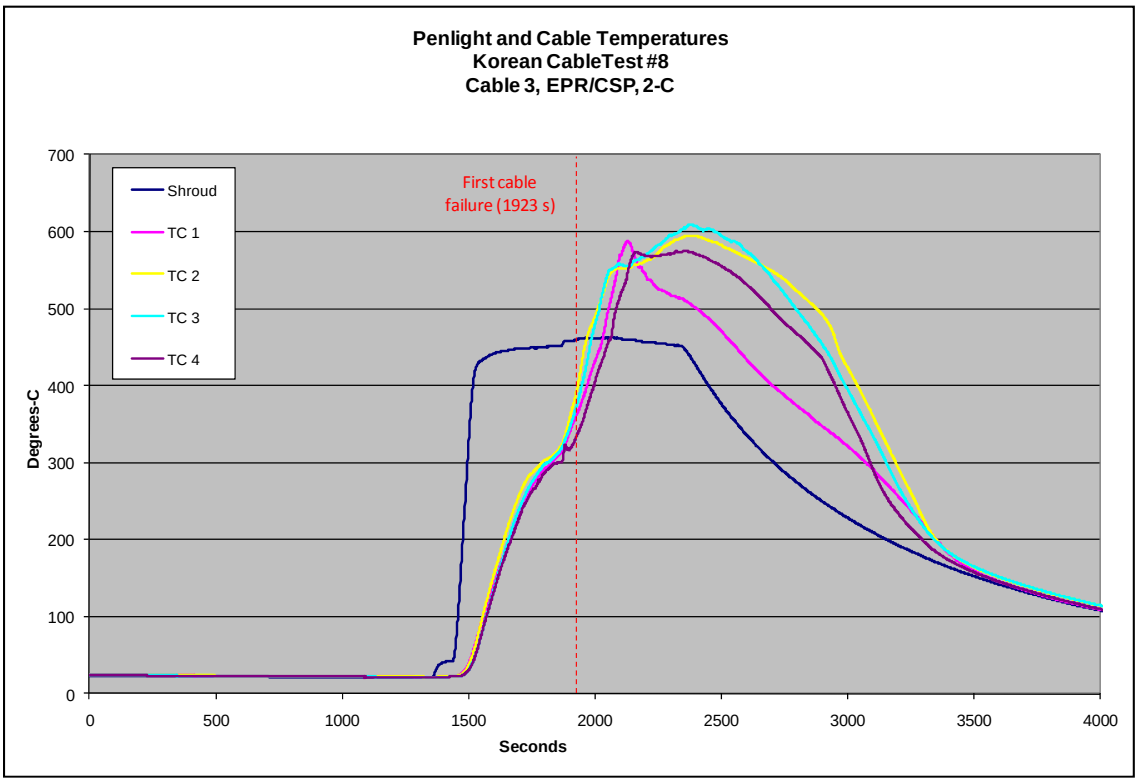
Drain wire connected to ground

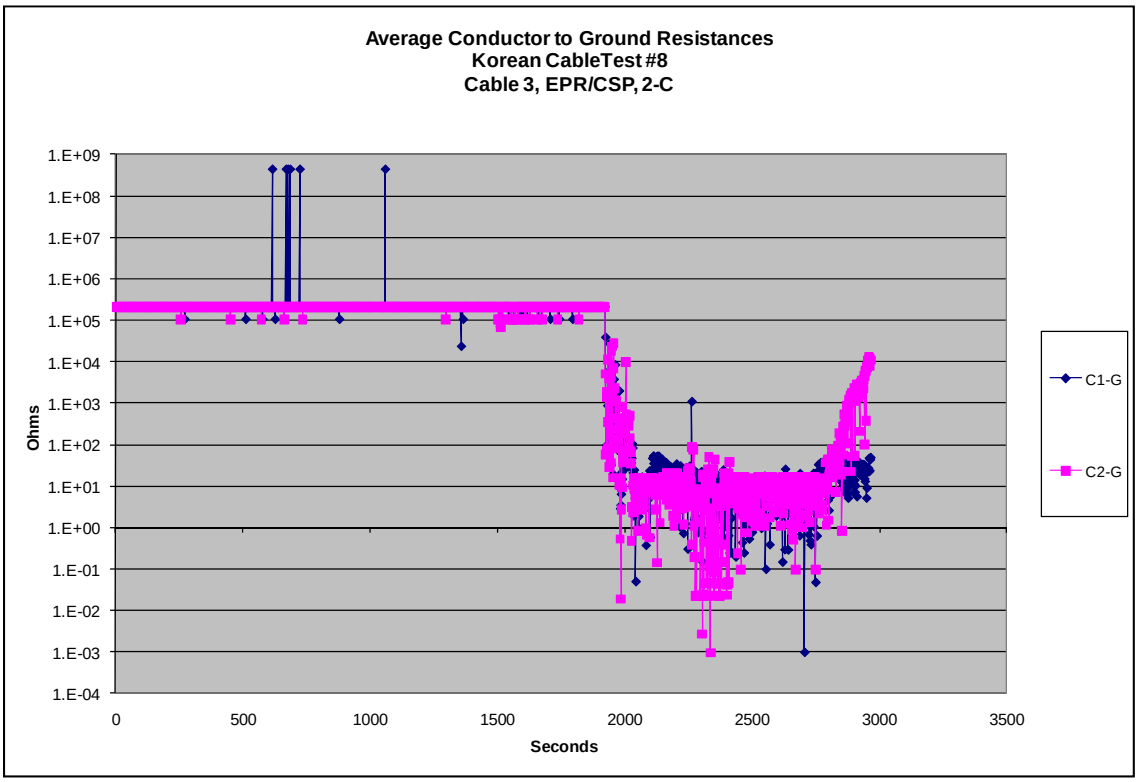
IRMS channel assignments for electrically monitored cable

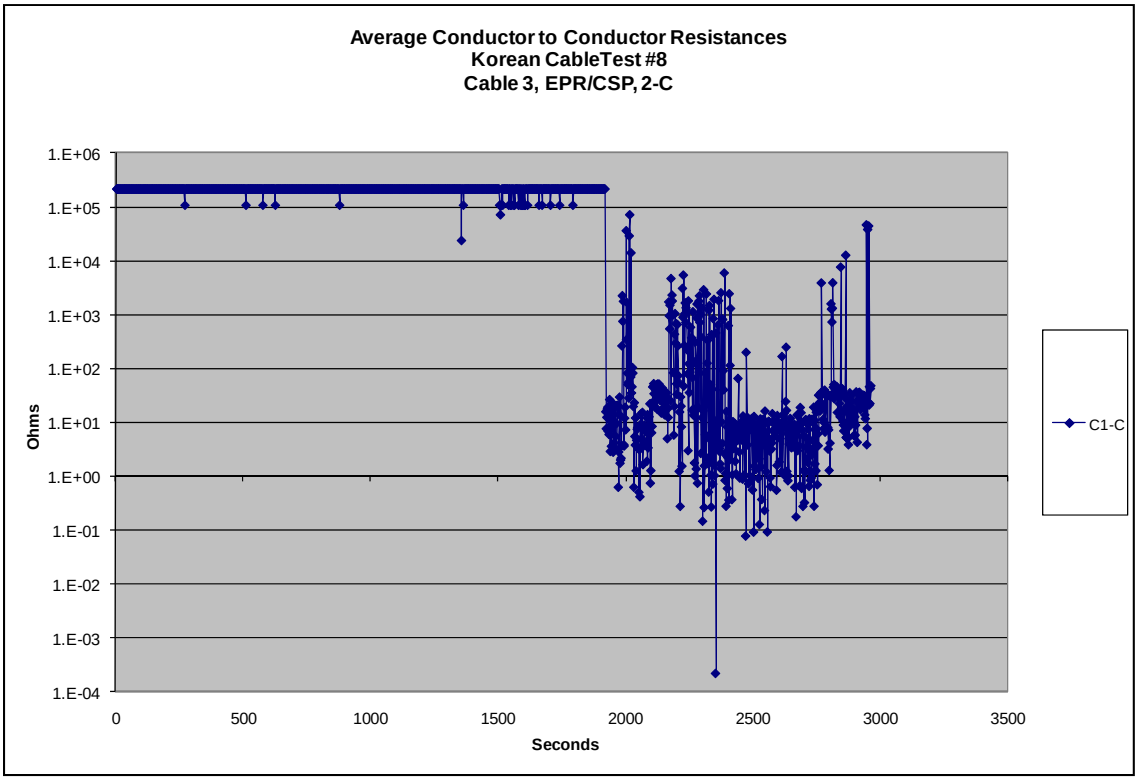
IRMS Channel	Test Cable
1	Black
2	White

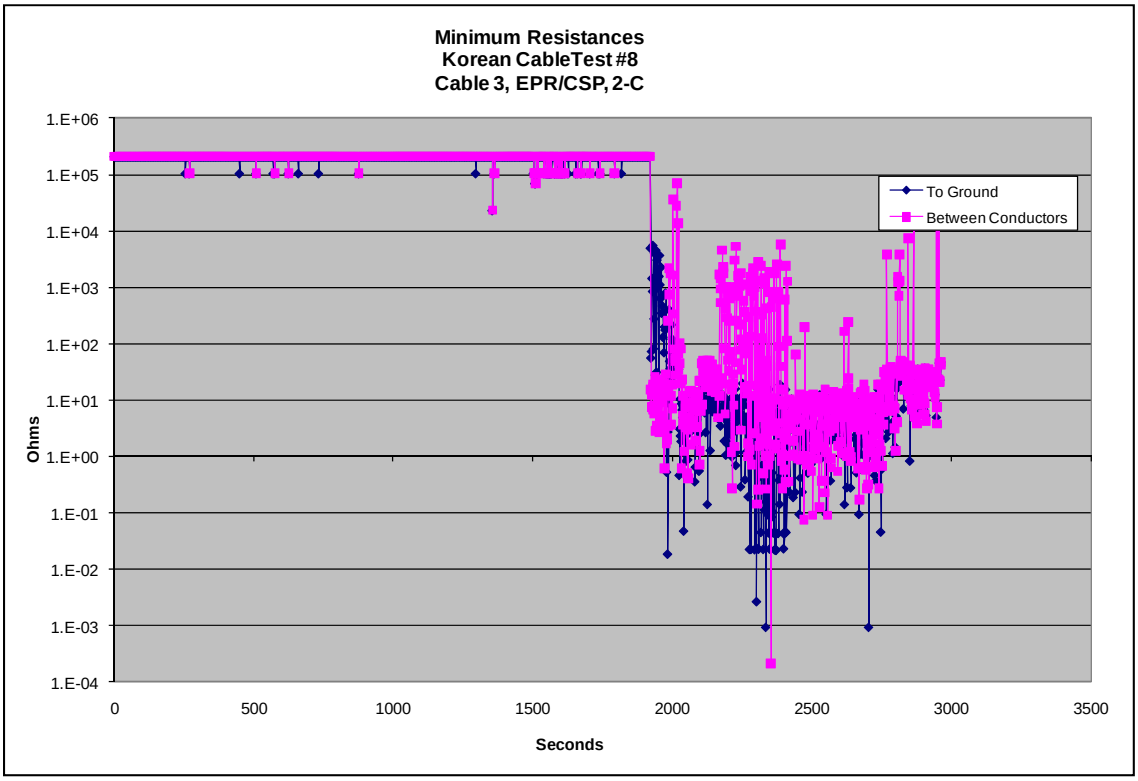
The Penlight shroud temperature was initially set at 450C and held at that value until electrical failure of the cable occurred.

Summary of Observed Faulting Behavior for Korean Cable Test #8		
Time (s)	**Event**	**Comments**
1438	Penlight On; set at 450C (12.6 kW/m2)	
1923	Conductor 1 shorts to conductor 2 at less than 100 ohms	Initial failure is by conductor to conductor shorting; average cable temperature 377C at center
1925	Conductors 1 & 2 both short to ground at less than 100 ohms	All conductors are shorted to ground




Average Conductor to Ground Resistances
Korean CableTest #8
Cable 3, EPR/CSP, 2-C
Ohms
1.E+09
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
0
500
1000
1500
2000
2500
3000
3500
Seconds
C1-G
C2-G


Average Conductor to Conductor Resistances
Korean CableTest #8
Cable 3, EPR/CSP, 2-C
Ohms
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
0
500
1000
1500
2000
2500
3000
3500
Seconds
C1-C

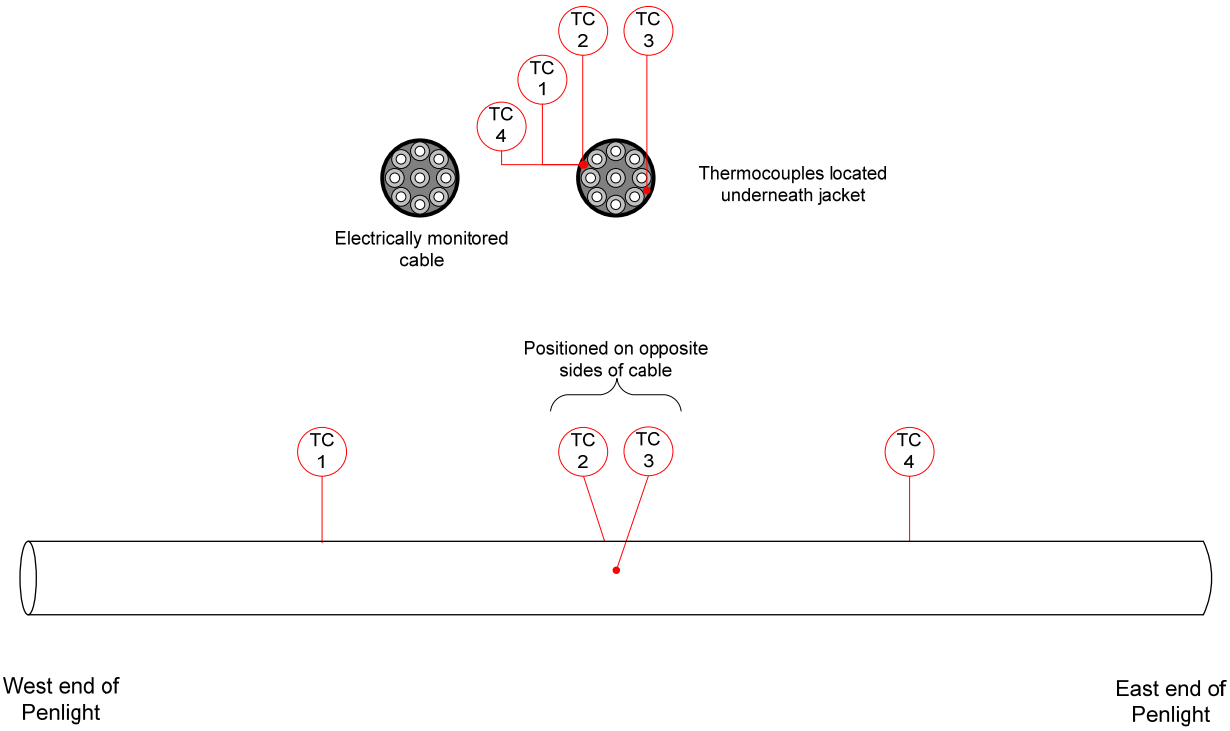


Korean Cable Test #9

Test conditions:

Cable: 9-conductor, 14 AWG, EPR insulated, CSP jacketed, control cable (Cable ID 5).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud initially set to temperature of 450C, nominal 12.6 kW/m2 flux from shroud.
Electrical response monitoring: IRMS system using seven channels - one for each insulated conductor monitored by IRMS channels 1, 3, 4, 5 & 6; IRMS channels 2 & 7 monitored 2 conductors each. The cable tray was grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see thermocouple map).

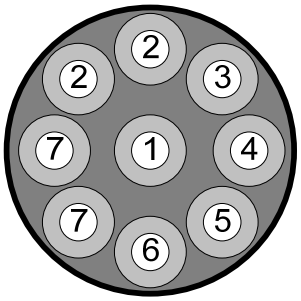
Two cables were included in Test #9, one electrically monitored, one thermally monitored. The test cables had a pink jacket and white conductor insulation with printed numbers.



Map for placement of thermocouples inserted within the thermally monitored cable during Test #9.

Thermo-couple Name	Location
TC1	Within cable just below cable jacket, to the East of the center position
TC2	Within cable just below cable jacket, at center position
TC3	Within cable just below cable jacket, opposite side from Cable 2, center position
TC4	Within cable just below cable jacket, to the West of the center position

All seven of the IRMS channels were connected to the electrically monitored test cable.



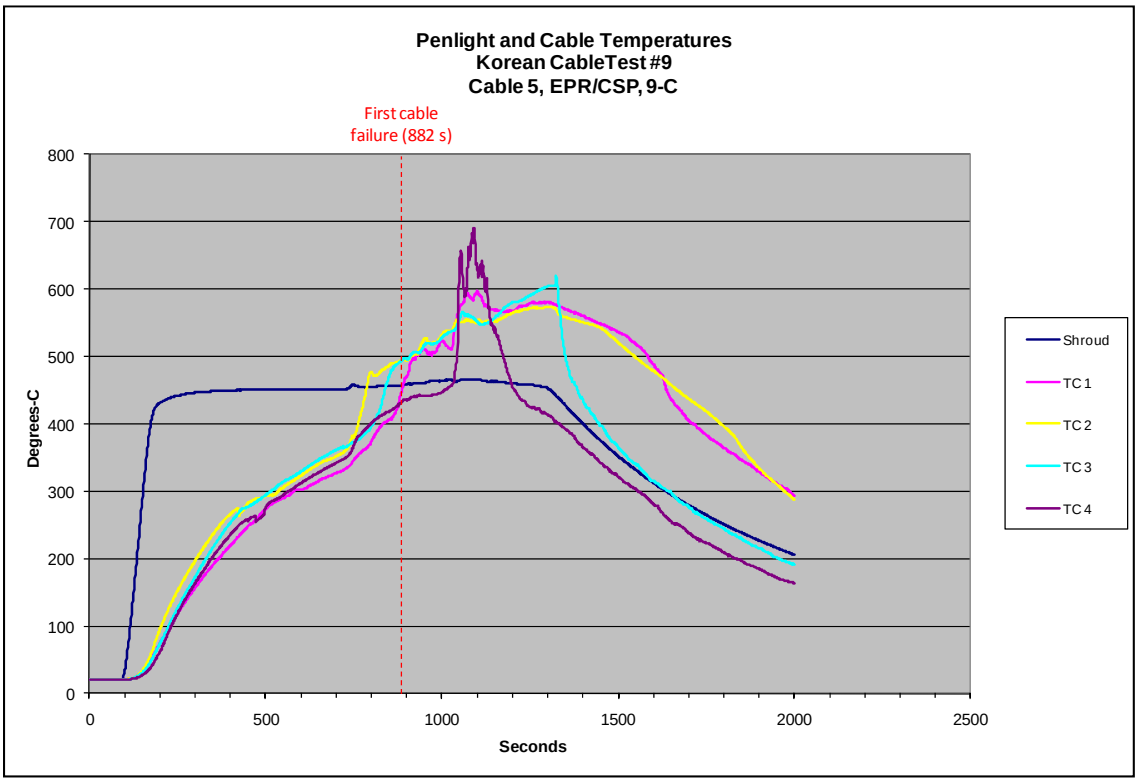
IRMS channel assignments for electrically monitored cable

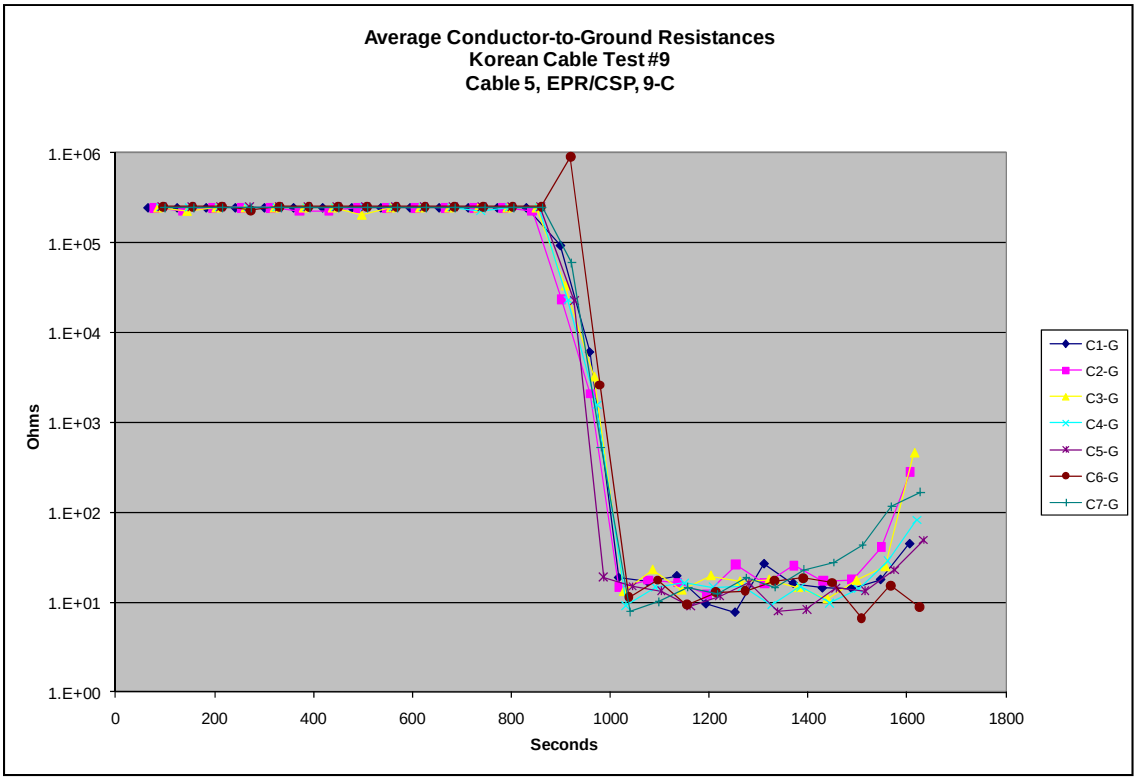
IRMS Channel	Test Cable
1	Black
2	White & Green-Black

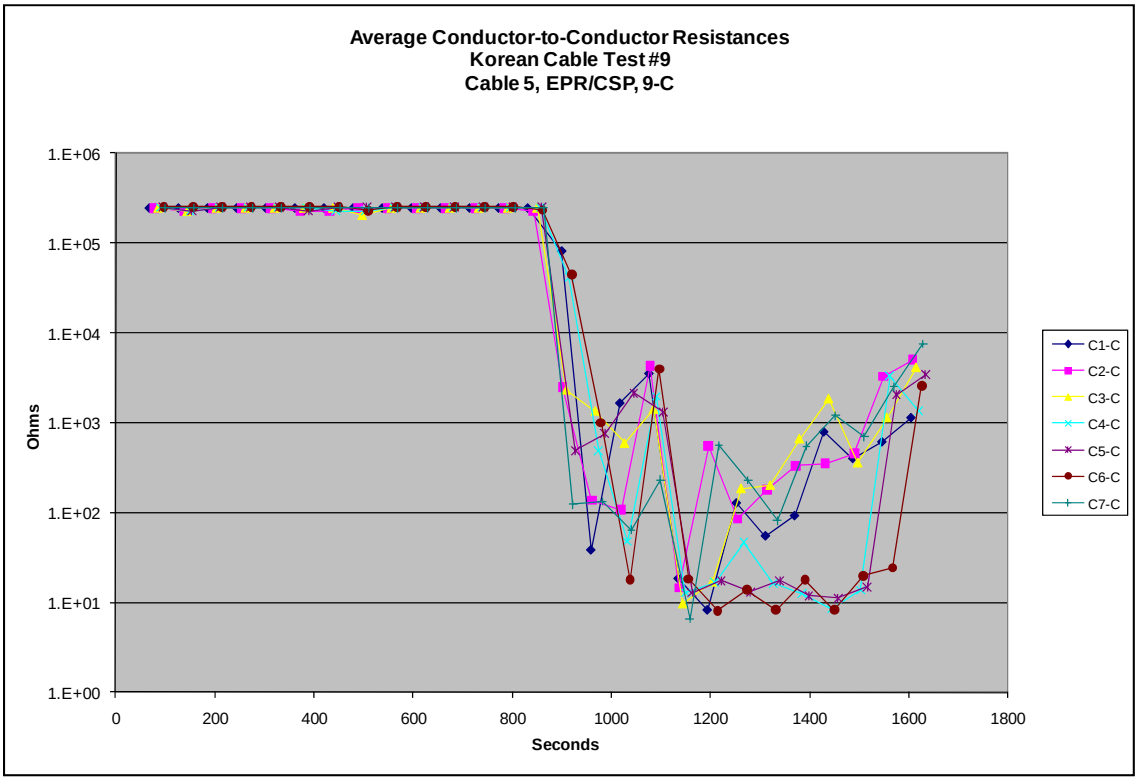
3	Red
4	Green
5	Orange
6	Blue
7	White-Black & Red-Black

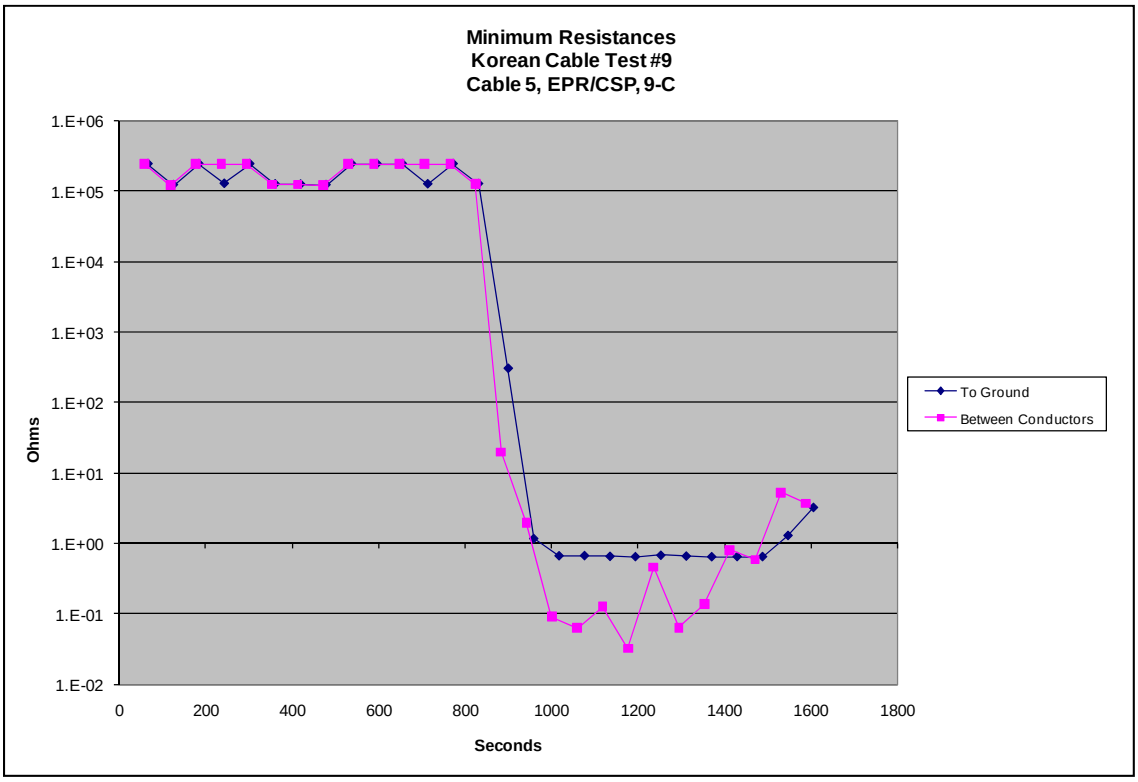
The Penlight shroud temperature was initially set at 450C and held at that value until electrical failure of the cable occurred.

Summary of Observed Faulting Behavior for Korean Cable Test #9		
Time (s)	**Event**	**Comments**
92	Penlight On; set at 450C (12.6 kW/m2)	
882-897	Conductor 1 shorts to conductors 2, 3, 5 & 7 at less than 100 ohms	Initial failures are by conductor-to-conductor shorting; average cable temperature is 492C at center.
900	Conductor 2 shorts to conductor 3 at less than 1000 ohms	
901	Conductors 2 & 4 short to ground at less than 1000 ohms	
902-910	Conductor 2 shorts to conductors 4 & 7 at less than 100 ohms	
916-922	Conductor 3 shorts to conductors 5, 6 & 7 at less than 1000 ohms	
925-930	Conductor 4 shorts to conductors 5, 6 & 7 at less than 100 ohms	
933-936	Conductor 5 shorts to conductors 6 & 7 at less than 100 ohms	
939	Conductor 6 shorts to conductor 7 at less than 100 ohms	
947-953	Conductor 1 shorts to conductors 4 & 6 at less than 100 ohms	
958-964	Conductor 2 shorts to conductors 3, 4 & 5 at less than 100 ohms	
958-981	All conductors short to ground at less than 100 ohms	All conductors are shorted to ground


Penlight and Cable Temperatures
Korean CableTest #9
Cable 5, EPR/CSP, 9-C
First cable failure (882 s)
Degrees-C
Seconds
Shroud
TC 1
TC 2
TC 3
TC 4


Average Conductor-to-Ground Resistances
Korean Cable Test #9
Cable 5, EPR/CSP, 9-C
Ohms
Seconds
C1-G
C2-G
C3-G
C4-G
C5-G
C6-G
C7-G


Average Conductor-to-Conductor Resistances
Korean Cable Test #9
Cable 5, EPR/CSP, 9-C
Ohms
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
0
200
400
600
800
1000
1200
1400
1600
1800
Seconds
C1-C
C2-C
C3-C
C4-C
C5-C
C6-C
C7-C

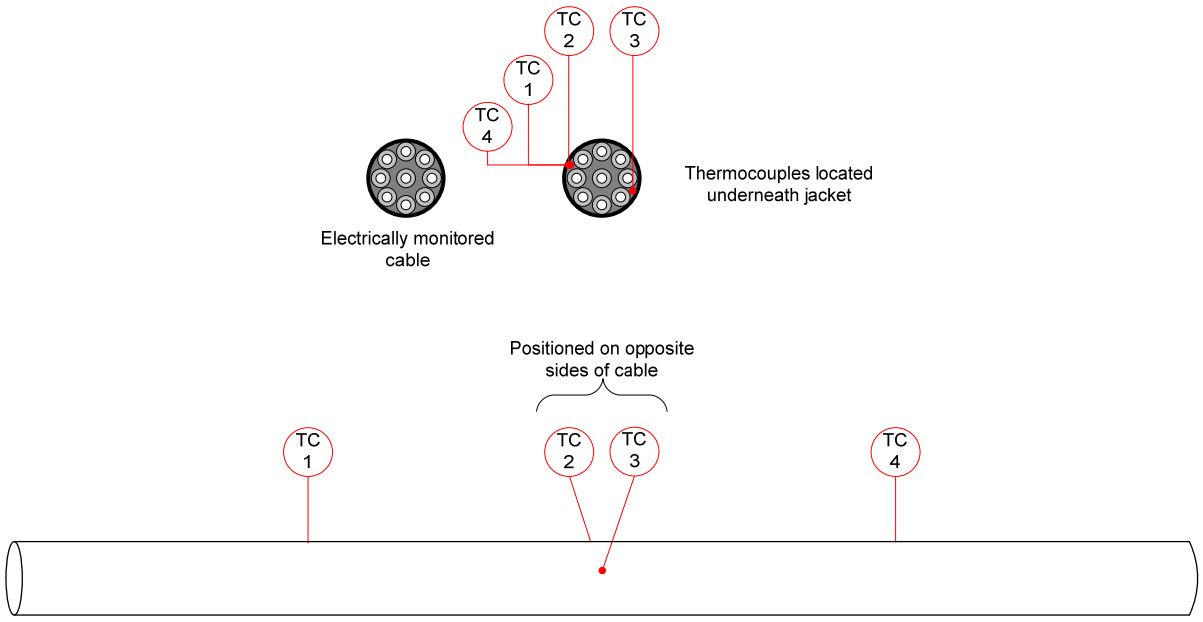

Minimum Resistances
Korean Cable Test #9
Cable 5, EPR/CSP, 9-C
Ohms
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
0
200
400
600
800
1000
1200
1400
1600
1800
Seconds
To Ground
Between Conductors

Korean Cable Test #10

Test conditions:

Cable: 9-conductor, 14 AWG, EPR insulated, CR jacketed, control cable (Cable ID 8).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud initially set to temperature of 450C, nominal 12.6 kW/m2 flux from shroud.
Electrical response monitoring: IRMS system using seven channels - one for each insulated conductor monitored by IRMS channels 1, 3, 4, 5 & 6; IRMS channels 2 & 7 monitored 2 conductors each. The cable tray was grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see thermocouple map).

Two cables were included in Test #10, one electrically monitored with the IRMS, one thermally monitored. The cable had a black CR jacket and a black insulated center conductor and eight white insulated other conductors with printed numbers.

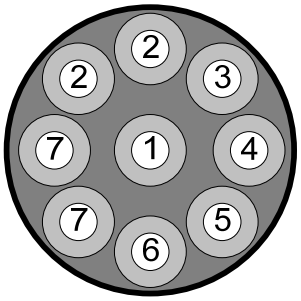


Map for placement of thermocouples inserted within the thermally monitored cable during Test #10.

Thermo-couple	Location

Name	
TC1	Within cable just below cable jacket, to the West of the center position
TC2	Within cable just below cable jacket, at center position
TC3	Within cable just below cable jacket, opposite side from Cable 2, center position
TC4	Within cable just below cable jacket, to the East of the center position

All seven of the available IRMS channels were connected to the electrically monitored test cable.



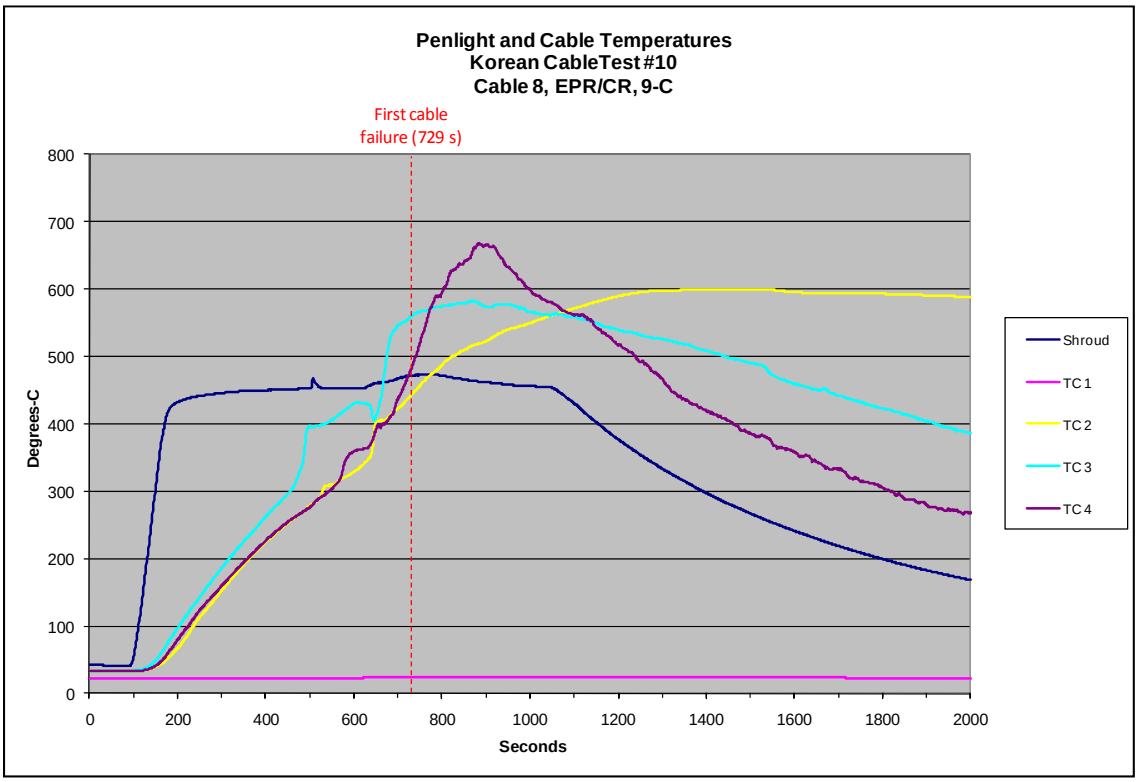
IRMS channel assignments for electrically monitored cable

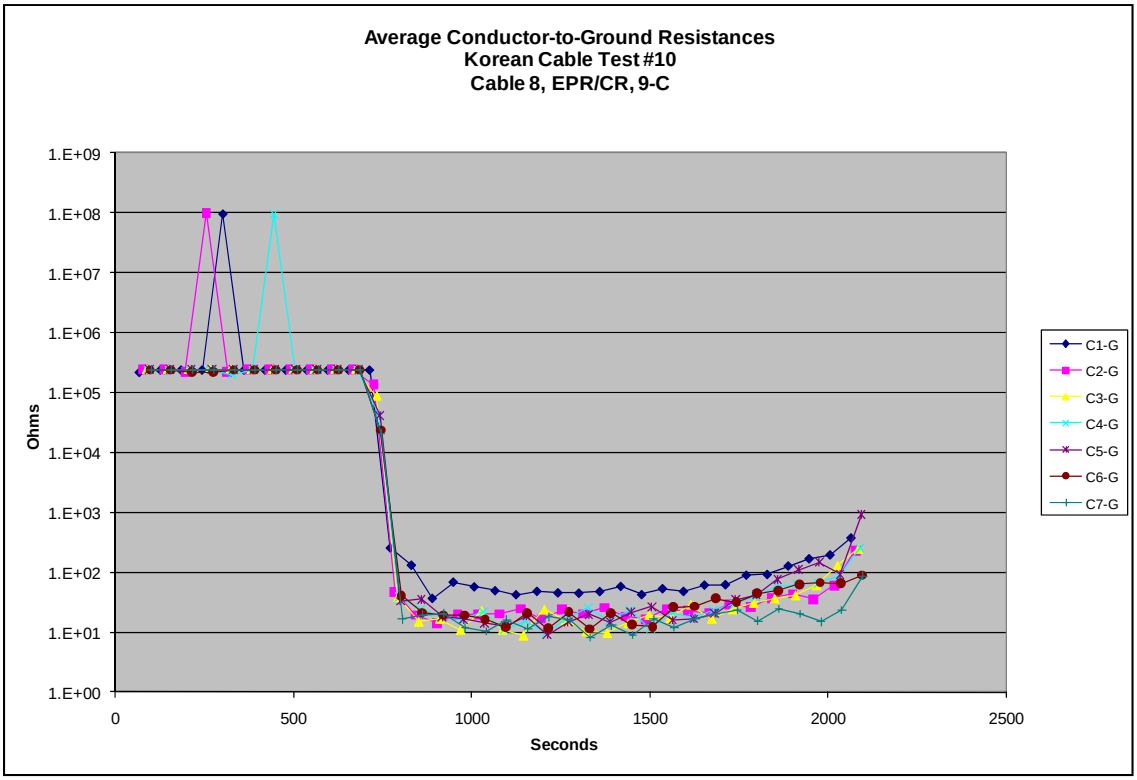
IRMS Channel	Test Cable
1	Black
2	White & Green-Black
3	Red
4	Green
5	Orange
6	Blue
7	White-Black & Red-Black

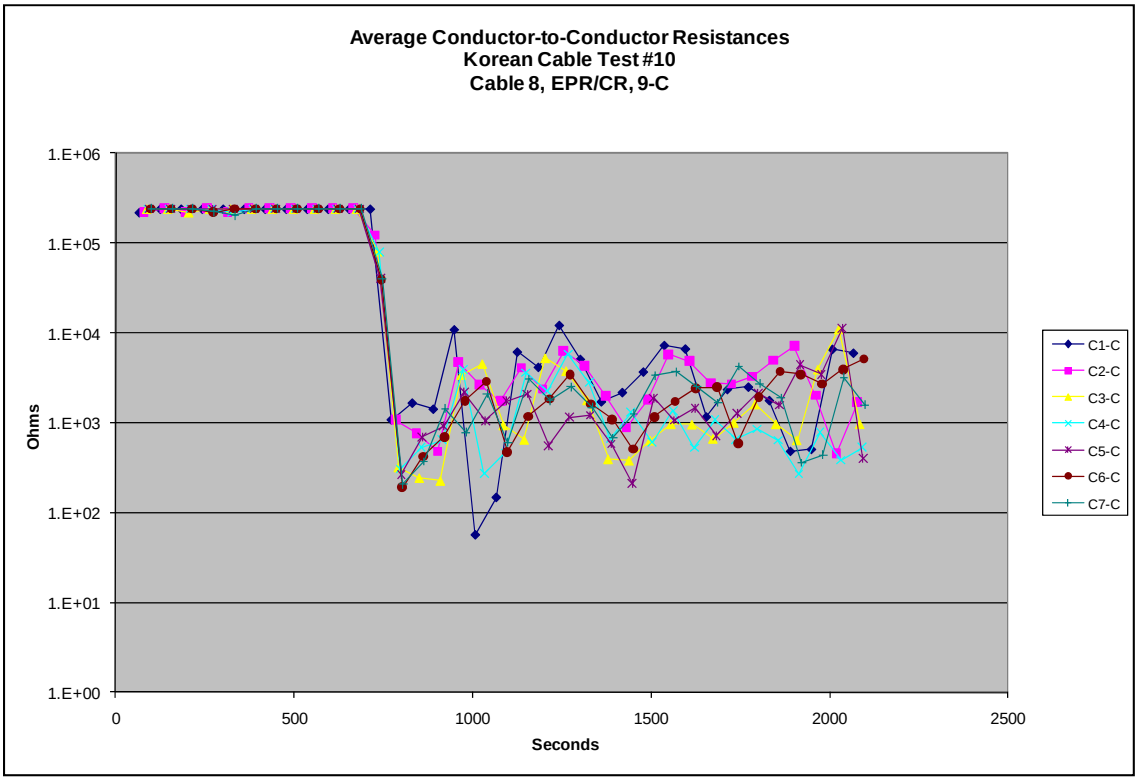
The Penlight shroud temperature was initially set at 450C and held at that value until electrical failure of the cable occurred.

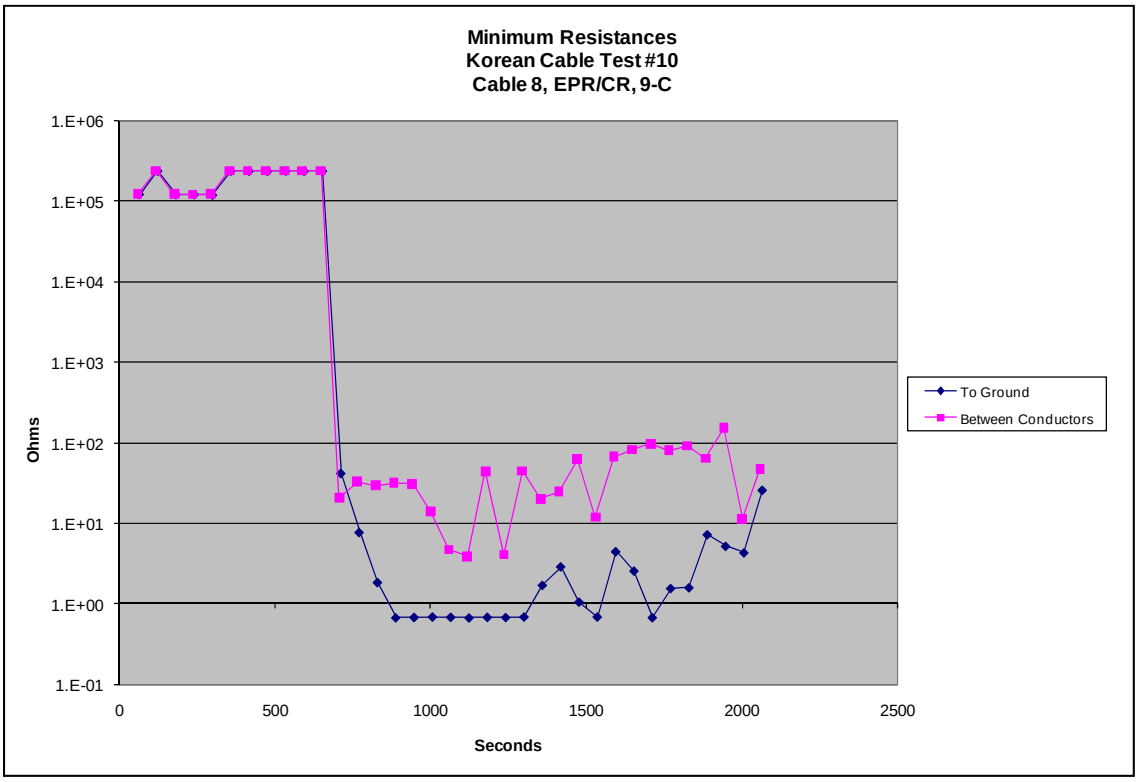
Summary of Observed Faulting Behavior for Korean Cable Test #10		
Time (s)	**Event**	**Comments**
92	Penlight On; set at 450C (12.6 kW/m2)	
729-734	Conductor 2 shorts to conductors 5 & 6 at less than 1000 ohms and to conductor 7 at less than 100 ohms	Initial failures are by conductor-to-conductor shorting; cable temperature 442C (TC-2).
737-743	Conductor 3 shorts to conductors 4, 5 & 6 at less than 1000 ohms	

738-744	Conductors 4, 5 & 6 short to ground at less than 1000 ohms	
746	Conductor 7 shorts to ground at less than 100 ohms	
746	Conductor 3 shorts to conductor 7 at less than 100 ohms	
749-754	Conductor 4 shorts to conductor 6 at less than 1000 ohms and to conductors 5 & 7 at less than 100 ohms	
757-760	Conductor 5 shorts to conductor 6 at less than 1000 ohms and to conductor 7 at less than 100 ohms	
763	Conductor 6 shorts to conductor 7 at less than 100 ohms	
771-779	Conductor 1 shorts to conductors 4, 5, 6 & 7 at less than 1000 ohms	
772-803	Conductors 1, 2, 3, 4, 5 & 6 short to ground at less than 100 ohms	All conductors are shorted to ground
Additional Observations		
Observation 1	The progression of failure modes for this cable followed that expected for a typical thermoset-insulated cable: conductor-to-conductor shorts followed by shorting to ground.	
Observation 2	Cable thermocouple TC-1 did not perform as expected.	


Penlight and Cable Temperatures
Korean CableTest #10
Cable 8, EPR/CR, 9-C
First cable failure (729 s)
Degrees-C
Seconds
Shroud
TC 1
TC 2
TC 3
TC 4


Average Conductor-to-Ground Resistances
Korean Cable Test #10
Cable 8, EPR/CR, 9-C
Ohms
Seconds
C1-G
C2-G
C3-G
C4-G
C5-G
C6-G
C7-G


Average Conductor-to-Conductor Resistances
Korean Cable Test #10
Cable 8, EPR/CR, 9-C
Ohms
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
0
500
1000
1500
2000
2500
Seconds
C1-C
C2-C
C3-C
C4-C
C5-C
C6-C
C7-C

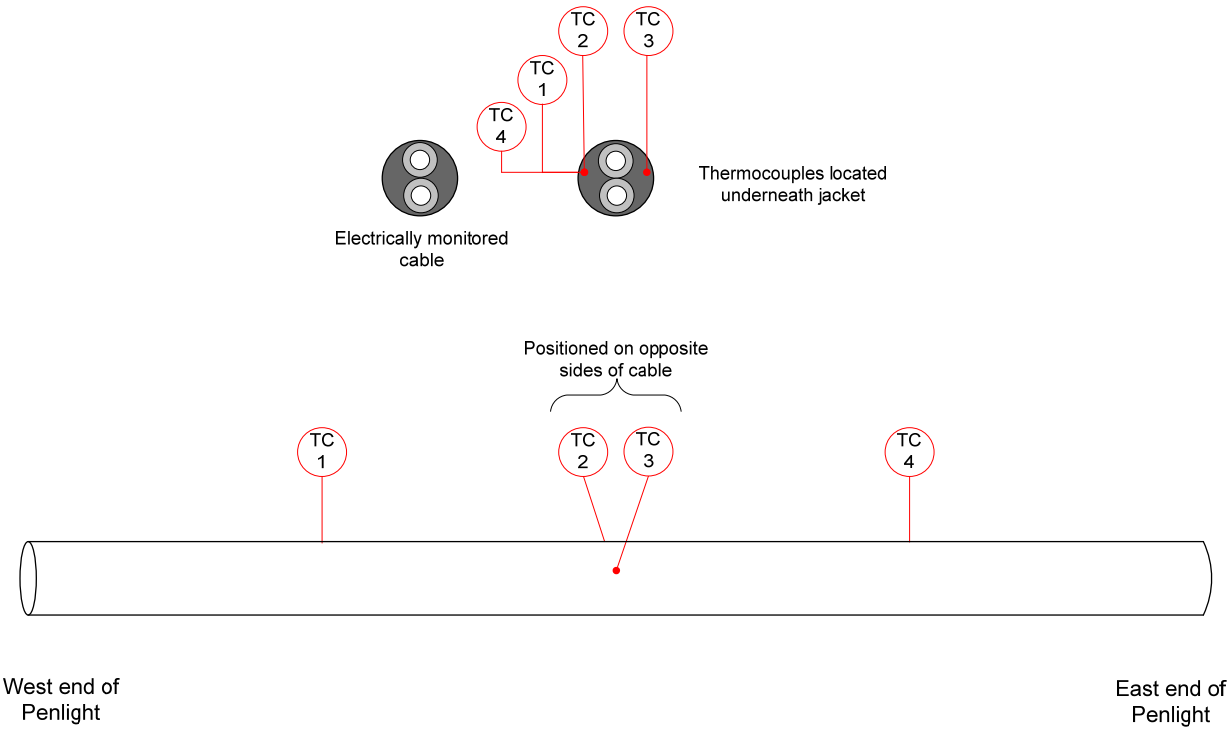

Minimum Resistances
Korean Cable Test #10
Cable 8, EPR/CR, 9-C
Ohms
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
0
500
1000
1500
2000
2500
Seconds
To Ground
Between Conductors

Korean Cable Test #11

Test conditions:

Cable: 2-conductor without drain wire or shield, 16 AWG, EPR insulated, CSP jacketed, power cable (Cable ID 10).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud initially set to temperature of 440C, nominal 11.9 kW/m^2 flux from shroud.
Electrical response monitoring: IRMS system using two channels - one for each insulated conductor, cable tray was grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see thermocouple map).

Two cables were included in Test #11, one electrically monitored, one thermally monitored. The cables had red jackets and black and white conductor insulation. This type of cable did not have a metal shield or drain wire.

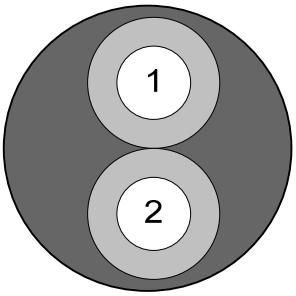


Map for placement of thermocouples inserted within the thermally monitored cable during Test #11.

Thermo-couple	Location

Name	
TC1	Within cable just below cable jacket, to the West of the center position
TC2	Within cable just below cable jacket, at center position
TC3	Within cable just below cable jacket, opposite side from Cable 2, center position
TC4	Within cable just below cable jacket, to the East of the center position

Two IRMS channels were connected to the electrically monitored test cable.

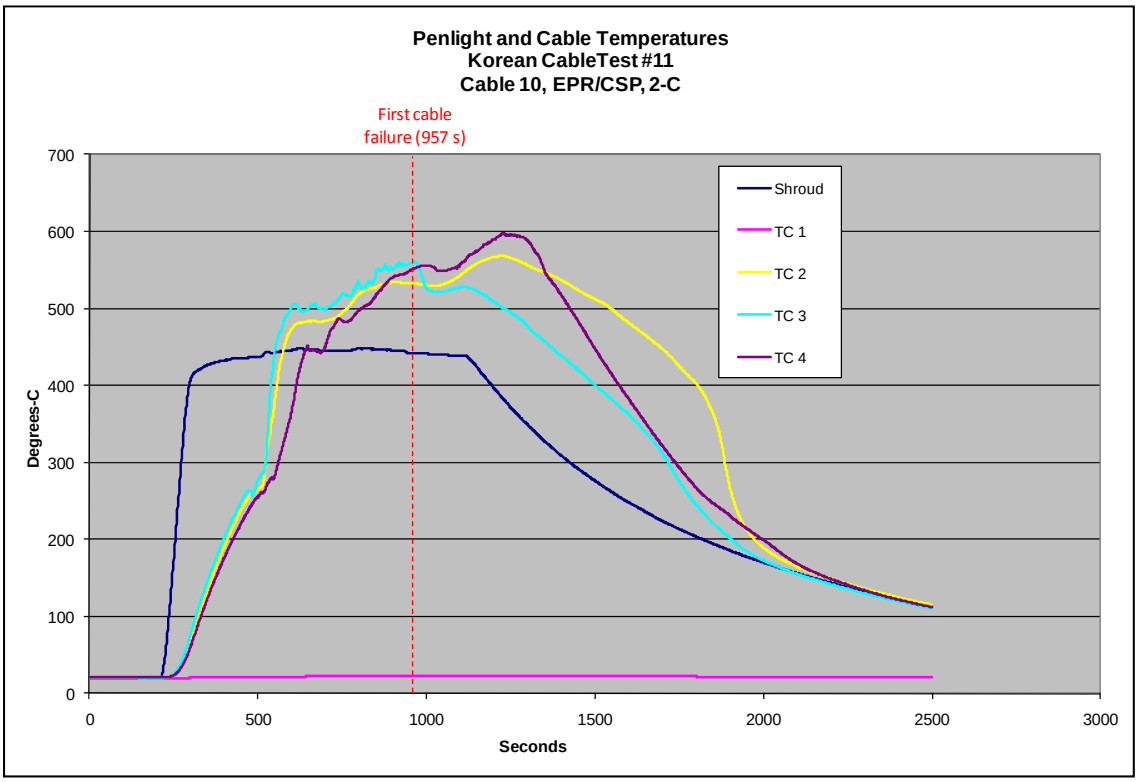


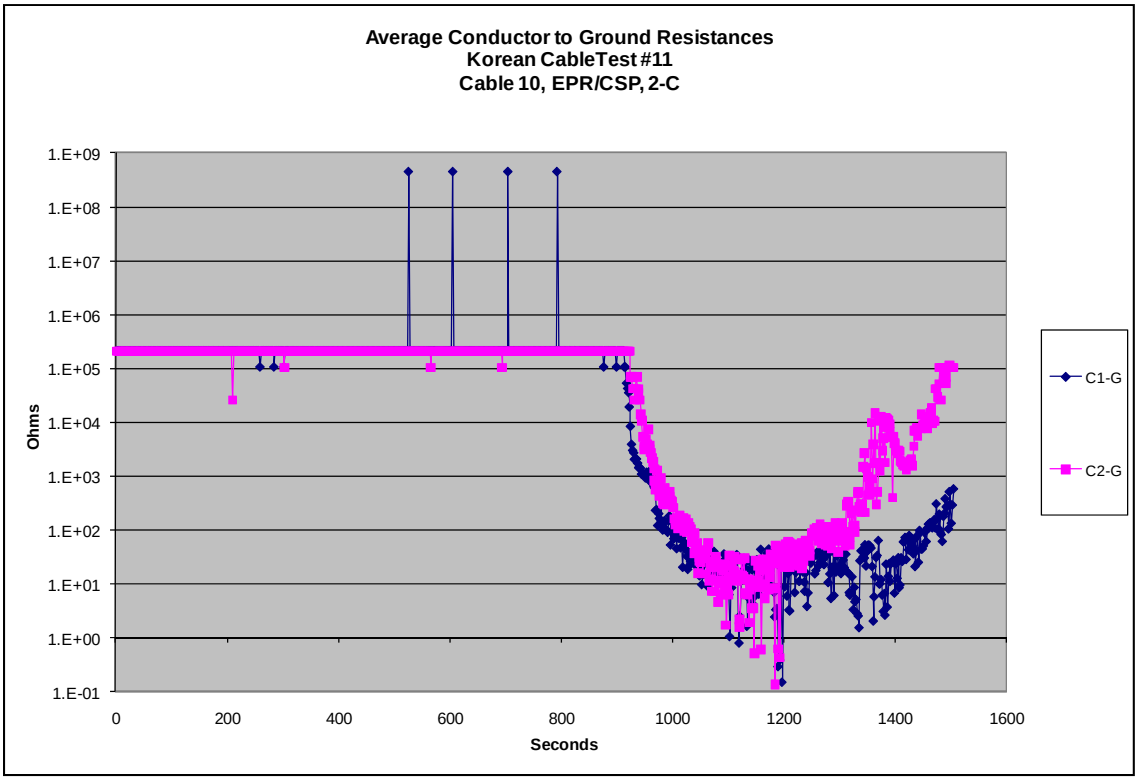
IRMS channel assignments for electrically monitored cable

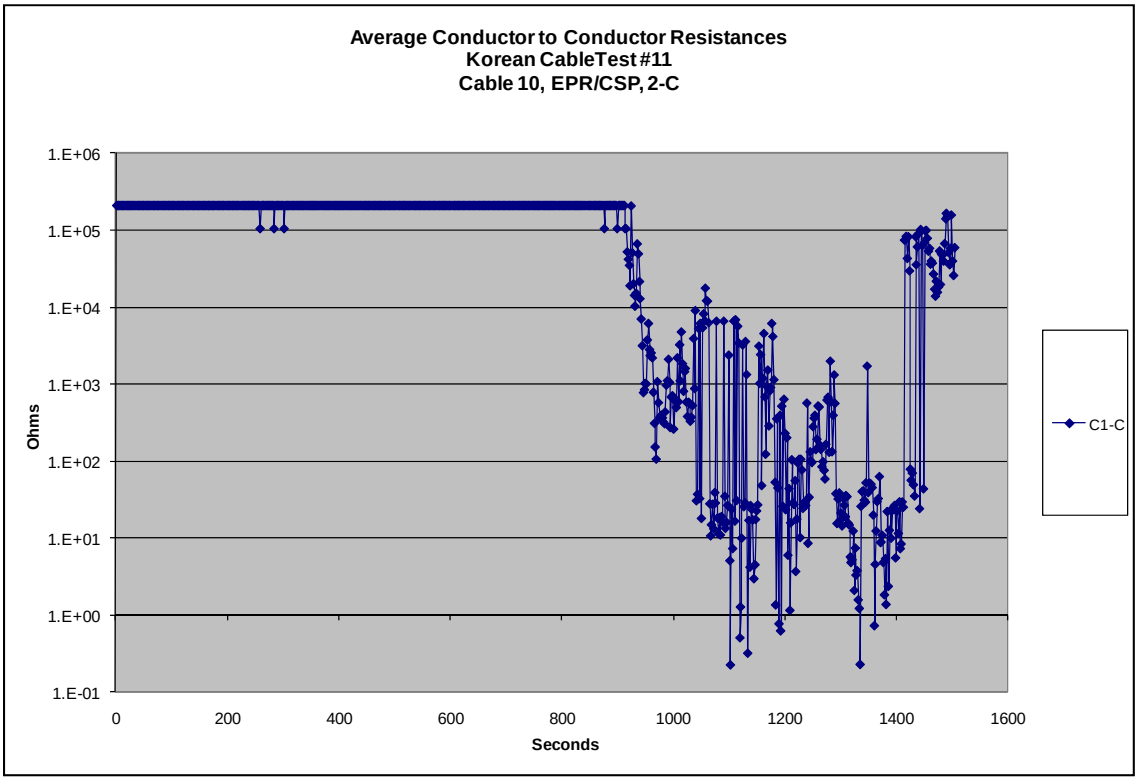
IRMS Channel	Test Cable
1	Black
2	White

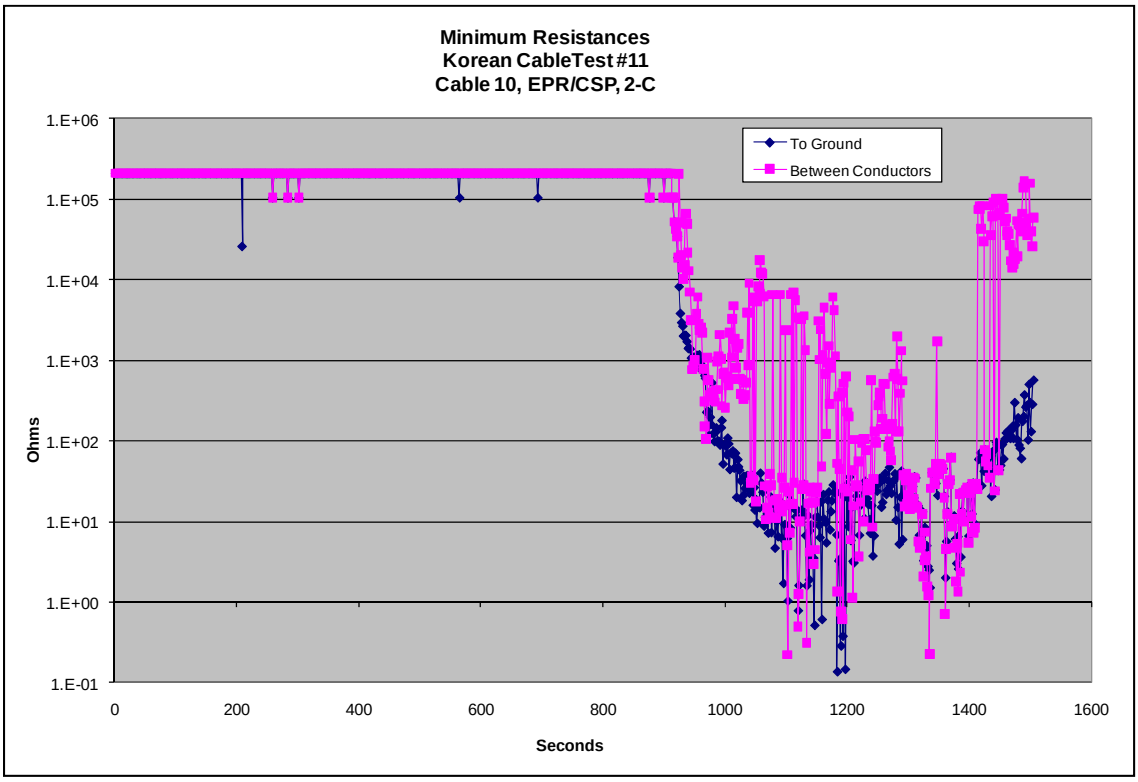
The Penlight shroud temperature was initially set at 440C and held at that value until electrical failure of the cable occurred.

Summary of Observed Faulting Behavior for Korean Cable Test #11		
Time (s)	**Event**	**Comments**
212	Penlight On; set at 440C (11.9 kW/m2)	
947	Conductor 1 shorts to conductor 2 at less than 1000 ohms	Initial failure is by conductor to conductor shorting; average cable temperature 545C at center
952	Conductor 1 shorts to ground at less than 1000 ohms	
968	Conductor 2 shorts to ground at less than 1000 ohms	All conductors are shorted to ground
983	Conductor 1 shorts to ground at less than 100 ohms	
1022	Conductor 2 shorts to ground at less than 100 ohms	
1042	Conductor 1 shorts to conductor 2 at less than 100 ohms	
Additional Notes		
	Cable thermocouple TC 1 did not perform as expected.	


Penlight and Cable Temperatures
Korean CableTest #11
Cable 10, EPR/CSP, 2-C
First cable
failure (957 s)
Shroud
TC 1
TC 2
TC 3
TC 4
Degrees-C
Seconds
0
100
200
300
400
500
600
700
0
500
1000
1500
2000
2500
3000


Average Conductor to Ground Resistances
Korean CableTest #11
Cable 10, EPR/CSP, 2-C
C1-G
C2-G
Ohms
Seconds
1.E-01
1.E+00
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
1.E+07
1.E+08
1.E+09
0
200
400
600
800
1000
1200
1400
1600


Average Conductor to Conductor Resistances
Korean CableTest #11
Cable 10, EPR/CSP, 2-C
Ohms
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
0
200
400
600
800
1000
1200
1400
1600
Seconds
C1-C

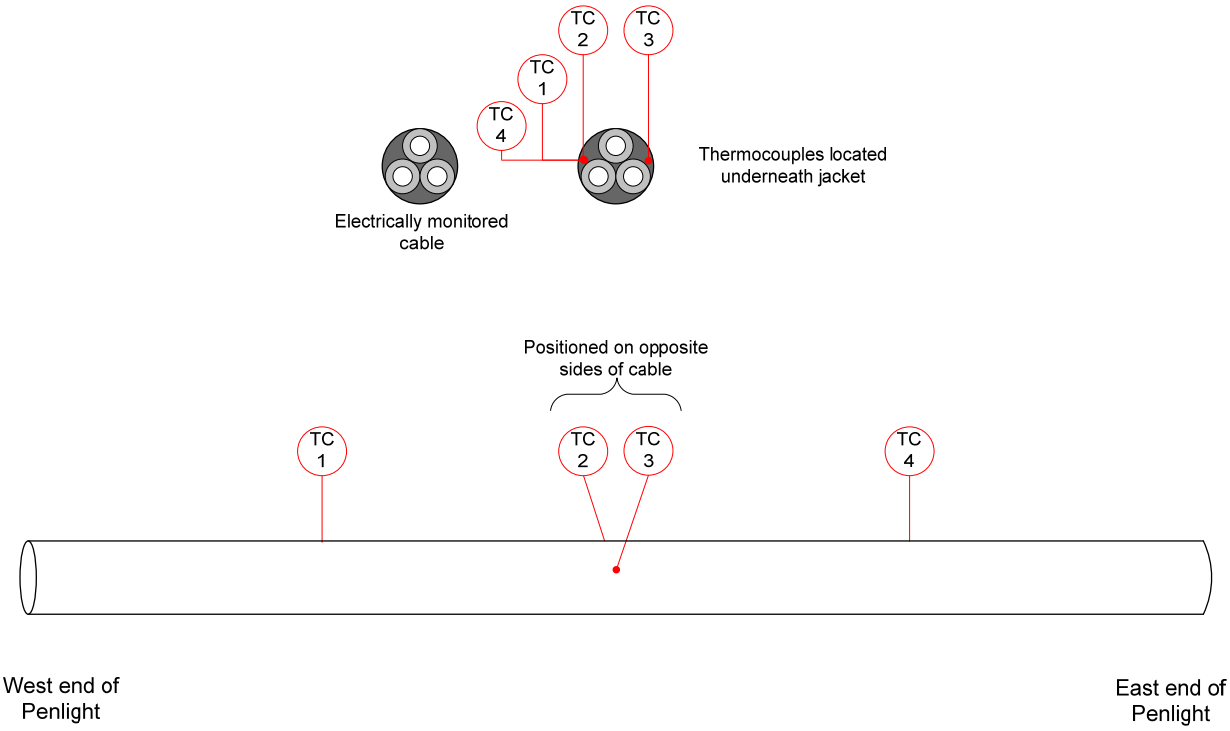

Minimum Resistances
Korean CableTest #11
Cable 10, EPR/CSP, 2-C
Ohms
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
0
200
400
600
800
1000
1200
1400
1600
Seconds
To Ground
Between Conductors

Korean Cable Test #12

Test conditions:

Cable: 3-conductor, 14 AWG, EPR insulated, CSP jacketed, power cable (Cable ID 13).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud set to temperature of 450C, nominal 12.6 kW/m^2 flux from shroud.
Electrical response monitoring: IRMS system using three channels - one for each insulated conductor. The cable tray was grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see maps).

Two cables were included in Test #12, one electrically monitored, one thermally monitored. The test cables had a black jacket and black, white, and red conductor insulation.

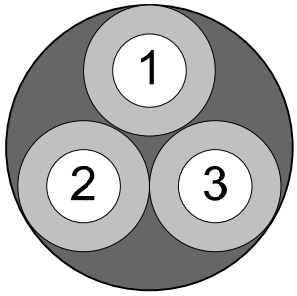


Map for placement of thermocouples inserted within the thermally monitored cable during Test #12.

Thermo-couple Name	Location
TC1	Within cable just below cable jacket, to the West of the center position
TC2	Within cable just below cable jacket, at center position
TC3	Within cable just below cable jacket, opposite side from Cable 2, center position

TC4	Within cable just below cable jacket, to the East of the center position

Three of the IRMS channels were connected to the electrically monitored test cable.

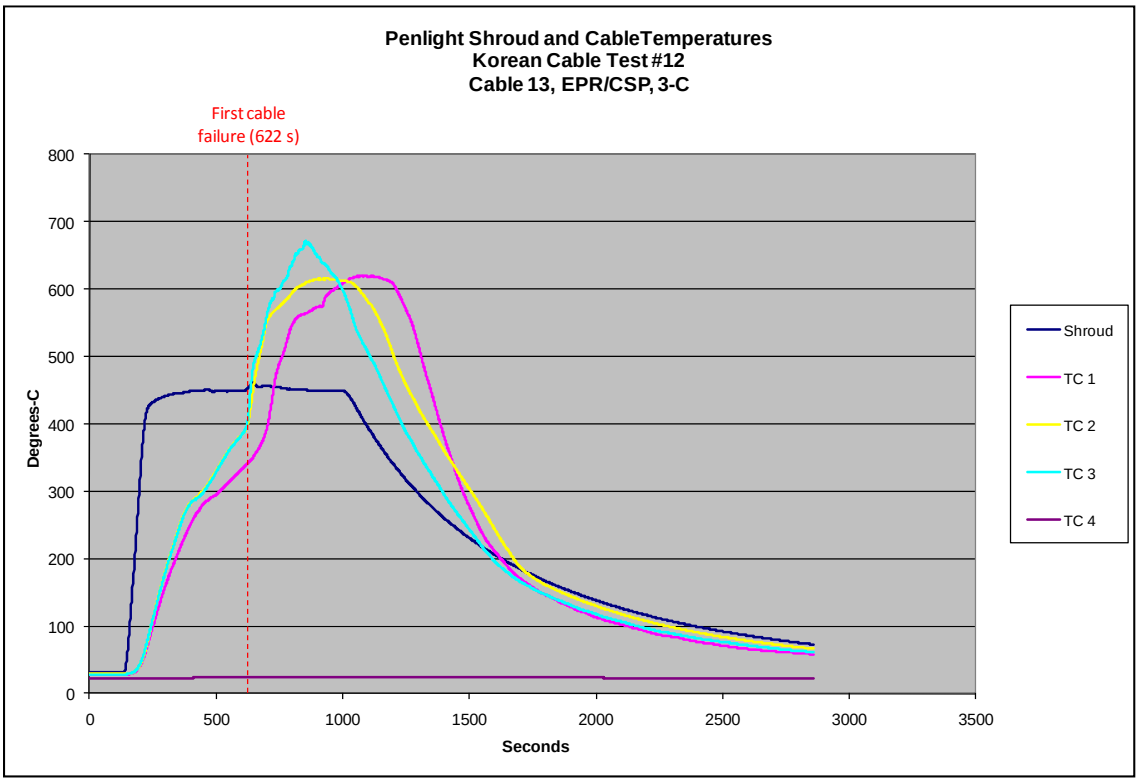


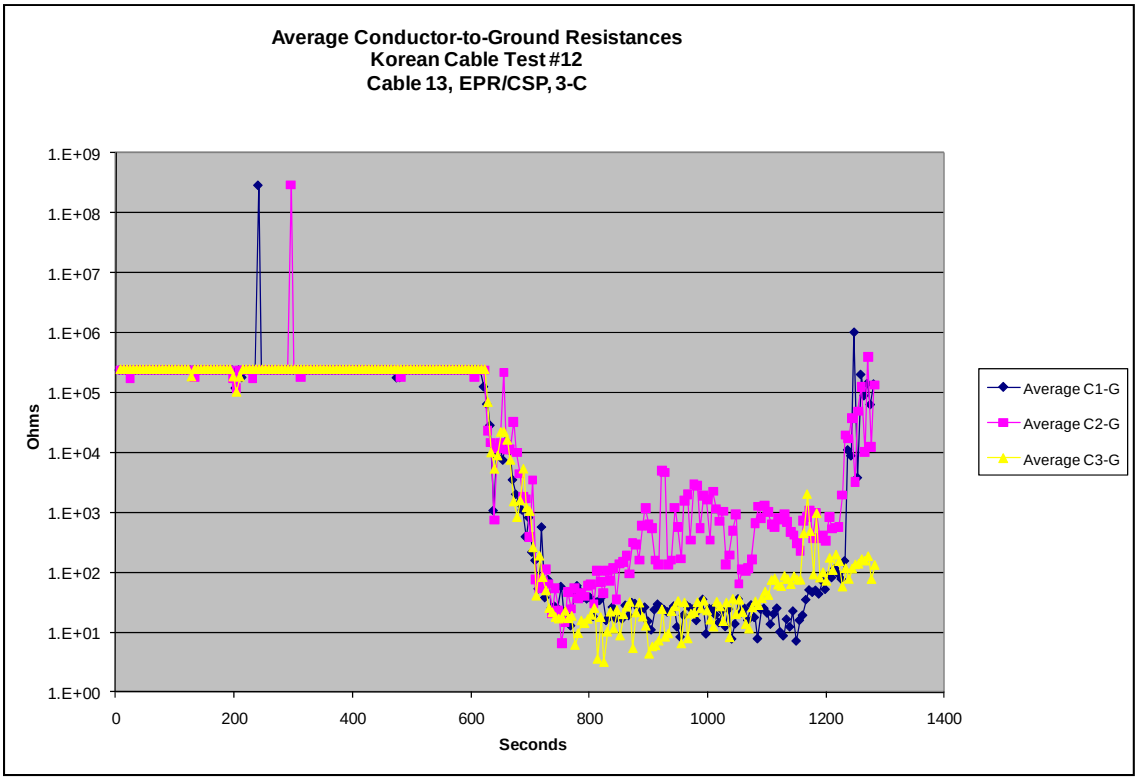
IRMS channel assignments for electrically monitored cable

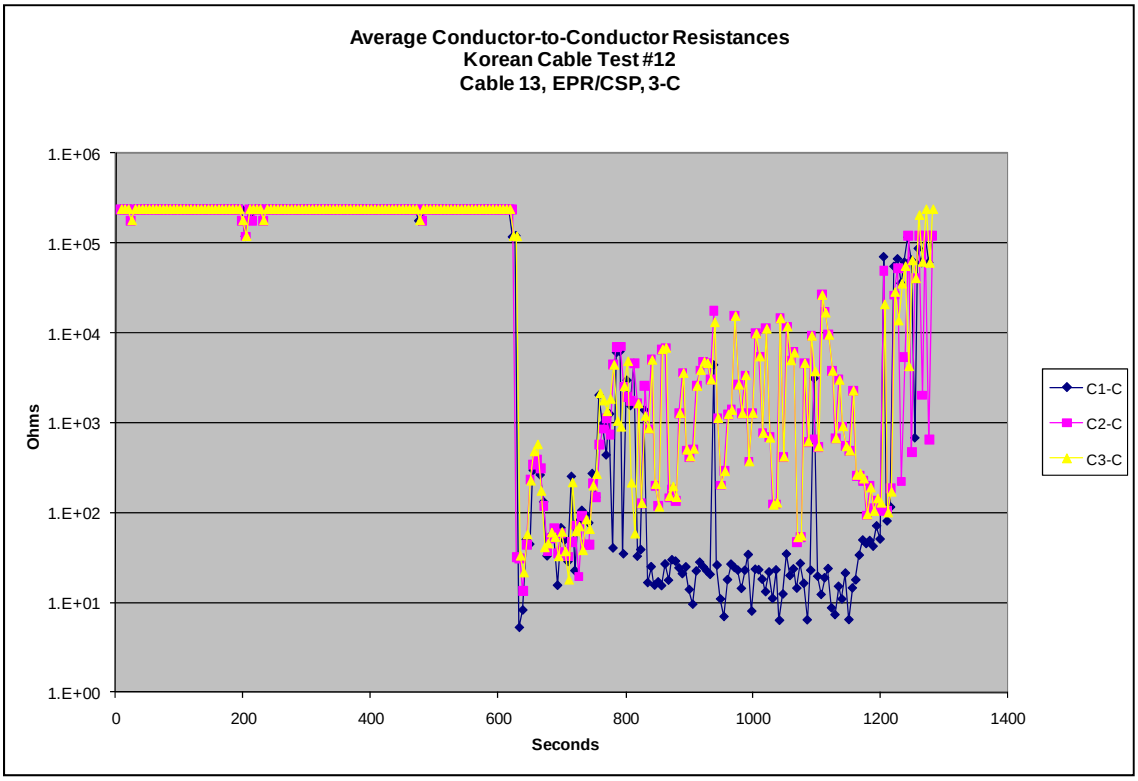
IRMS Channel	Test Cable
1	Black
2	White
3	Red

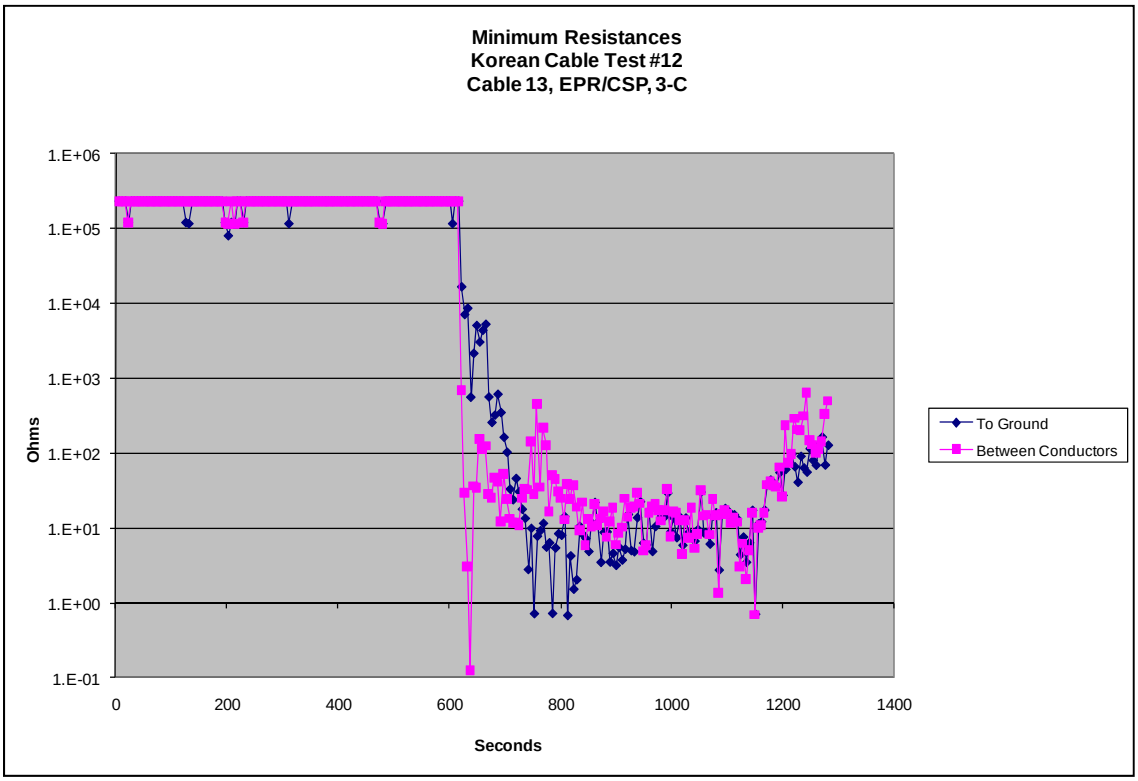
The Penlight shroud temperature was initially set at 450C and held at that value until electrical failure of the cable occurred.

Summary of Observed Faulting Behavior for Korean Cable Test #12		
Time (s)	**Event**	**Comments**
137	Penlight On; set at 450C (12.6 kW/m2)	
622	Conductor 1 shorts to conductor 3 at less than 1000 ohms.	Initial failure is by conductor-to-conductor shorting; average cable temperature is 398C at center.
626	Conductor 2 shorts to conductors 1 & 3 at less than 100 ohms	
634	Conductor 1 shorts to conductor 3 at less than 100 ohms.	
638	Conductors 1, 2 & 3 short to ground at less than 1000 ohms	All conductors are shorted to ground
Additional Observations		
	Cable thermocouple TC-4 did not perform as expected.	


Penlight Shroud and CableTemperatures
Korean Cable Test #12
Cable 13, EPR/CSP, 3-C
First cable failure (622 s)
Degrees-C
Seconds
Shroud
TC 1
TC 2
TC 3
TC 4


Average Conductor-to-Ground Resistances
Korean Cable Test #12
Cable 13, EPR/CSP, 3-C
Ohms
Seconds
Average C1-G
Average C2-G
Average C3-G


Average Conductor-to-Conductor Resistances
Korean Cable Test #12
Cable 13, EPR/CSP, 3-C
Ohms
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
0
200
400
600
800
1000
1200
1400
Seconds
C1-C
C2-C
C3-C

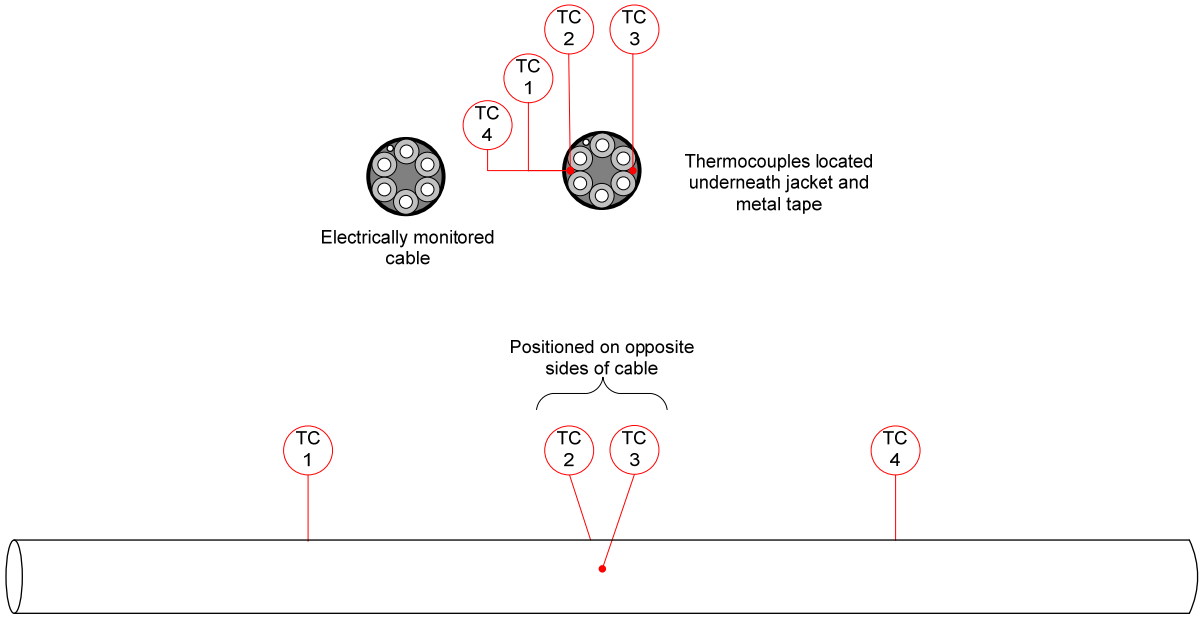

Minimum Resistances
Korean Cable Test #12
Cable 13, EPR/CSP, 3-C
Ohms
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
0
200
400
600
800
1000
1200
1400
Seconds
To Ground
Between Conductors

Korean Cable Test #13

Test conditions:

Cable: 6-conductor, 16 AWG, EPR insulated, CSP jacketed, instrument cable (Cable ID 1).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud initially set to temperature of 450C, nominal 12.6 kW/m^2 flux from shroud.
Electrical response monitoring: SCDU system using seven circuit paths - one for each insulated conductor and the uninsulated drain wire, the cable tray was grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see thermocouple map).

Two cables were included in Test #13, one electrically monitored, one thermally monitored. The cable had a blue jacket and white conductor insulation with printed numbers. A metal tape surrounded the conductor bundle and was connected to the CPT ground during the test.

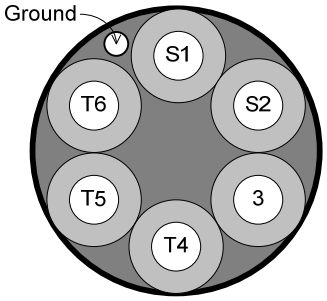


Map for placement of thermocouples inserted within the thermally monitored cable during Test #13.

Thermo-couple Name	Location

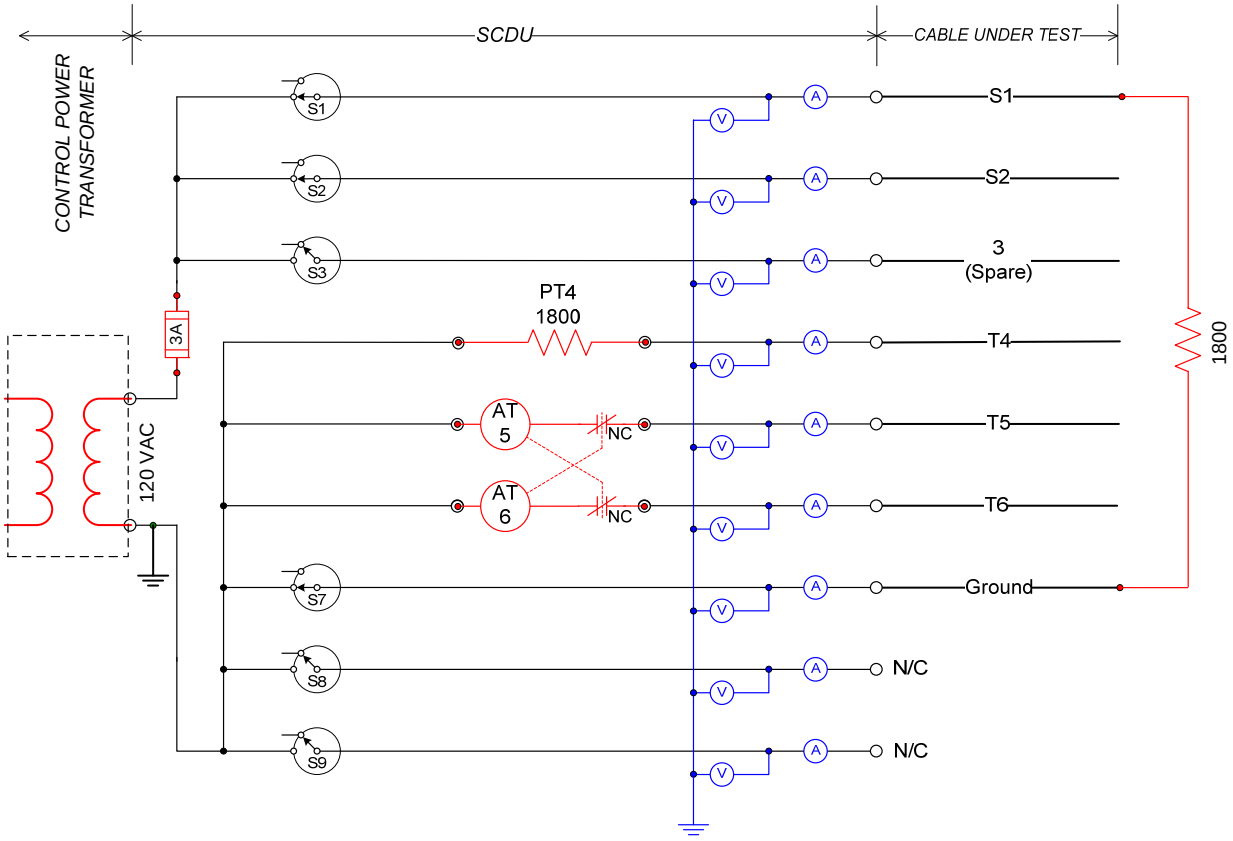
TC1	Within cable just below cable jacket and metal tape, to the West of the center position
TC2	Within cable just below cable jacket and metal tape, at center position
TC3	Within cable just below cable jacket and metal tape, opposite side from Cable 2, center position
TC4	Within cable just below cable jacket and metal tape, to the East of the center position

All of the seven available SCDU circuit paths were connected to the electrically monitored test cable.



SCDU channel assignments for electrically monitored cable

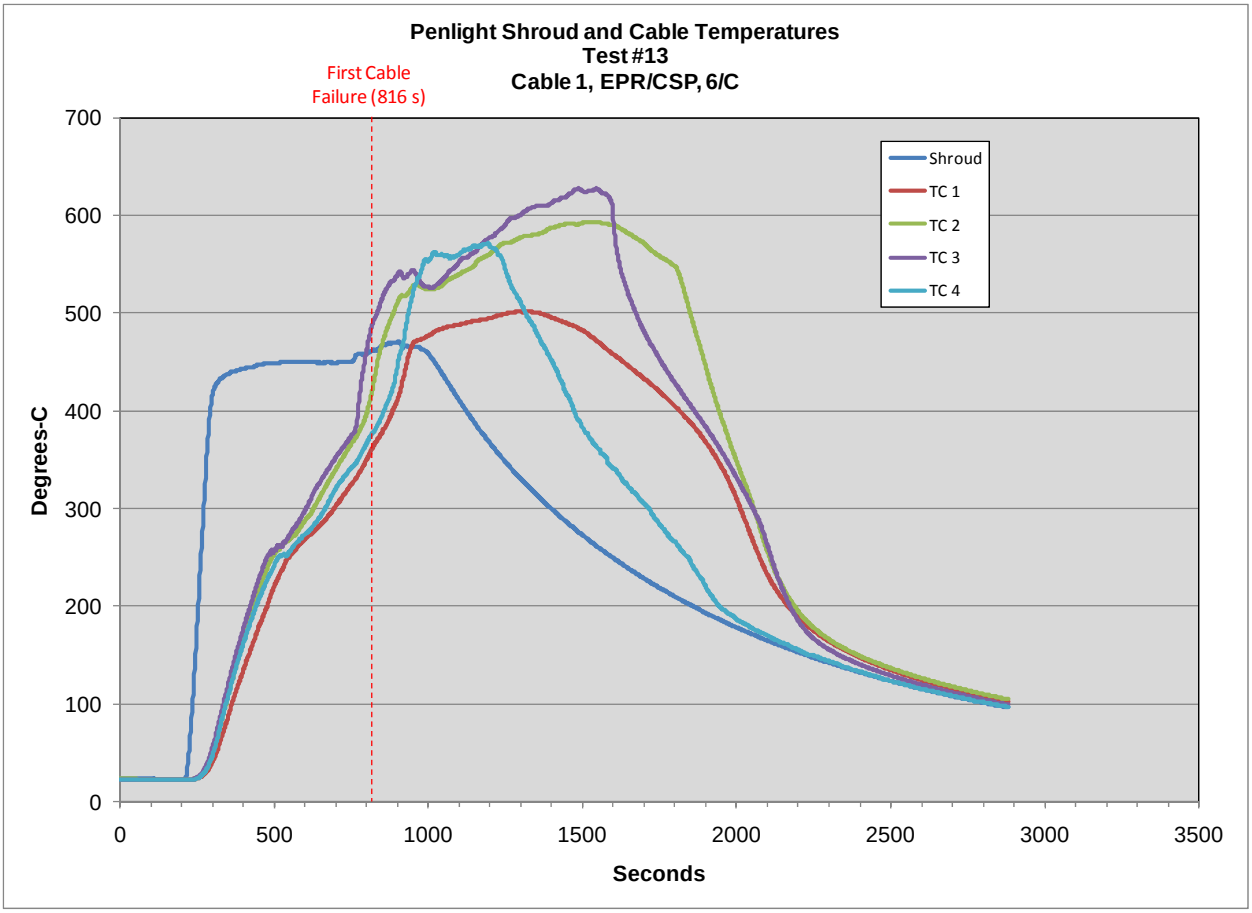
SCDU Channel	Test Cable
S1	Black
S2	White
3 (Spare)	Red
T4	Green
T5	Orange
T6	Blue
Ground	Drain wire

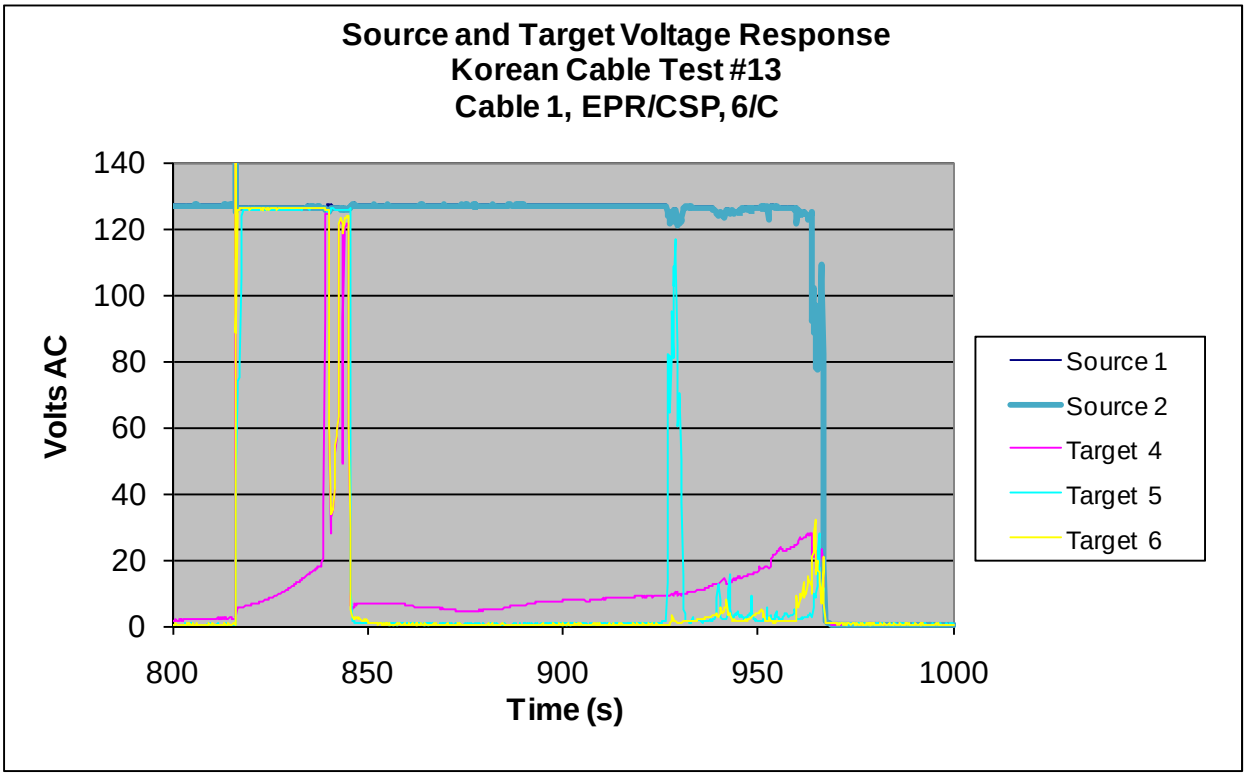


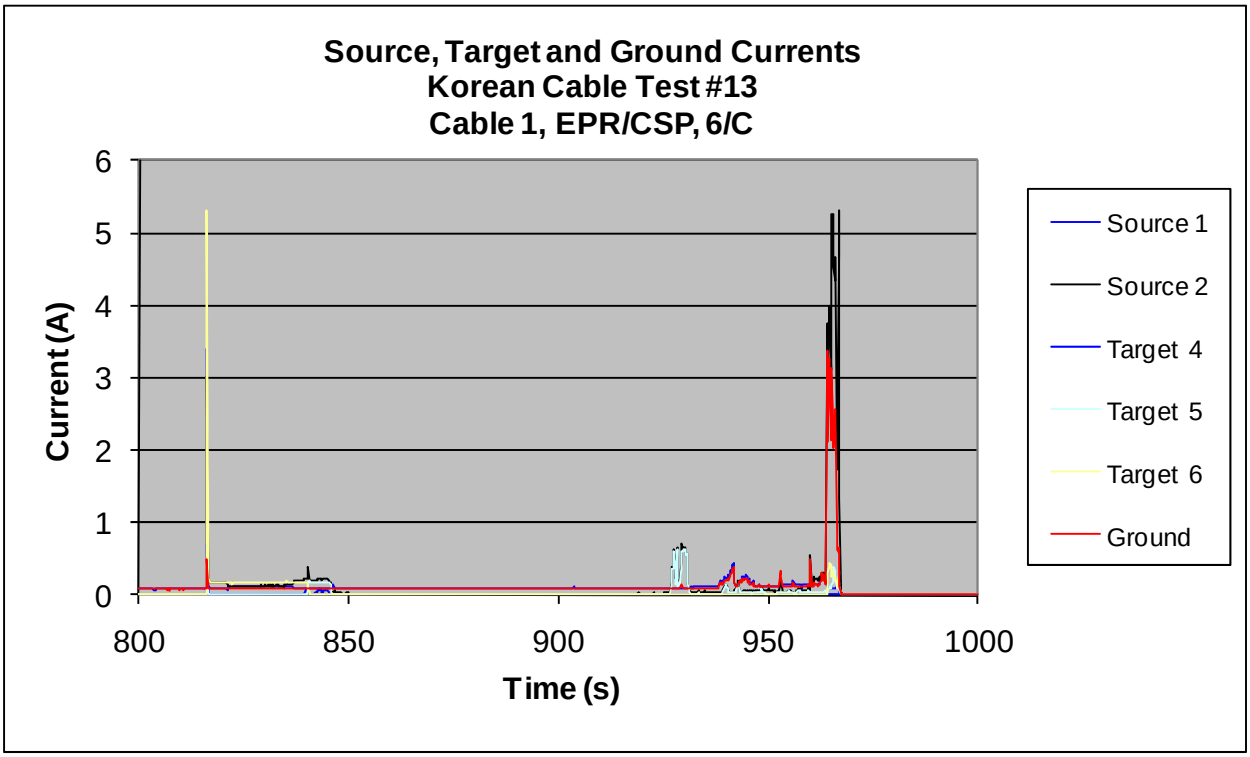
Cable conductor connections to SCDU during Test #13

The Penlight shroud temperature was initially set at 450C and held at that value until electrical failure of the cable occurred.

Summary of Observed Faulting Behavior during Korean Cable Test #13		
Time (s)	**Event**	**Comments**
213	Penlight On; set at 450C (12.6 kW/m2)	
816-840	Spurious actuation of T6 due to hot short from S2	Initial failure manifest as a spurious actuation due to hot short (24 s duration); 451C average cable temperature
817	Hot short on T5 from S2	No spurious actuation because T5 is locked out by T6
839-840	Hot short on T4 from S2	
840-846	Spurious actuation of T5 due to hot short from S2	
842-845	Hot short on T6 from S2	No spurious actuation because T6 is locked out by T5
843-845	Hot shorts on T4 from S2	
927-931	T5 coil chattering	Insufficient voltage for coil pickup
939-943	T5 coil chattering	
964-967	T5 & T6 coils chattering	
967	Fuse clears	


Penlight Shroud and Cable Temperatures
Test #13
Cable 1, EPR/CSP, 6/C
First Cable
Failure (816 s)
Shroud
TC 1
TC 2
TC 3
TC 4
Degrees-C
Seconds
0
100
200
300
400
500
600
700
0
500
1000
1500
2000
2500
3000
3500


Source and Target Voltage Response
Korean Cable Test #13
Cable 1, EPR/CSP, 6/C
Volts AC
140
120
100
80
60
40
20
0
800
850
900
950
1000
Time (s)
Source 1
Source 2
Target 4
Target 5
Target 6

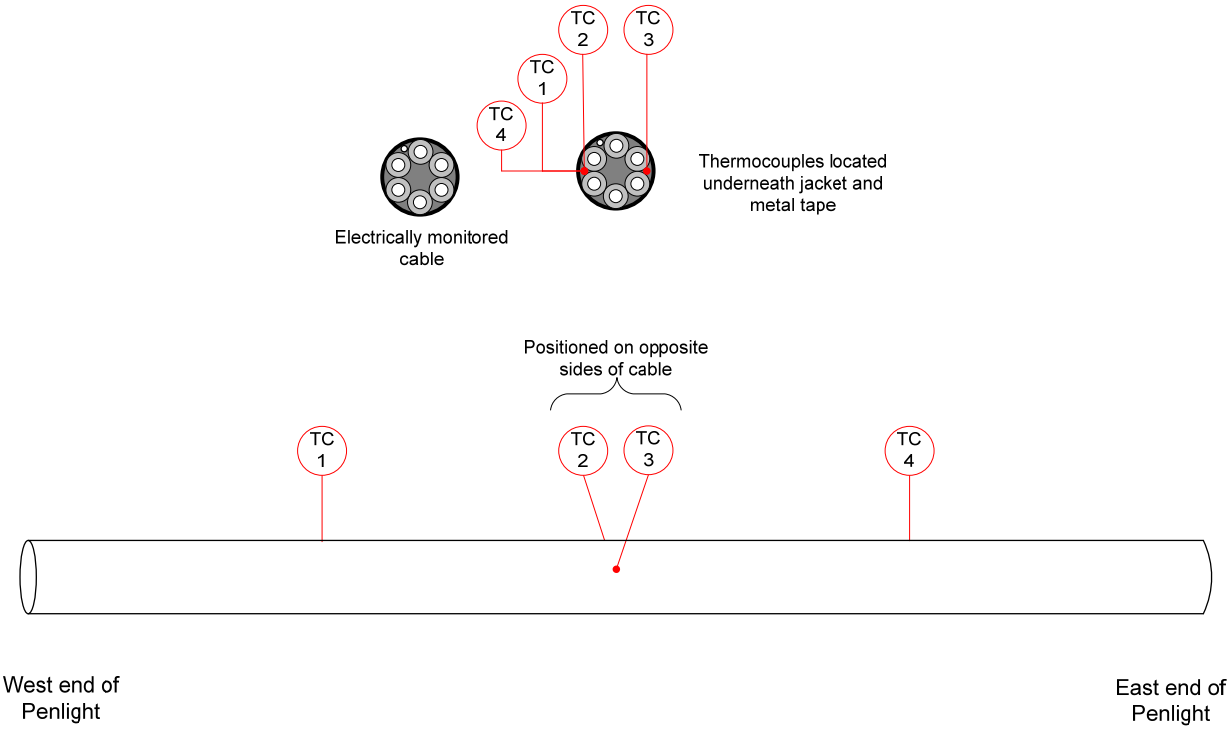

Source, Target and Ground Currents
Korean Cable Test #13
Cable 1, EPR/CSP, 6/C
Current (A)
6
5
4
3
2
1
0
800
850
900
950
1000
Time (s)
Source 1
Source 2
Target 4
Target 5
Target 6
Ground

Korean Cable Test #14

Test conditions:

Cable: 6-conductor, 16 AWG, EPR insulated, CSP jacketed, instrument cable (Cable ID 1).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud initially set to temperature of 450C, nominal 12.6 kW/m^2 flux from shroud.
Electrical response monitoring: SCDU system using seven circuit paths - one for each insulated conductor and the uninsulated drain wire, the cable tray was grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see thermocouple map).

Two cables were included in Test #14, one electrically monitored, one thermally monitored. The cable had a blue jacket and white conductor insulation with printed numbers. A metal tape surrounded the conductor bundle and was connected to the CPT ground during the test.

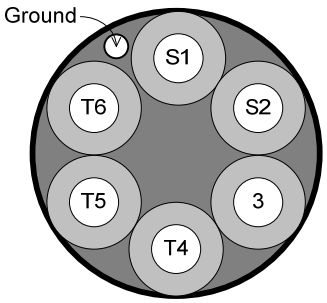


Map for placement of thermocouples inserted within the thermally monitored cable during Test #14.

Thermo-couple Name	Location
TC1	Within cable just below cable jacket and metal tape, to the West of the center position
TC2	Within cable just below cable jacket and metal tape, at center position
TC3	Within cable just below cable jacket and metal tape, opposite side from Cable 2, center position

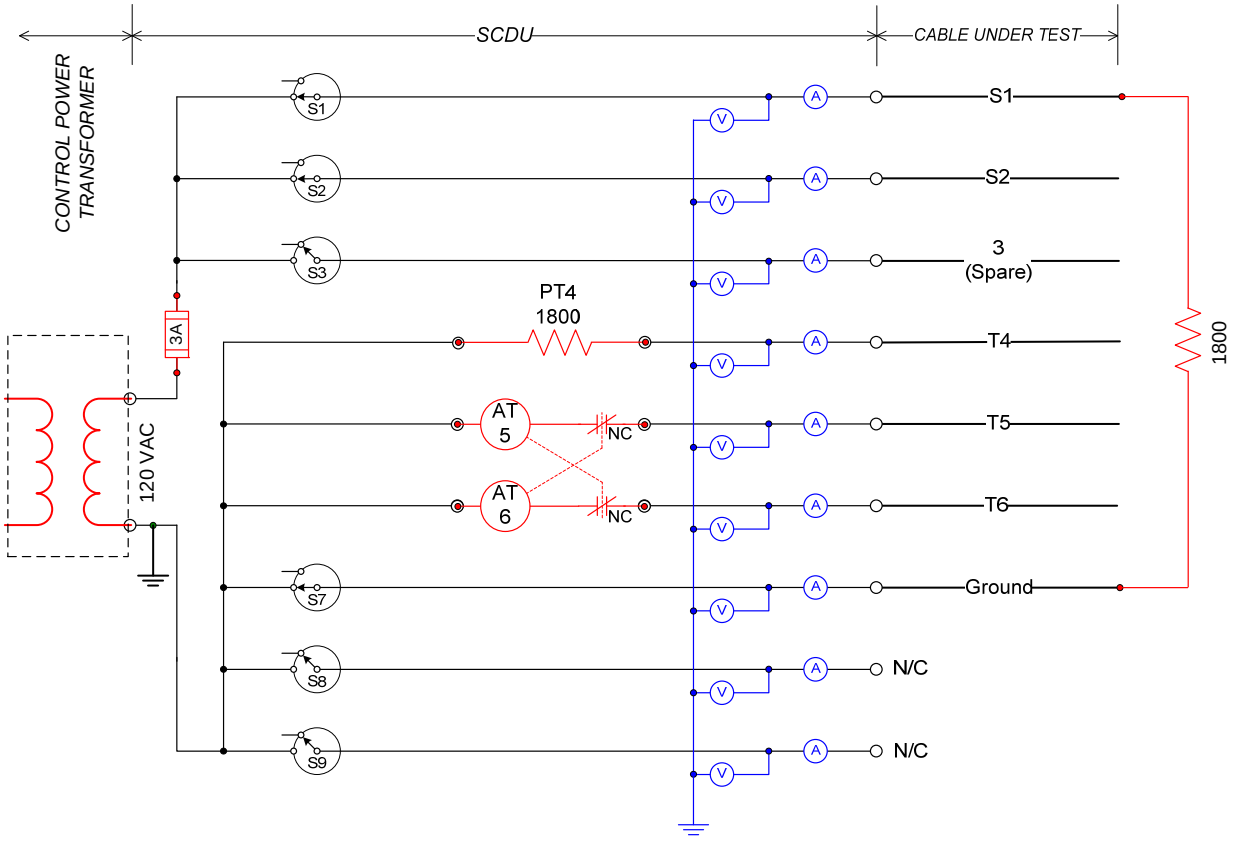
TC4	Within cable just below cable jacket and metal tape, to the East of the center position

All of the seven available SCDU circuit paths were connected to the electrically monitored test cable.



SCDU channel assignments for electrically monitored cable

SCDU Channel	Test Cable
S1	Black
S2	White
3 (Spare)	Red
T4	Green
T5	Orange
T6	Blue
Ground	Drain wire

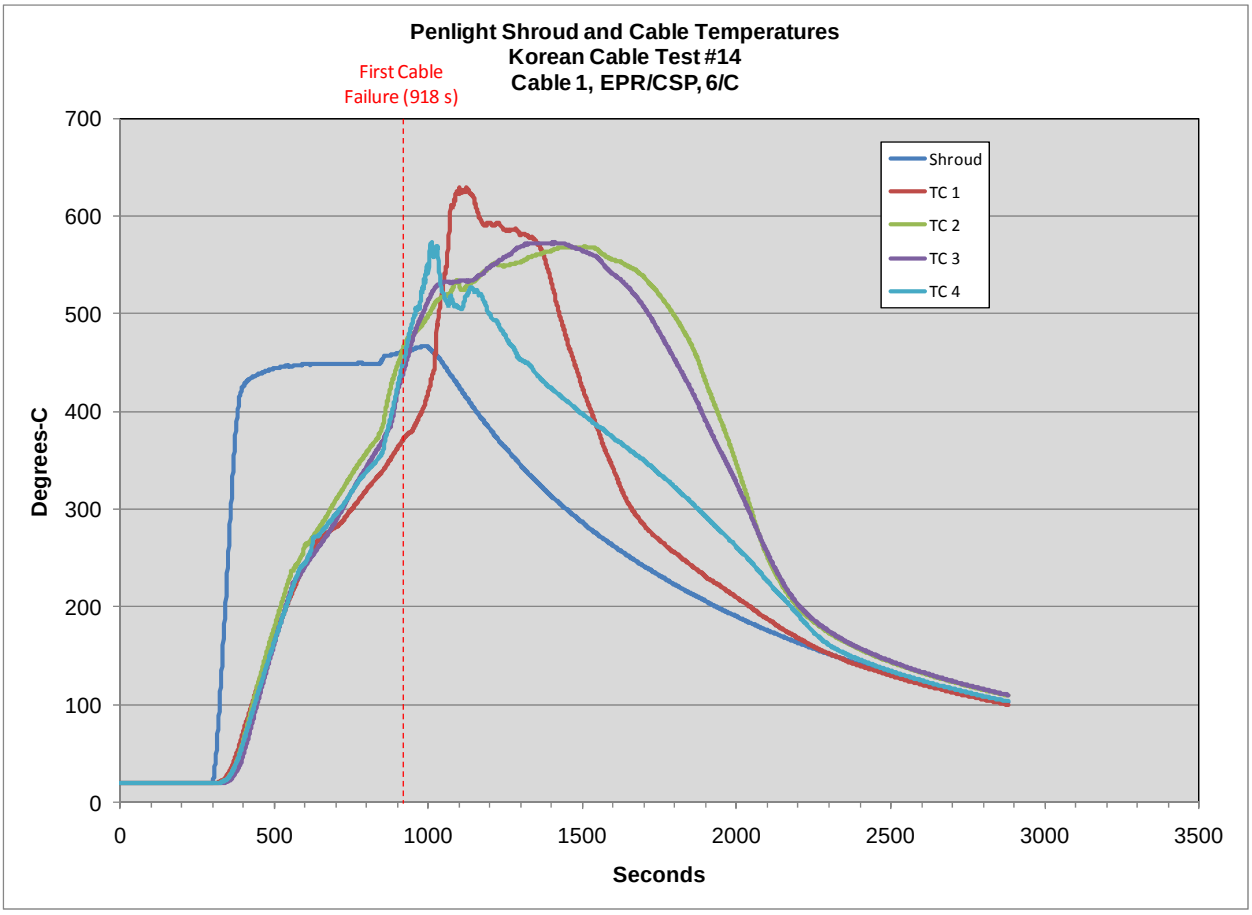


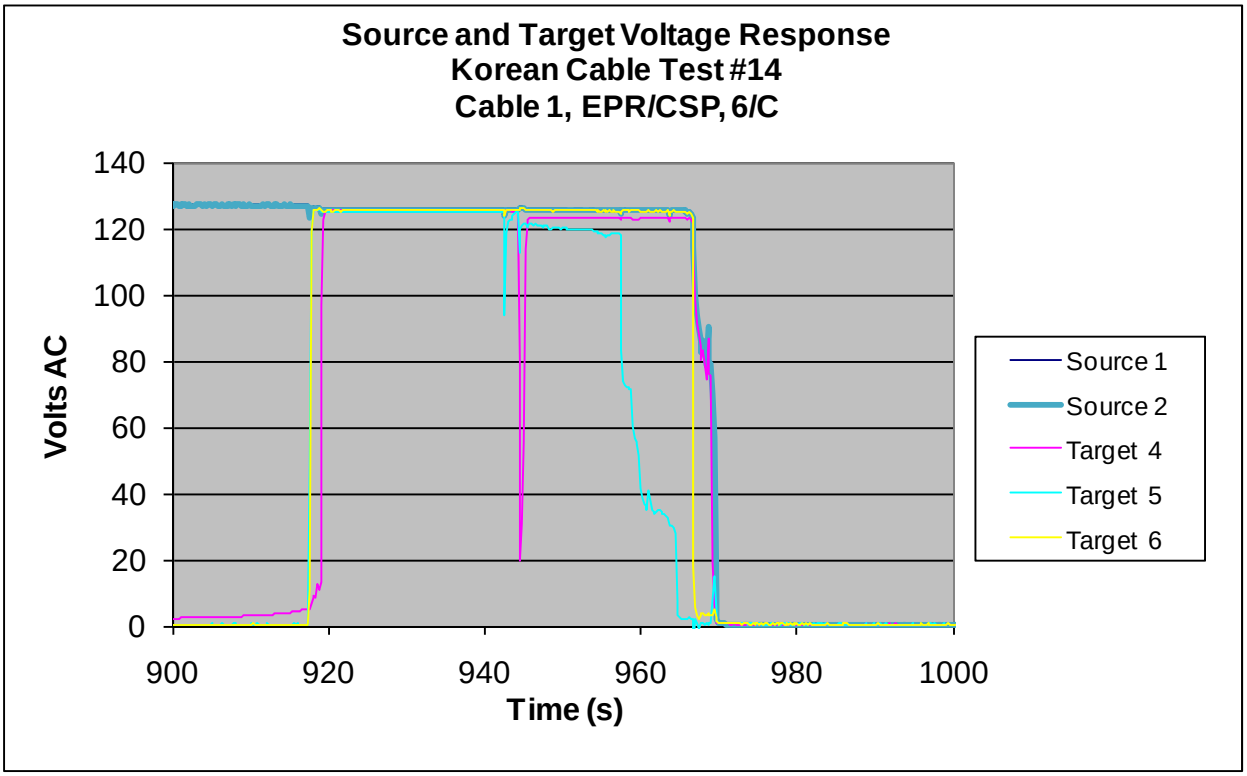
Cable conductor connections to SCDU during Test #14

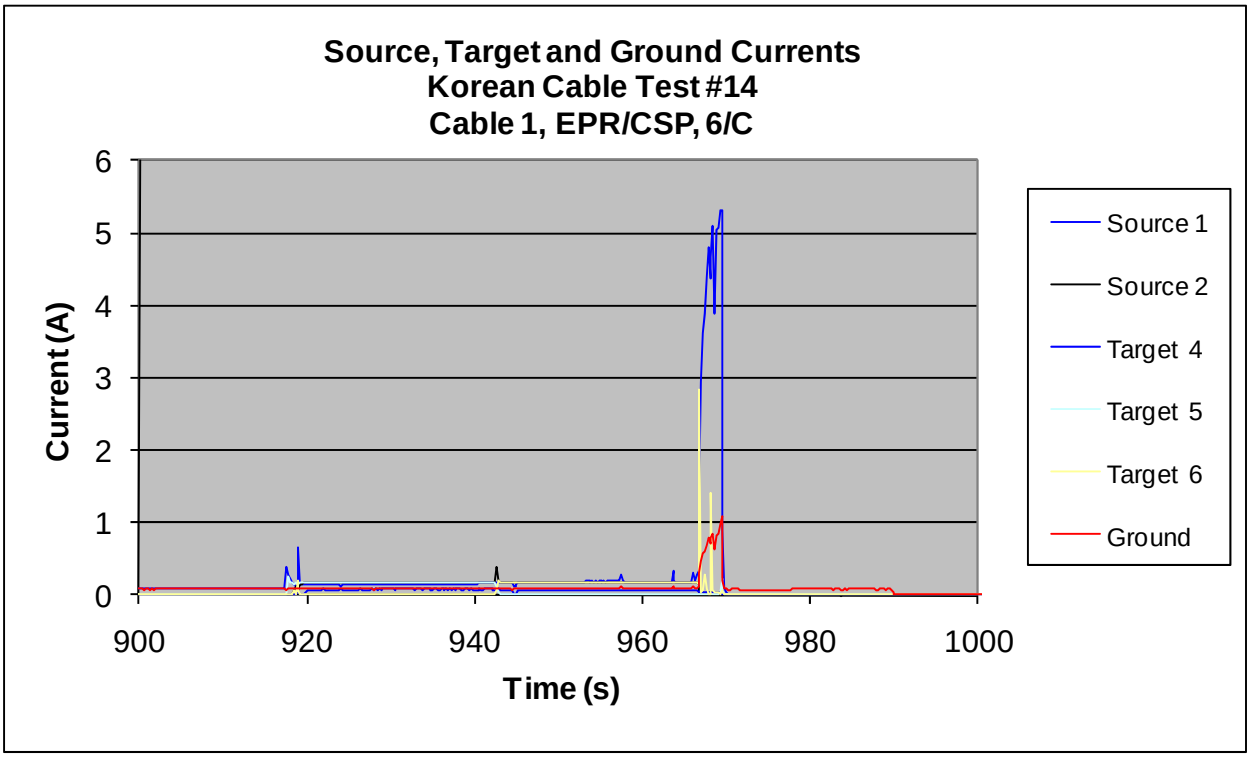
The Penlight shroud temperature was initially set at 450C and held at that value until electrical failure of the cable occurred.

Summary of Observed Faulting Behavior during Korean Cable Test #14		
Time (s)	**Event**	**Comments**
300	Penlight On; set at 450C (12.6 kW/m2)	
918-919	Spurious actuation of T5 due to hot short from S1	Initial failure manifest as a spurious actuation due to hot short (1 s duration); 451C average cable temperature
918-943	Hot short on T6	No spurious actuation because T6 is locked out by T5
919-920	Spurious actuation of T5 due to hot short from S1 & S2	
919-944	Hot short on T4	
920-943	Spurious actuation of T5 due to hot short from S2	
943-967	Spurious actuation of T6 due to hot short from S2	
943-957	Hot short on T5	No spurious actuation because T5 is locked out by T6
945-967	Hot short on T4	

970	Fuse clears	




Source and Target Voltage Response
Korean Cable Test #14
Cable 1, EPR/CSP, 6/C
Volts AC
140
120
100
80
60
40
20
0
900
920
940
960
980
1000
Time (s)
Source 1
Source 2
Target 4
Target 5
Target 6

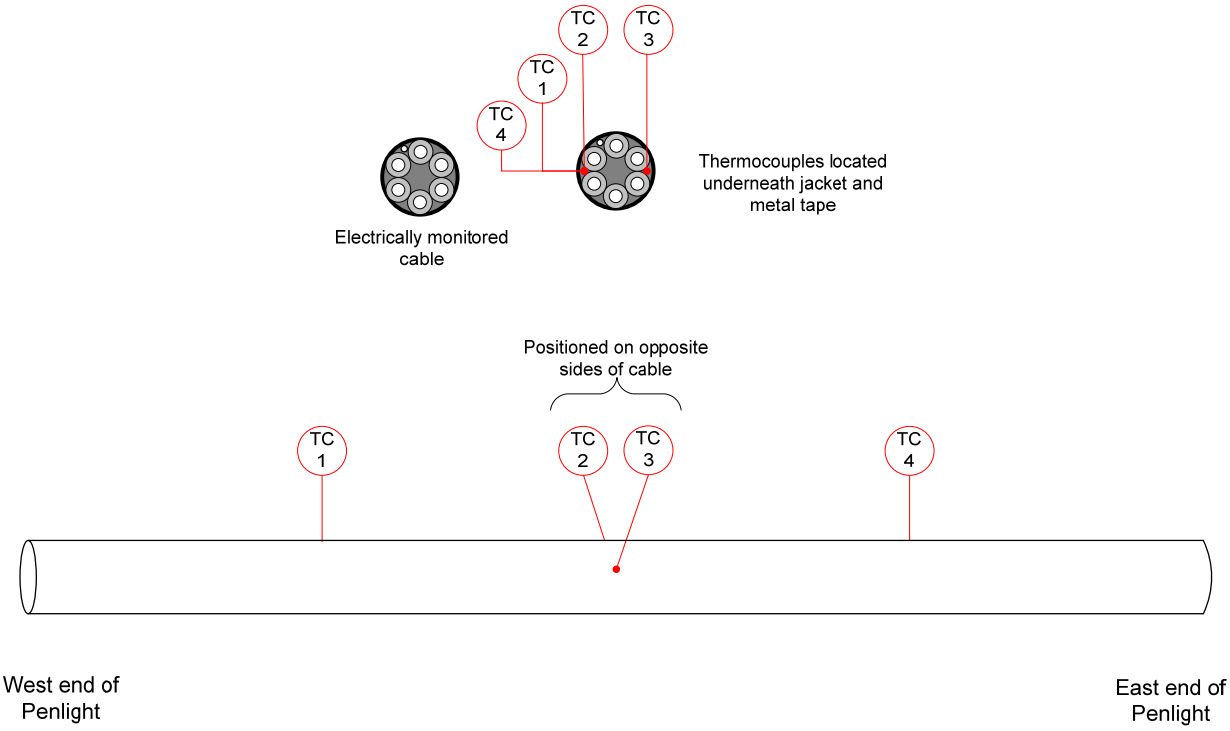

Source, Target and Ground Currents
Korean Cable Test #14
Cable 1, EPR/CSP, 6/C
Current (A)
6
5
4
3
2
1
0
900
920
940
960
980
1000
Time (s)
Source 1
Source 2
Target 4
Target 5
Target 6
Ground

Korean Cable Test #15

Test conditions:

Cable: 6-conductor, 16 AWG, EPR insulated, CSP jacketed, instrument cable (Cable ID 1).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud initially set to temperature of 450C, nominal 12.6 kW/m^2 flux from shroud.
Electrical response monitoring: SCDU system using seven circuit paths - one for each insulated conductor and the uninsulated drain wire, the cable tray was grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see thermocouple map).

Two cables were included in Test #15, one electrically monitored, one thermally monitored. The cable had a blue jacket and white conductor insulation with printed numbers. A metal tape surrounded the conductor bundle and was connected to the CPT ground during the test.

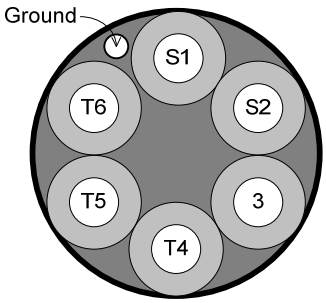


Map for placement of thermocouples inserted within the thermally monitored cable during Test #15.

Thermo-couple Name	Location
TC1	Within cable just below cable jacket and metal tape, to the West of the center position
TC2	Within cable just below cable jacket and metal tape, at center position
TC3	Within cable just below cable jacket and metal tape, opposite side from Cable 2, center position

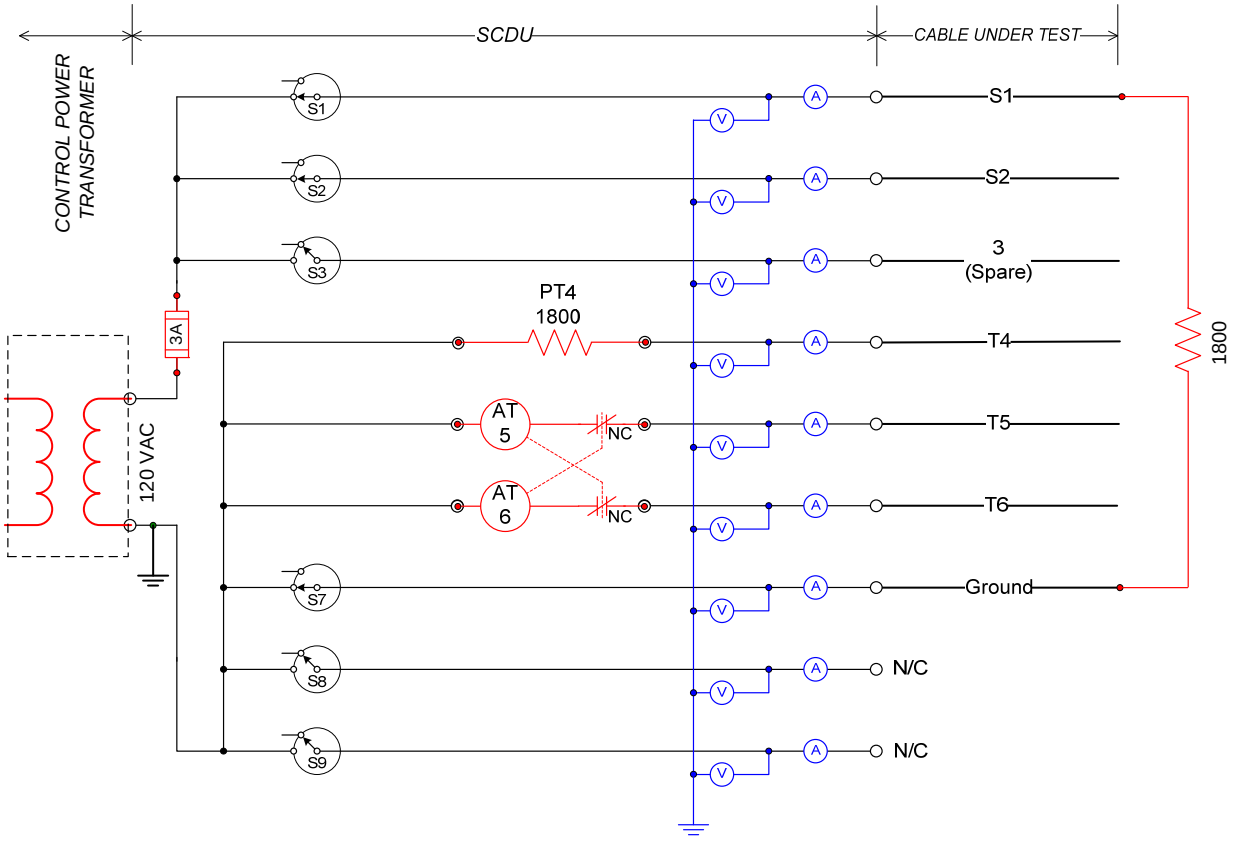
TC4	Within cable just below cable jacket and metal tape, to the East of the center position

All of the seven available SCDU circuit paths were connected to the electrically monitored test cable.



SCDU channel assignments for electrically monitored cable

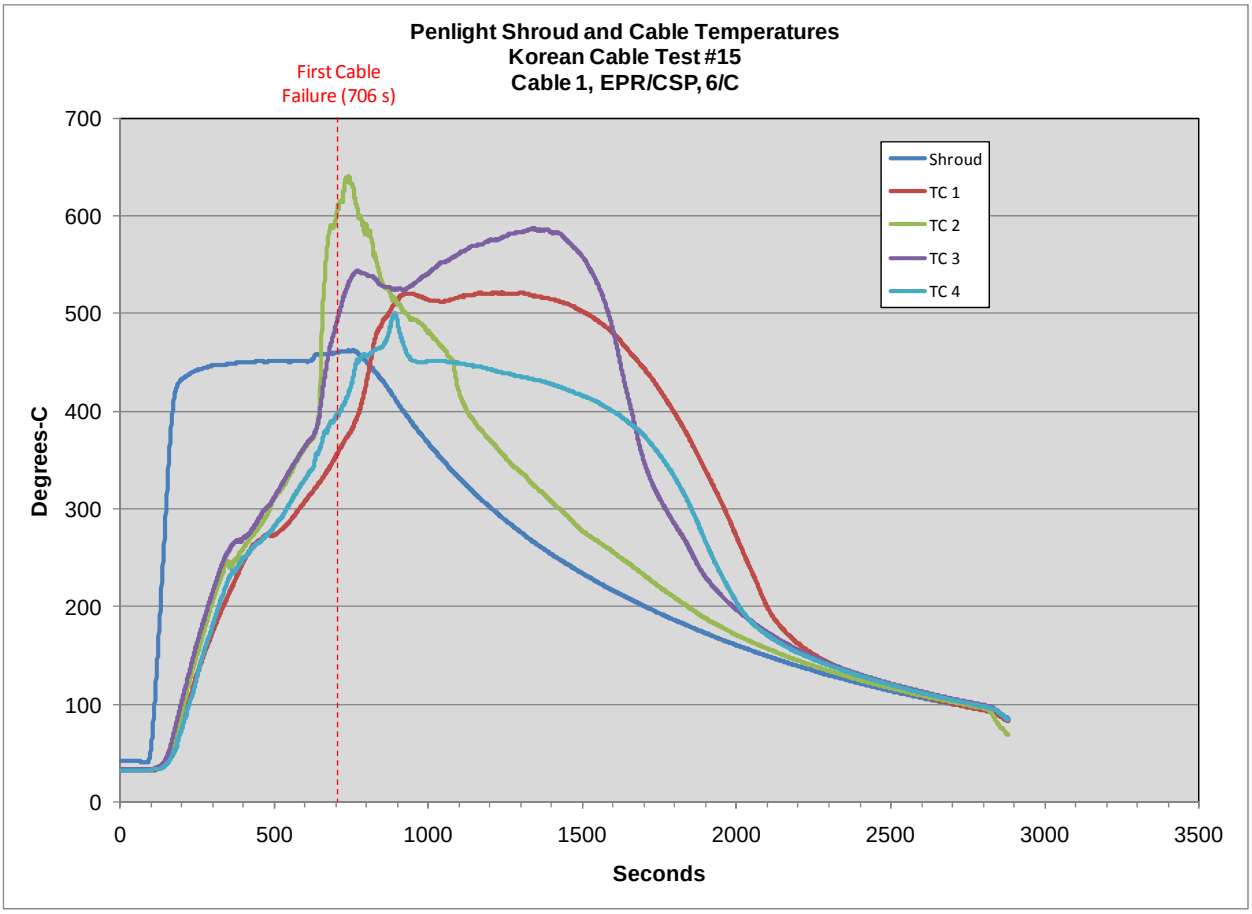
SCDU Channel	Test Cable
S1	Black
S2	White
3 (Spare)	Red
T4	Green
T5	Orange
T6	Blue
Ground	Drain wire

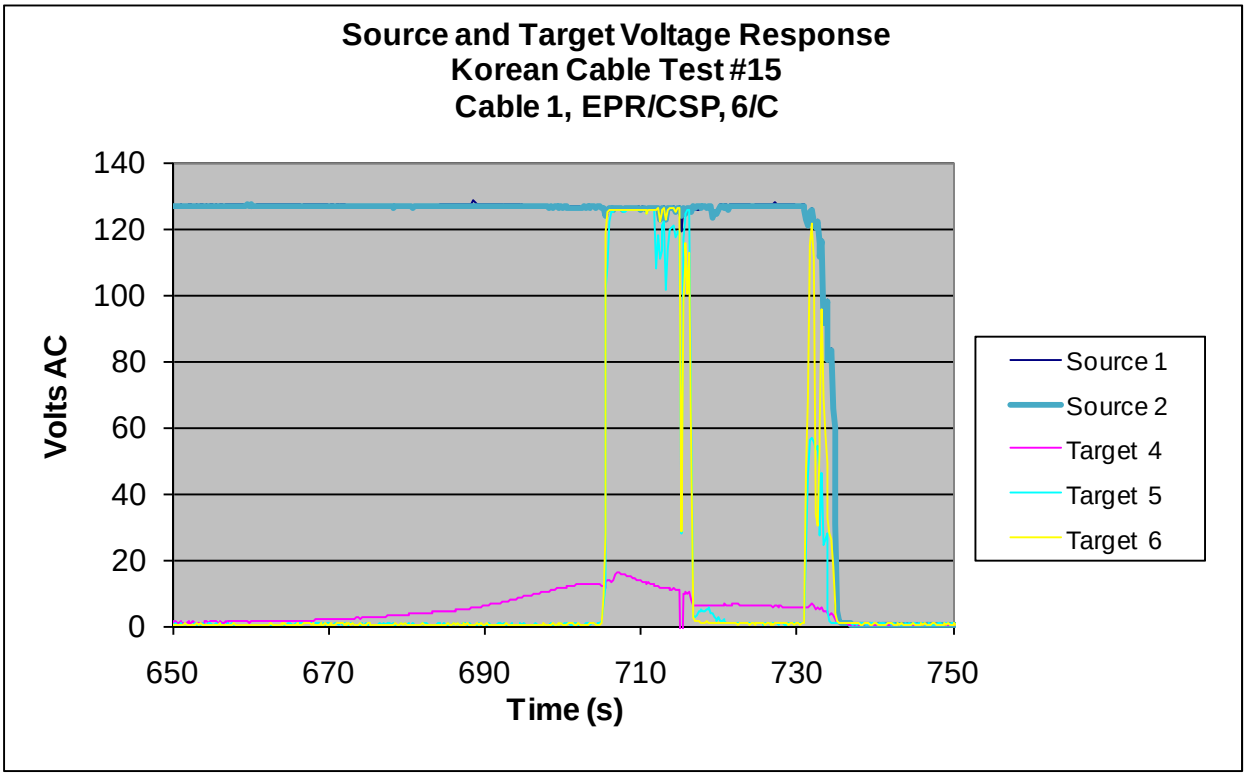


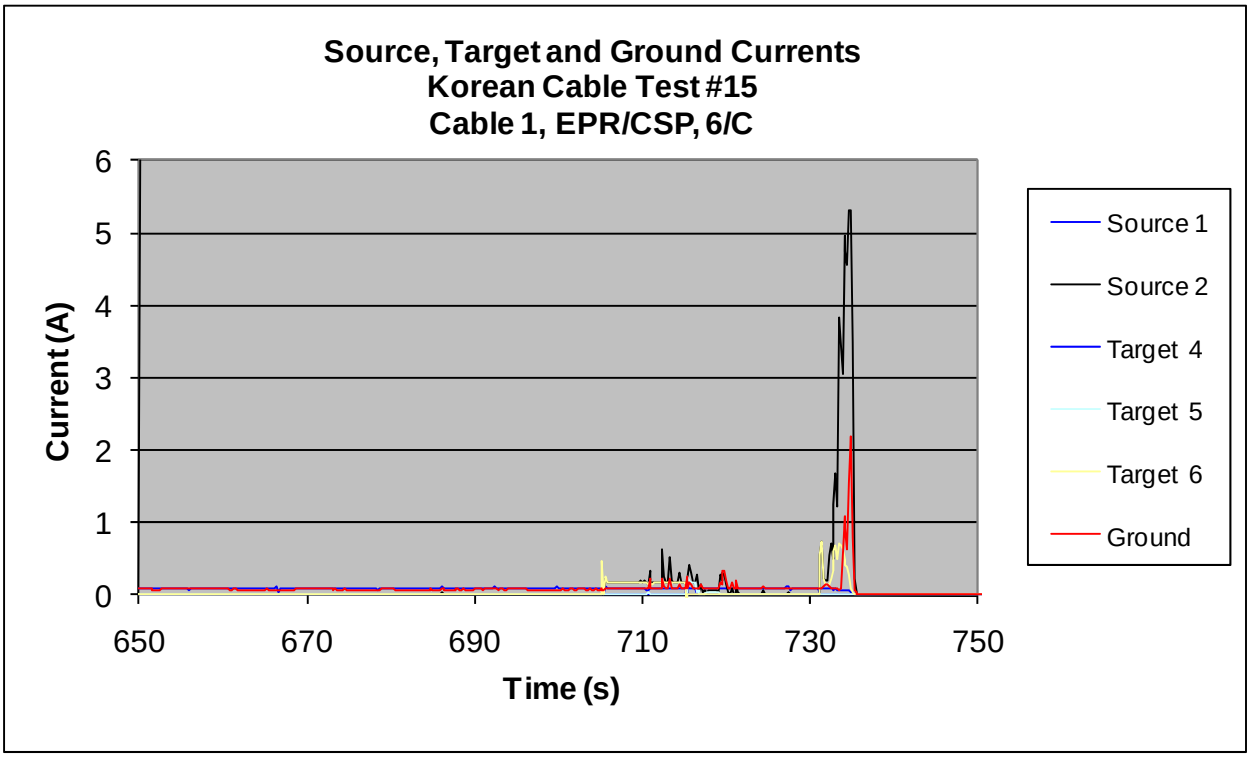
Cable conductor connections to SCDU during Test #15

The Penlight shroud temperature was initially set at 450C and held at that value until electrical failure of the cable occurred.

Summary of Observed Faulting Behavior during Korean Cable Test #15		
Time (s)	**Event**	**Comments**
93	Penlight On; set at 450C (12.6 kW/m2)	
706-715	Spurious actuation of T6 due to hot short from S2	Initial failure manifest as a spurious actuation due to hot short (9 s duration); 495C cable temperature (TC-3)
706-715	Hot short on T5	No spurious actuation because T5 is locked out by T6
715-716	Spurious actuation of T5 due to hot short from S2	
715-716	Hot short on T6	No spurious actuation because T6 is locked out by T5
731-735	T6 chattering	
735	Fuse clears	


Penlight Shroud and Cable Temperatures
Korean Cable Test #15
Cable 1, EPR/CSP, 6/C
First Cable Failure (706 s)
Shroud
TC 1
TC 2
TC 3
TC 4
Degrees-C
Seconds
0
100
200
300
400
500
600
700
0
500
1000
1500
2000
2500
3000
3500


Source and Target Voltage Response
Korean Cable Test #15
Cable 1, EPR/CSP, 6/C
Volts AC
140
120
100
80
60
40
20
0
650
670
690
710
730
750
Time (s)
Source 1
Source 2
Target 4
Target 5
Target 6

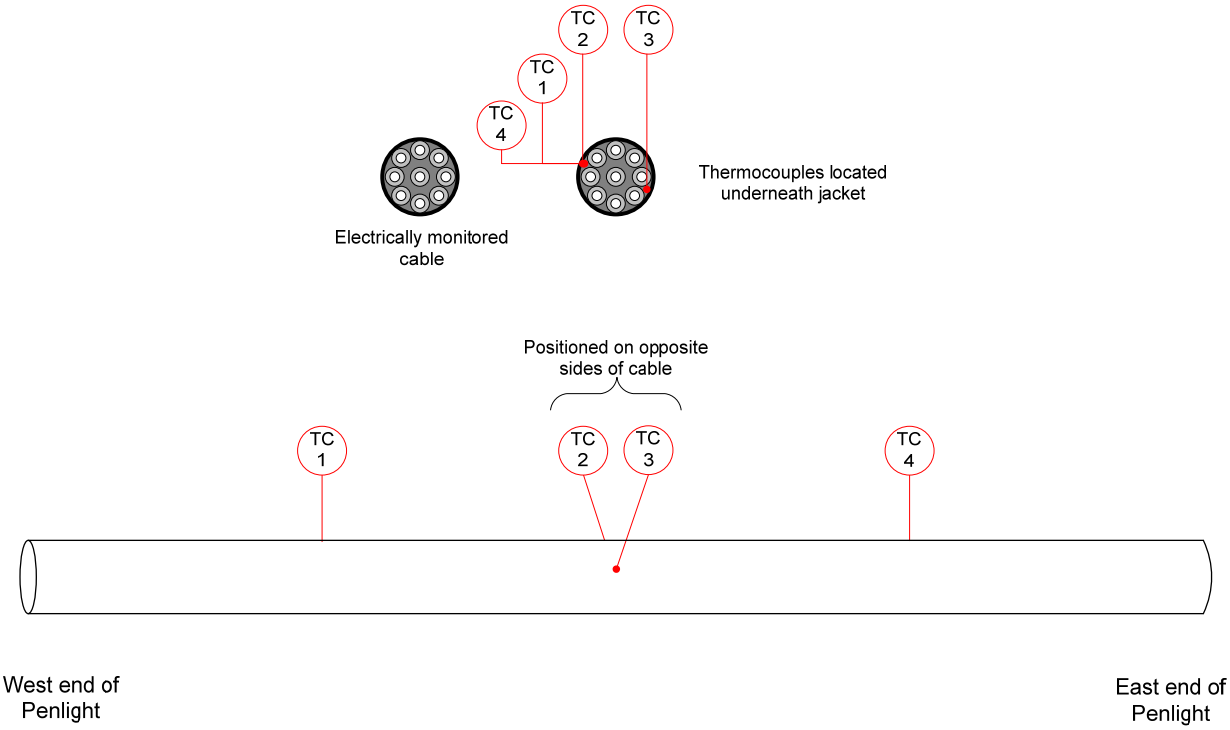

Source, Target and Ground Currents
Korean Cable Test #15
Cable 1, EPR/CSP, 6/C
Current (A)
6
5
4
3
2
1
0
650
670
690
710
730
750
Time (s)
Source 1
Source 2
Target 4
Target 5
Target 6
Ground

Korean Cable Test #16

Test conditions:

Cable: 9-conductor, 14 AWG, EPR insulated, CSP jacketed, control cable (Cable ID 5).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud initially set to temperature of 450C, nominal 12.6 kW/m2 flux from shroud.
Electrical response monitoring: SCDU system using seven circuit paths - one for each insulated conductor connected to S1, S3, T4, T6 and ground. SCDU circuit paths S2 and T5 were each connected to two of the insulated cable conductors. The cable tray was grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see thermocouple map).

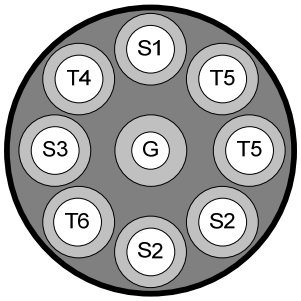
Two cables were included in Test #16, one electrically monitored, one thermally monitored. The test cables had a pink jacket and white conductor insulation with printed numbers.



Map for placement of thermocouples inserted within the thermally monitored cable during Test #16.

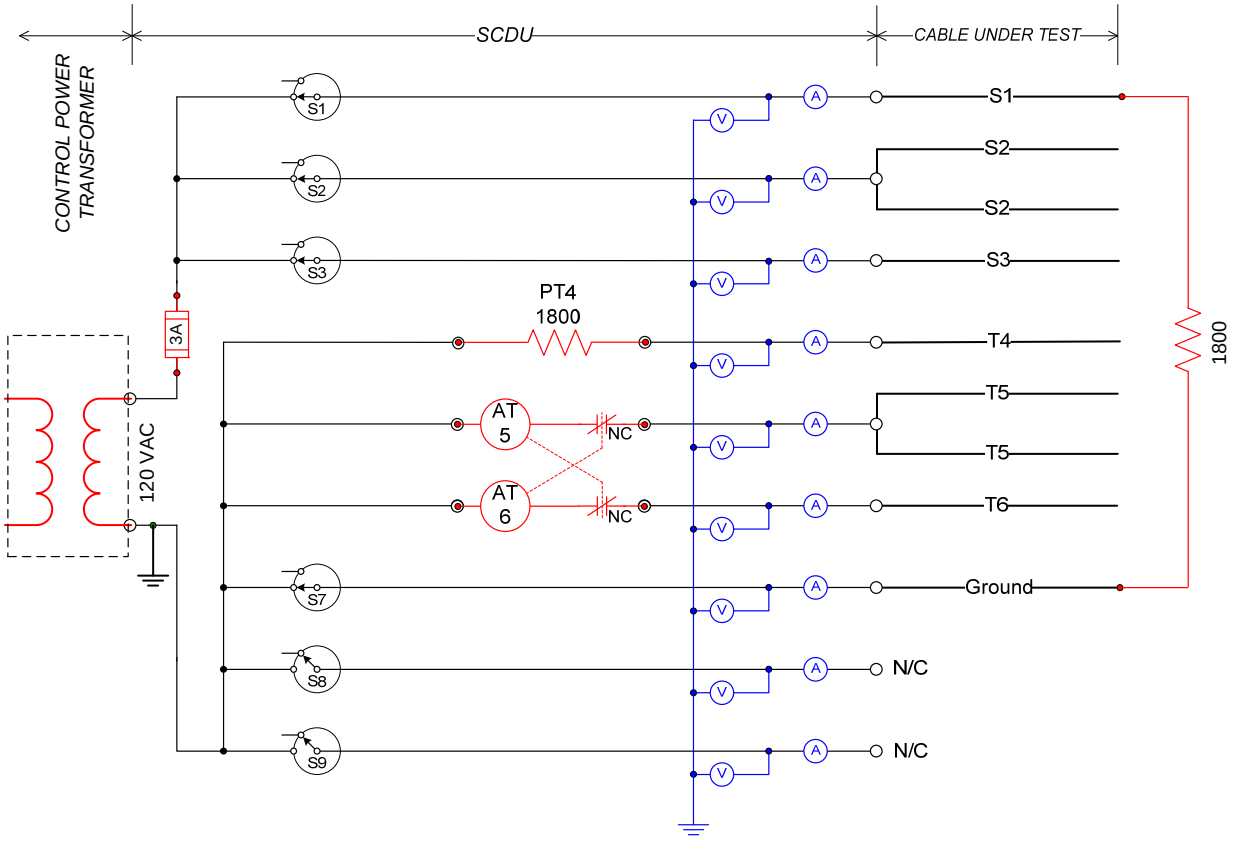
Thermo-couple Name	Location
TC1	Within cable just below cable jacket, to the East of the center position
TC2	Within cable just below cable jacket, at center position
TC3	Within cable just below cable jacket, opposite side from Cable 2, center position
TC4	Within cable just below cable jacket, to the West of the center position

All of the seven available SCDU circuit paths were connected to the electrically monitored test cable.



SCDU channel assignments for electrically monitored cable

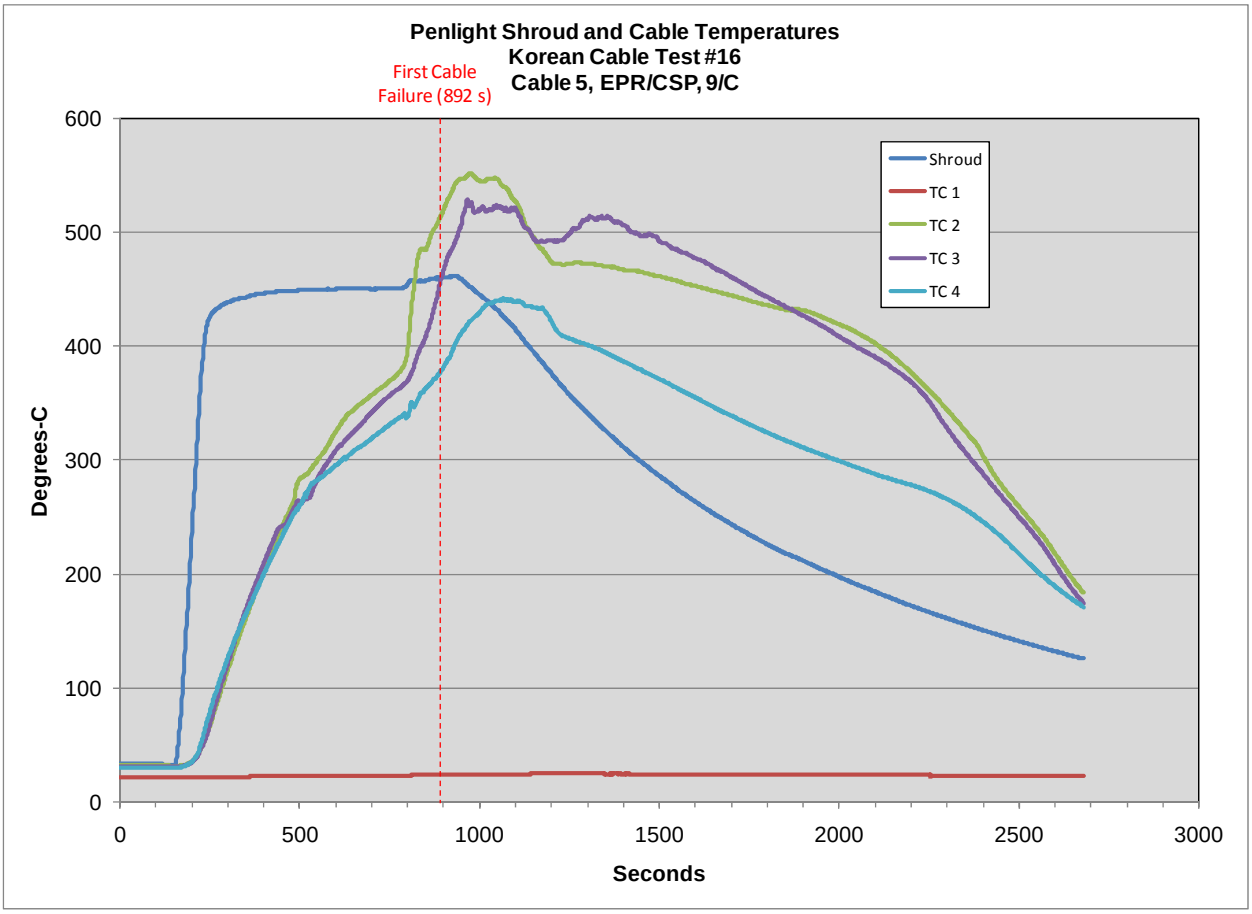
SCDU Channel	Test Cable
S1	White
S2	Orange & Blue
S3	Red-Black
T4	Green-Black
T5	Red & Green
T6	White-Black
Ground	Black

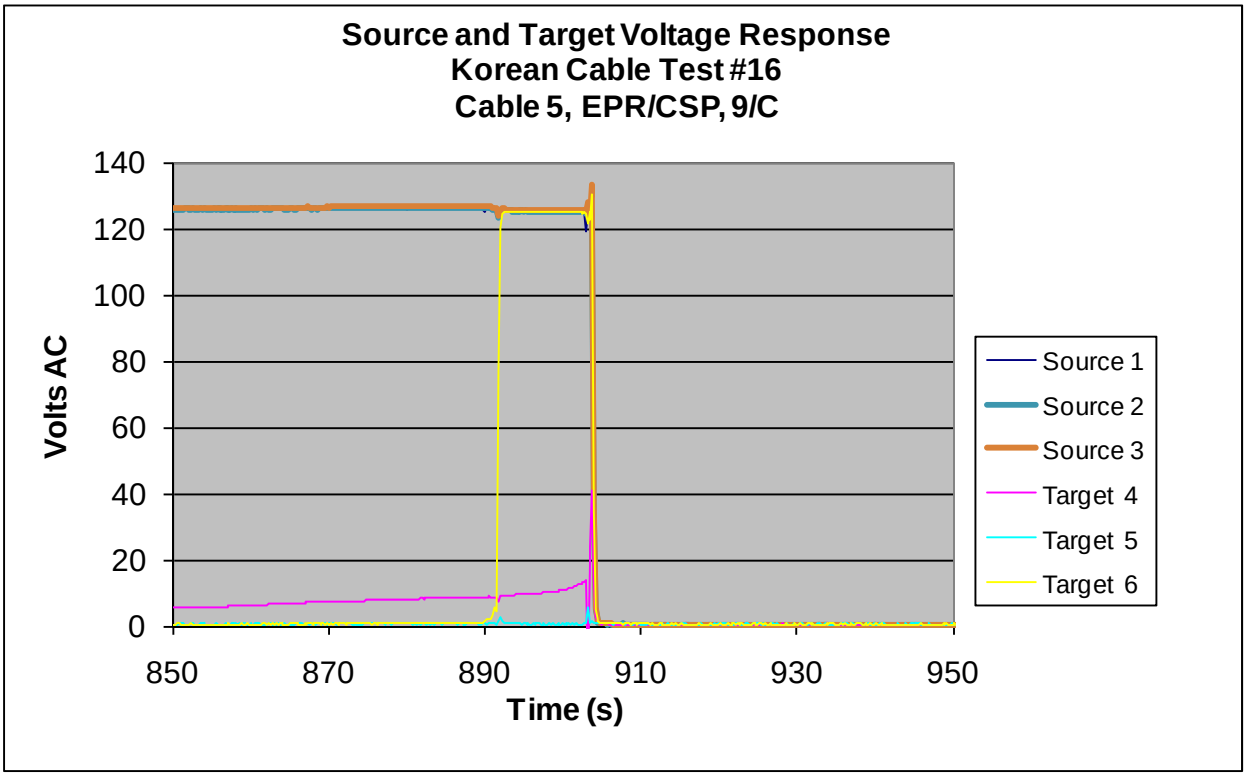


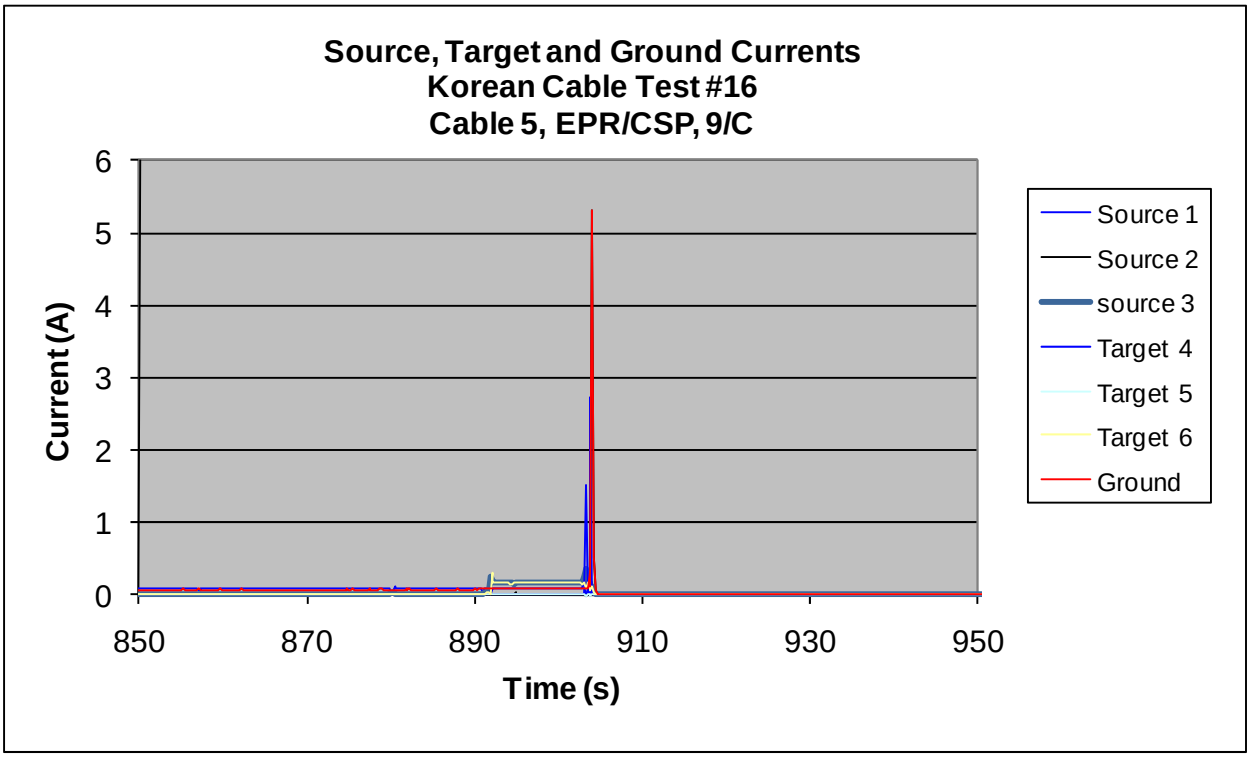
Cable conductor connections to SCDU during Test #16

The Penlight shroud temperature was initially set at 450C and held at that value until electrical failure of the cable occurred.

Summary of Observed Faulting Behavior during Korean Cable Test #16		
Time (s)	**Event**	**Comments**
154	Penlight On; set at 450C (12.6 kW/m2)	
892-904	Spurious actuation of T6 due to hot short from S3	Initial failure manifest as a spurious actuation due to hot short (12 s duration); 457C cable temperature (TC-3)
904	Fuse clears	
Additional observations		
1	Cable thermocouple TC-4 did not perform as expected.	


Penlight Shroud and Cable Temperatures
Korean Cable Test #16
Cable 5, EPR/CSP, 9/C
First Cable Failure (892 s)
Shroud
TC 1
TC 2
TC 3
TC 4
Degrees-C
Seconds
0
100
200
300
400
500
600
0
500
1000
1500
2000
2500
3000


Source and Target Voltage Response
Korean Cable Test #16
Cable 5, EPR/CSP, 9/C
Volts AC
140
120
100
80
60
40
20
0
850
870
890
910
930
950
Time (s)
Source 1
Source 2
Source 3
Target 4
Target 5
Target 6

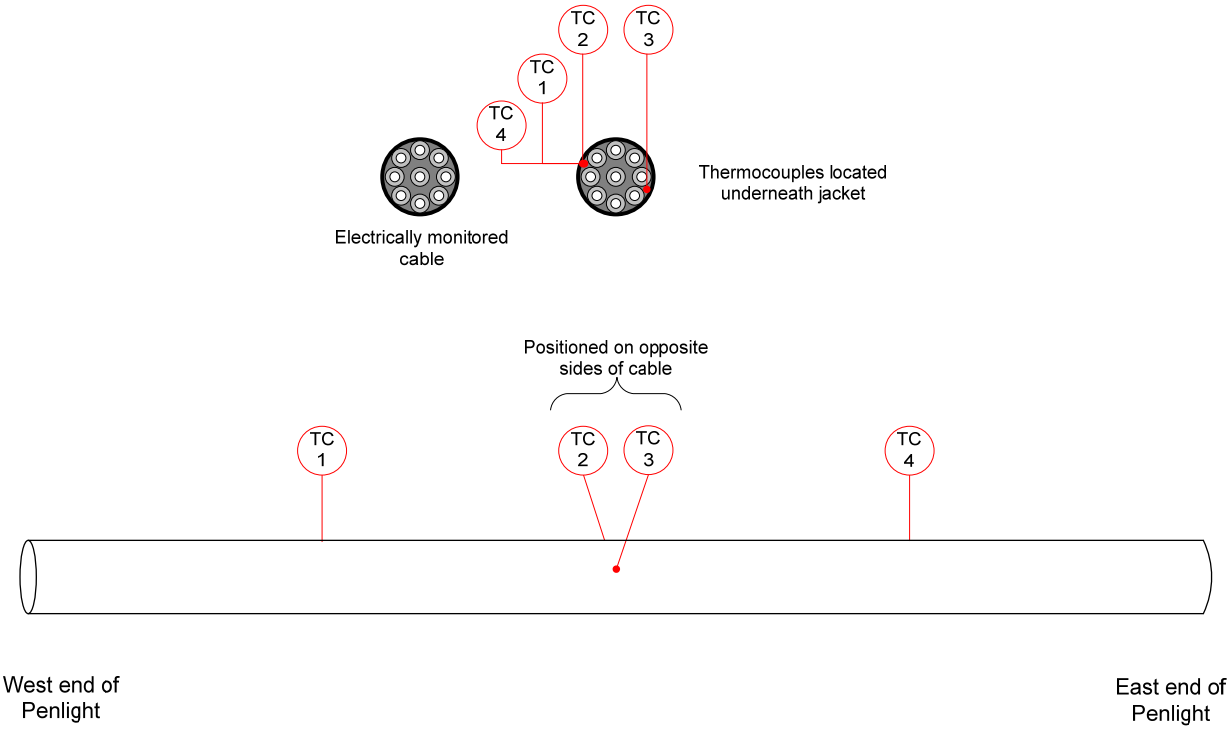

Source, Target and Ground Currents
Korean Cable Test #16
Cable 5, EPR/CSP, 9/C
Current (A)
6
5
4
3
2
1
0
850
870
890
910
930
950
Time (s)
Source 1
Source 2
source 3
Target 4
Target 5
Target 6
Ground

Korean Cable Test #17

Test conditions:

Cable: 9-conductor, 14 AWG, EPR insulated, CSP jacketed, control cable (Cable ID 5).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud initially set to temperature of 450C, nominal 12.6 kW/m2 flux from shroud.
Electrical response monitoring: SCDU system using seven circuit paths - one for each insulated conductor connected to S1, S3, T4, T6 and ground. SCDU circuit paths S2 and T5 were each connected to two of the insulated cable conductors. The cable tray was grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see thermocouple map).

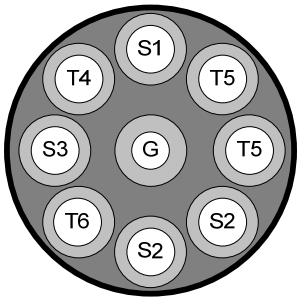
Two cables were included in Test #17, one electrically monitored, one thermally monitored. The test cables had a green jacket and white conductor insulation with printed numbers.



Map for placement of thermocouples inserted within the thermally monitored cable during Test #17.

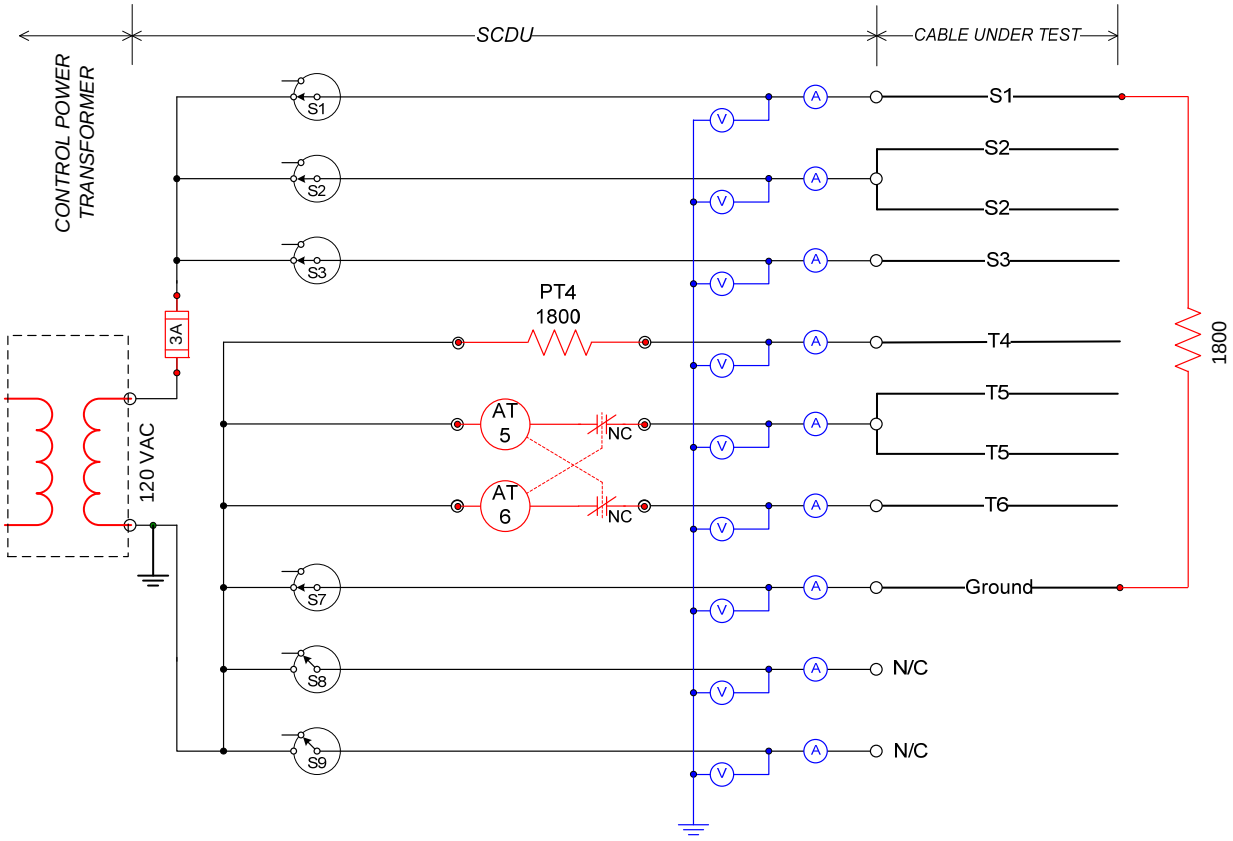
Thermo-couple Name	Location
TC1	Within cable just below cable jacket, to the East of the center position
TC2	Within cable just below cable jacket, at center position
TC3	Within cable just below cable jacket, opposite side from Cable 2, center position
TC4	Within cable just below cable jacket, to the West of the center position

All of the seven available SCDU circuit paths were connected to the electrically monitored test cable.



SCDU channel assignments for electrically monitored cable

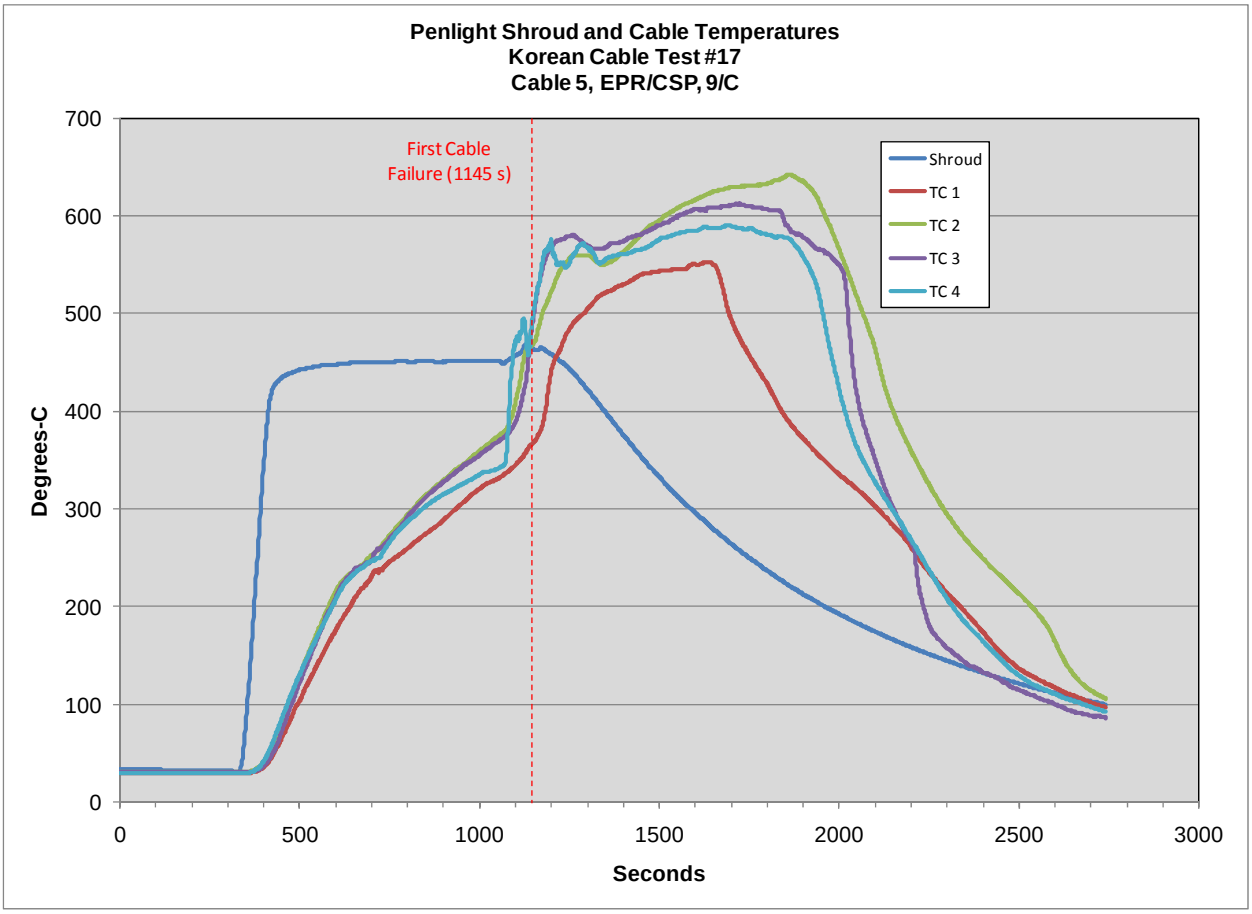
SCDU Channel	Test Cable
S1	White
S2	Orange & Blue
S3	Red-Black
T4	Green-Black
T5	Red & Green
T6	White-Black
Ground	Black

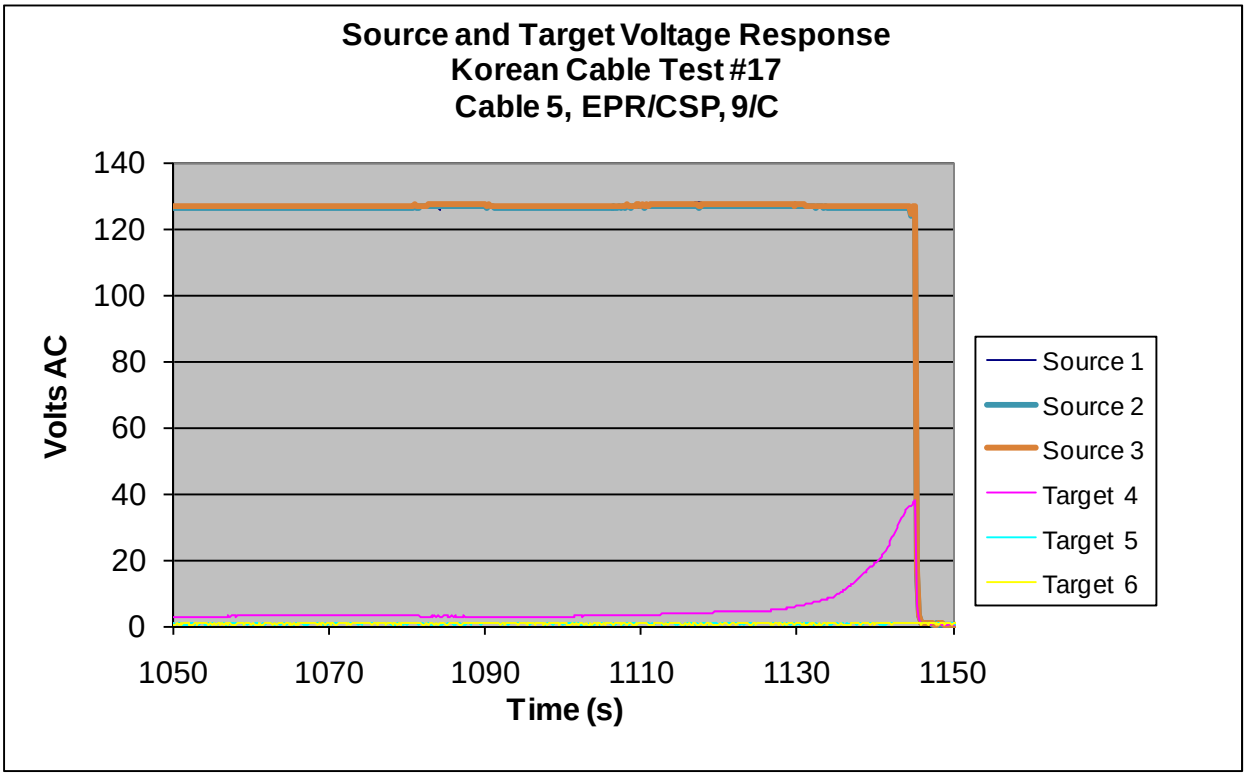


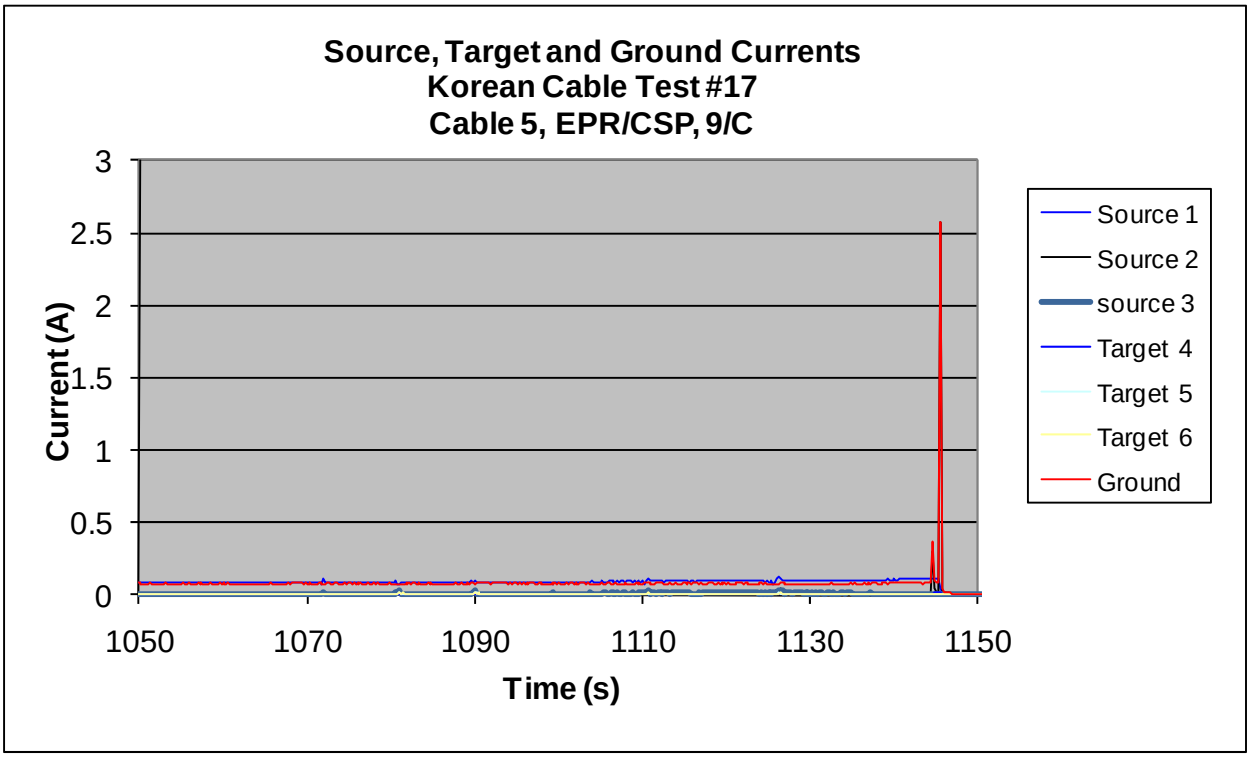
Cable conductor connections to SCDU during Test #17

The Penlight shroud temperature was initially set at 450C and held at that value until electrical failure of the cable occurred.

Summary of Observed Faulting Behavior during Korean Cable Test #17		
Time (s)	**Event**	**Comments**
334	Penlight On; set at 450C (12.6 kW/m2)	
1128-1145	Voltage on T4 begins increasing slightly	
1145	Fuse clears	Initial failure manifest as a fuse clear due to short to ground; 477C average cable temperature at center


Penlight Shroud and Cable Temperatures
Korean Cable Test #17
Cable 5, EPR/CSP, 9/C
First Cable
Failure (1145 s)
Shroud
TC 1
TC 2
TC 3
TC 4
Degrees-C
Seconds
0
100
200
300
400
500
600
700
0
500
1000
1500
2000
2500
3000


Source and Target Voltage Response
Korean Cable Test #17
Cable 5, EPR/CSP, 9/C
Volts AC
140
120
100
80
60
40
20
0
1050
1070
1090
1110
1130
1150
Time (s)
Source 1
Source 2
Source 3
Target 4
Target 5
Target 6

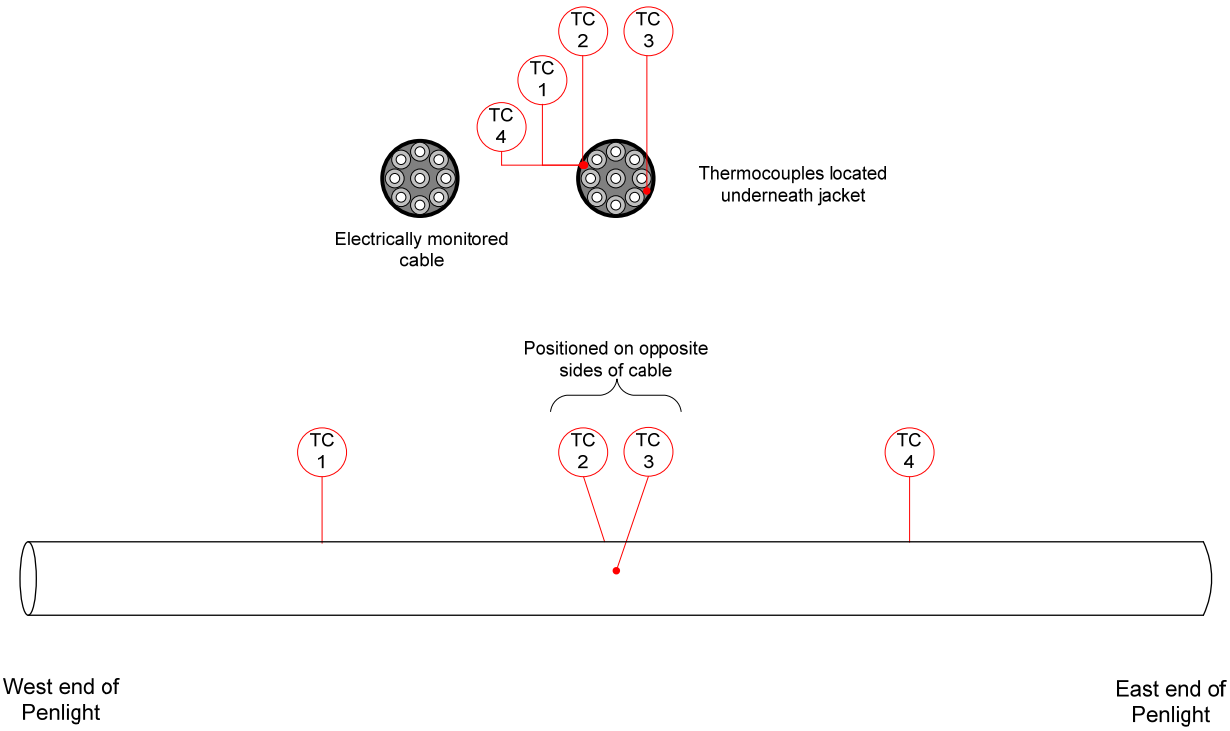

Source, Target and Ground Currents
Korean Cable Test #17
Cable 5, EPR/CSP, 9/C
Current (A)
3
2.5
2
1.5
1
0.5
0
1050
1070
1090
1110
1130
1150
Time (s)
Source 1
Source 2
source 3
Target 4
Target 5
Target 6
Ground

Korean Cable Test #18

Test conditions:

Cable: 9-conductor, 14 AWG, EPR insulated, CR jacketed, control cable (Cable ID 8).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud initially set to temperature of 450C, nominal 12.6 kW/m2 flux from shroud.
Electrical response monitoring: SCDU system using seven circuit paths - one for each insulated conductor connected to S1, S3, T4, T6 and ground. SCDU circuit paths S2 and T5 were each connected to two of the insulated cable conductors. The cable tray was grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see thermocouple map).

Two cables were included in Test #18, one electrically monitored, one thermally monitored. The test cables had a black jacket and eight conductors covered with white insulation and printed numbers in the outer ring of conductors, the center conductor was covered with black insulation.

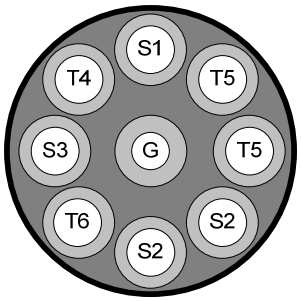


Map for placement of thermocouples inserted within the thermally monitored cable during Test #18.

Thermo-couple Name	Location
TC1	Within cable just below cable jacket, to the East of the center position

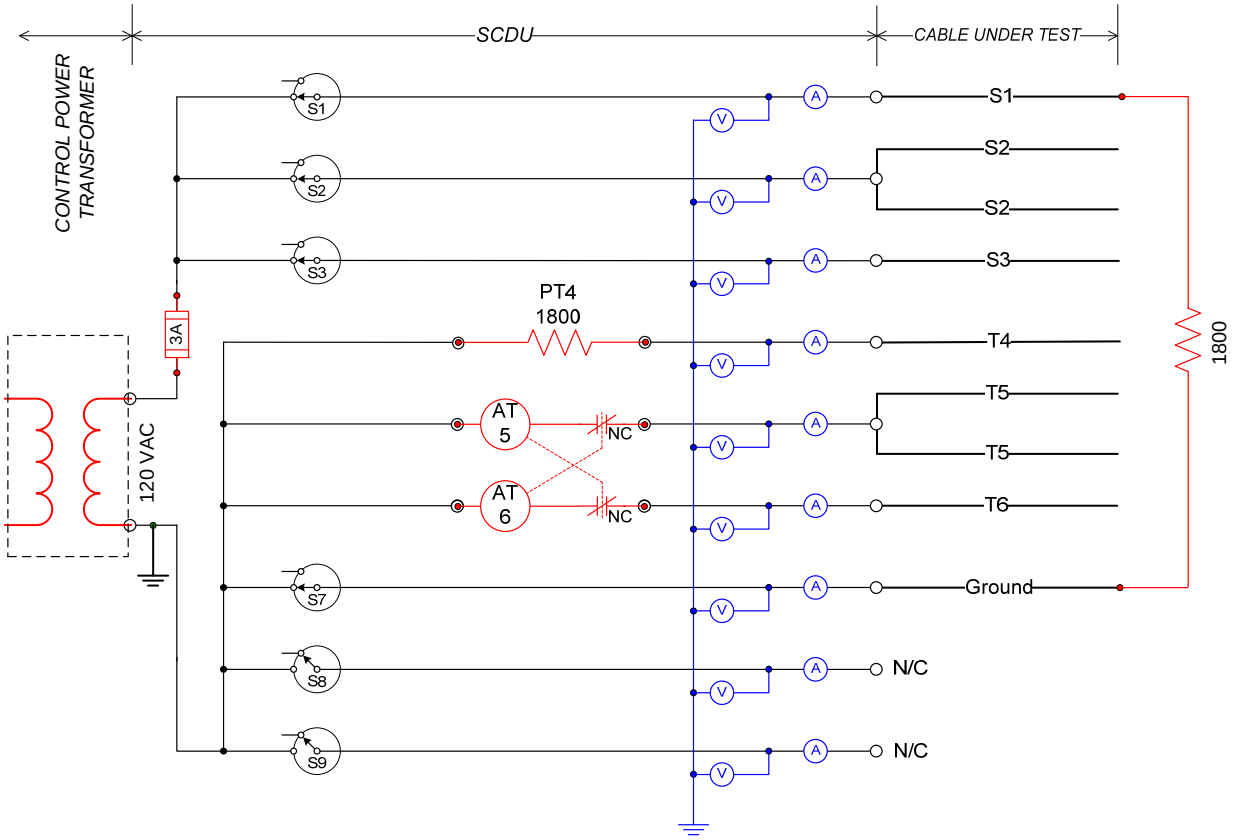
TC2	Within cable just below cable jacket, at center position
TC3	Within cable just below cable jacket, opposite side from Cable 2, center position
TC4	Within cable just below cable jacket, to the West of the center position

All of the seven available SCDU circuit paths were connected to the electrically monitored test cable.



SCDU channel assignments for electrically monitored cable

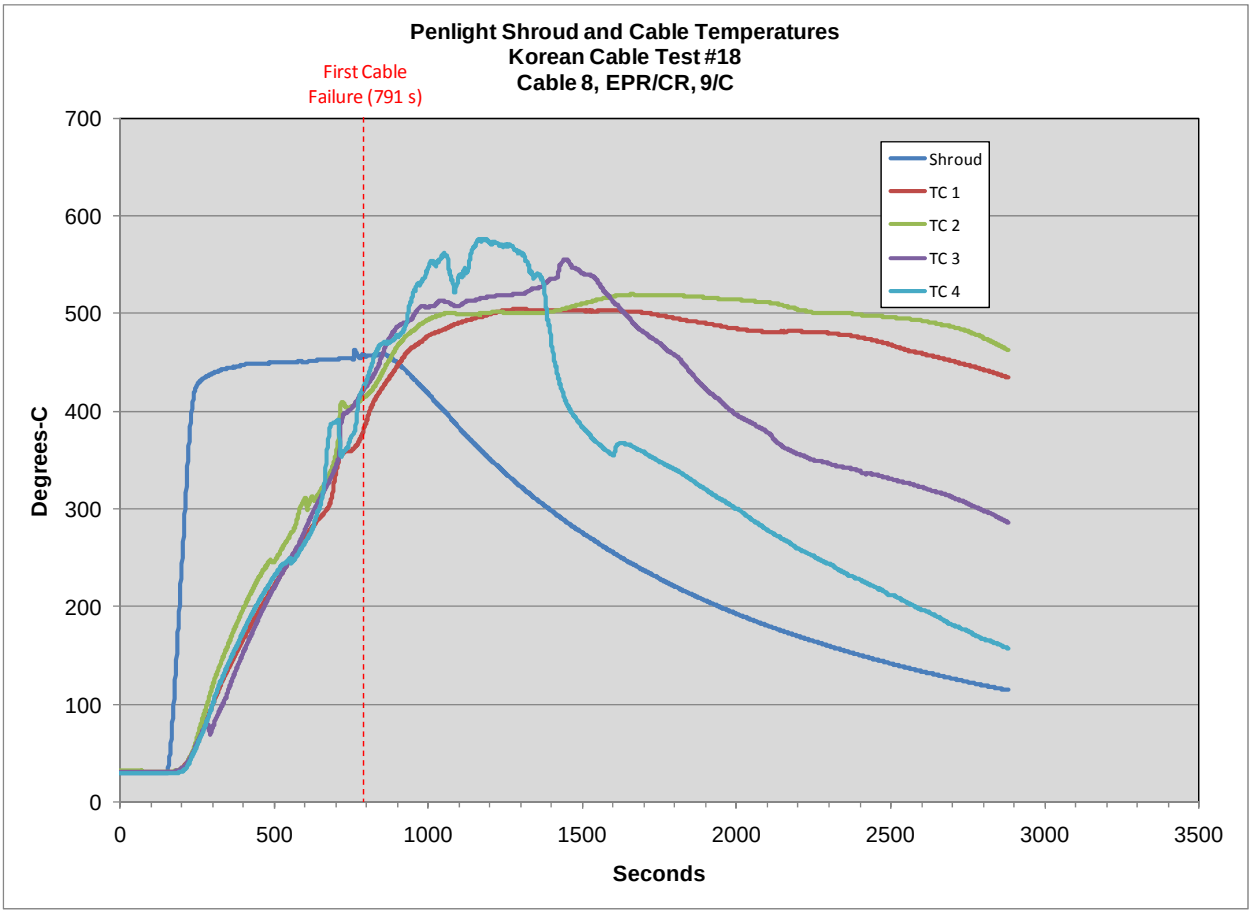
SCDU Channel	Test Cable
S1	White
S2	Orange & Blue
S3	Red-Black
T4	Green-Black
T5	Red & Green
T6	White-Black
Ground	Black

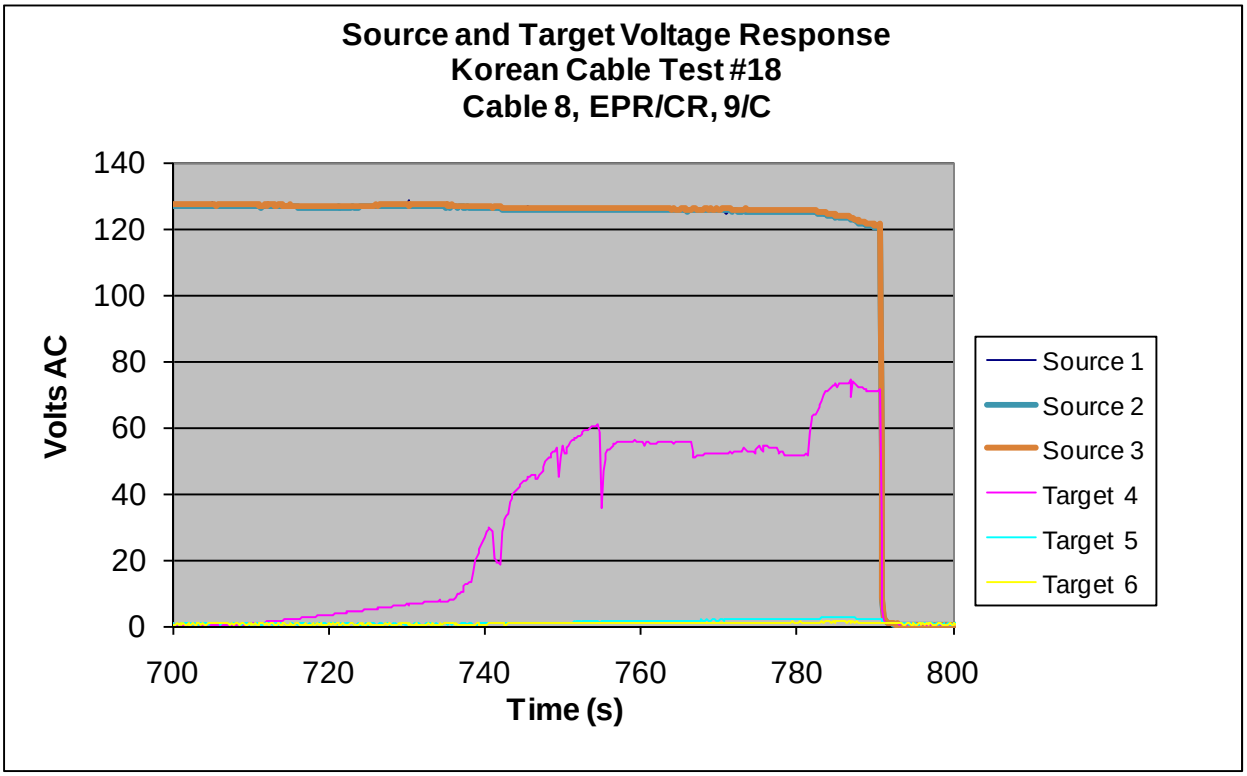


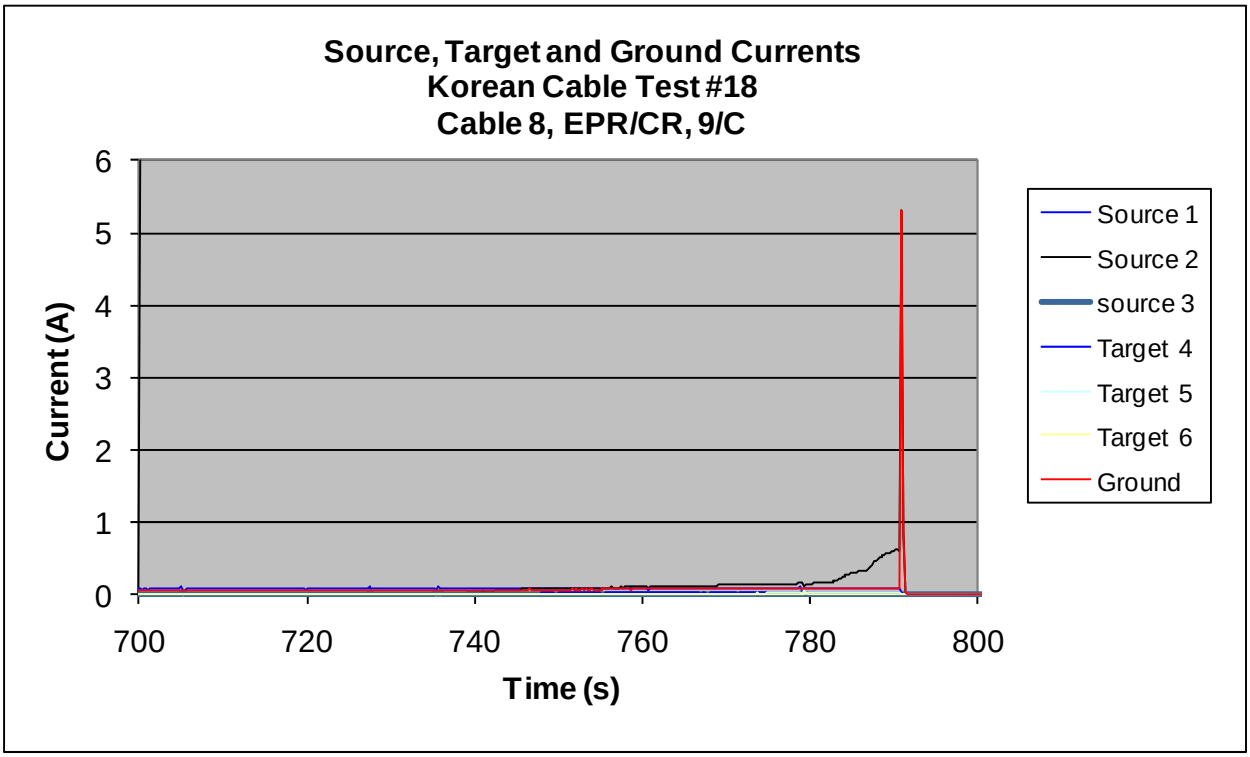
Cable conductor connections to SCDU during Test #18

The Penlight shroud temperature was initially set at 450C and held at that value until electrical failure of the cable occurred.

Summary of Observed Faulting Behavior during Korean Cable Test #18		
Time (s)	**Event**	**Comments**
153	Penlight On; set at 450C (12.6 kW/m2)	
710-791	Voltage on T4 begins increasing	
791	Fuse clears	Initial failure manifest as a fuse clear due to short to ground; 418C average cable temperature at center


Penlight Shroud and Cable Temperatures
Korean Cable Test #18
Cable 8, EPR/CR, 9/C
First Cable
Failure (791 s)
Shroud
TC 1
TC 2
TC 3
TC 4
Degrees-C
Seconds
0
100
200
300
400
500
600
700
0
500
1000
1500
2000
2500
3000
3500


Source and Target Voltage Response
Korean Cable Test #18
Cable 8, EPR/CR, 9/C
Volts AC
140
120
100
80
60
40
20
0
700
720
740
760
780
800
Time (s)
Source 1
Source 2
Source 3
Target 4
Target 5
Target 6

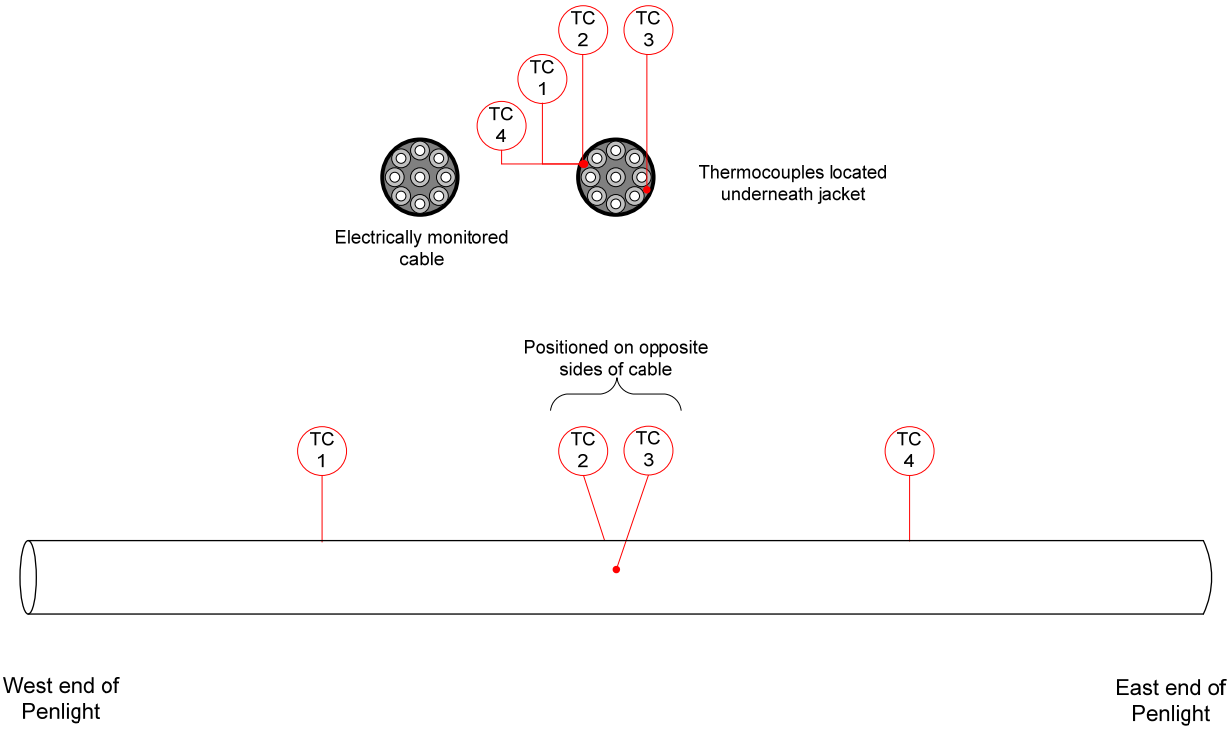

Source, Target and Ground Currents
Korean Cable Test #18
Cable 8, EPR/CR, 9/C
Current (A)
6
5
4
3
2
1
0
700
720
740
760
780
800
Time (s)
Source 1
Source 2
source 3
Target 4
Target 5
Target 6
Ground

Korean Cable Test #19

Test conditions:

Cable: 9-conductor, 14 AWG, EPR insulated, CSP jacketed, control cable (Cable ID 5).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud initially set to temperature of 450C, nominal 12.6 kW/m2 flux from shroud.
Electrical response monitoring: SCDU system using seven circuit paths - one for each insulated conductor connected to S1, S3, T4, T6 and ground. SCDU circuit paths S2 and T5 were each connected to two of the insulated cable conductors. The cable tray was grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see thermocouple map).

Two cables were included in Test #19, one electrically monitored, one thermally monitored. The test cables had a pink jacket and white conductor insulation with printed numbers. *NOTE: Test #19 was originally planned to include samples of the EPR/CR (Cable ID 8) cable, however, there was insufficient length of that cable available for testing, and thus another 9-conductor EPR/CSP cable (Cable ID 5) sample was substituted.*

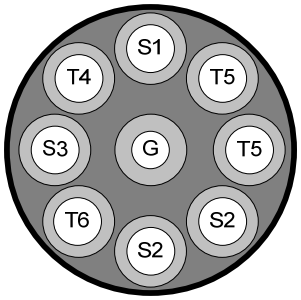


Map for placement of thermocouples inserted within the thermally monitored cable during Test #19.

Thermo-couple Name	Location

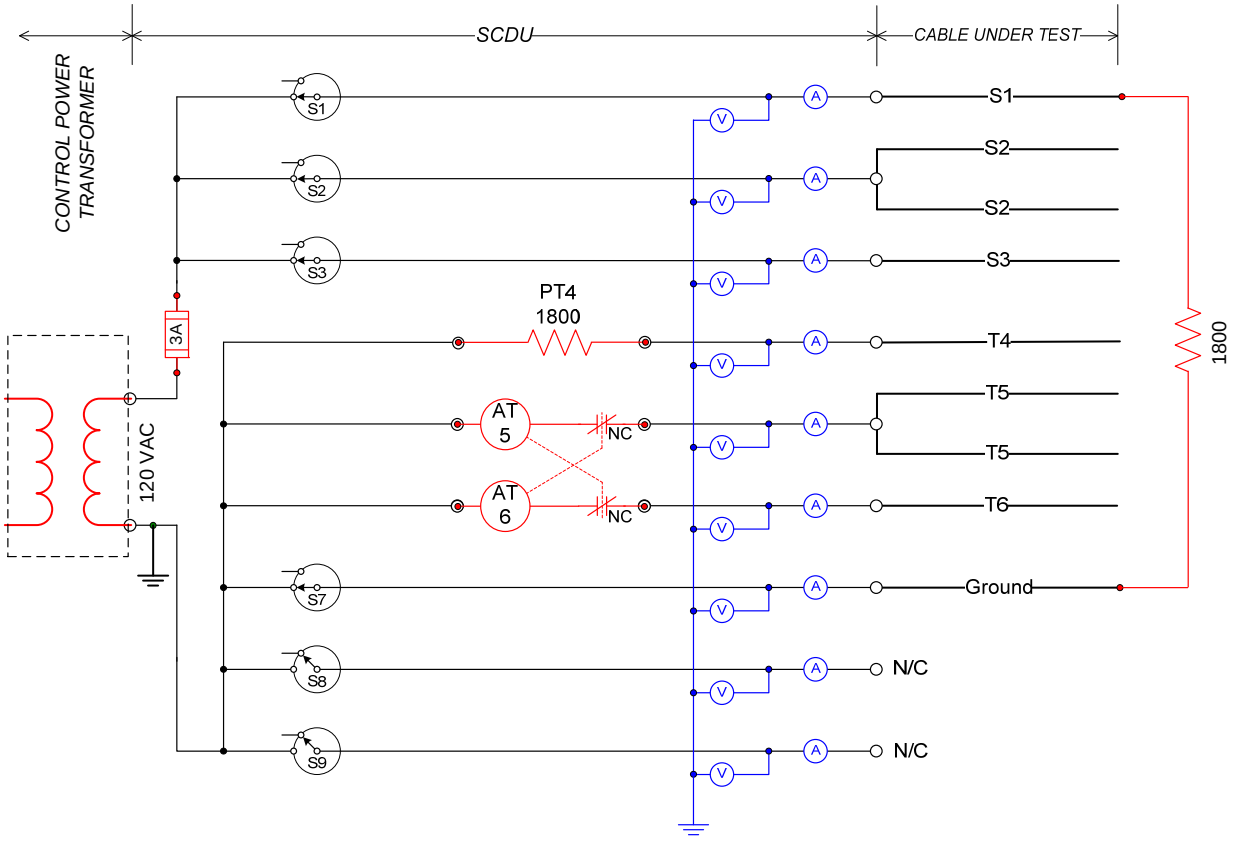
TC1	Within cable just below cable jacket, to the East of the center position
TC2	Within cable just below cable jacket, at center position
TC3	Within cable just below cable jacket, opposite side from Cable 2, center position
TC4	Within cable just below cable jacket, to the West of the center position

All of the seven available SCDU circuit paths were connected to the electrically monitored test cable.



SCDU channel assignments for electrically monitored cable

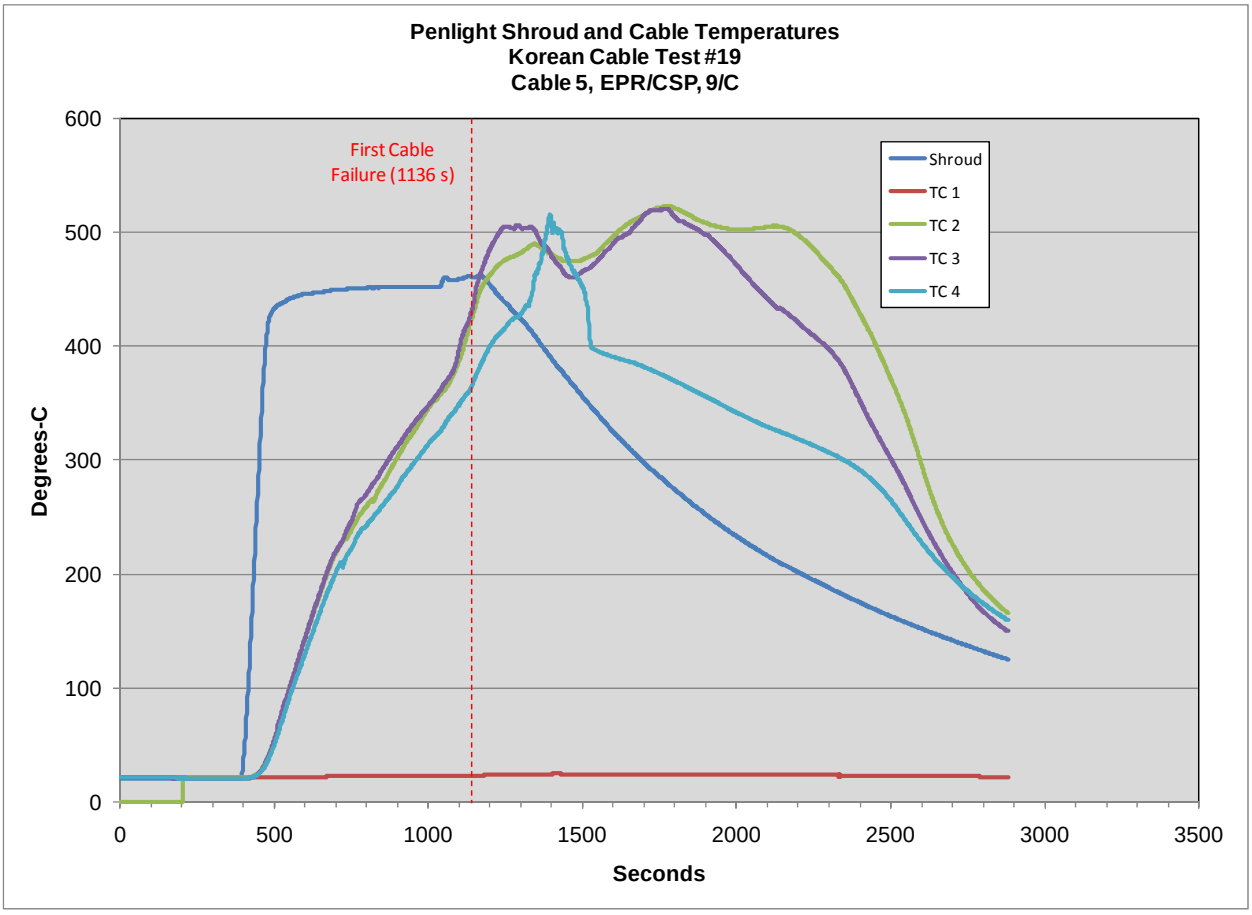
SCDU Channel	Test Cable
S1	White
S2	Orange & Blue
S3	Red-Black
T4	Green-Black
T5	Red & Green
T6	White-Black
Ground	Black

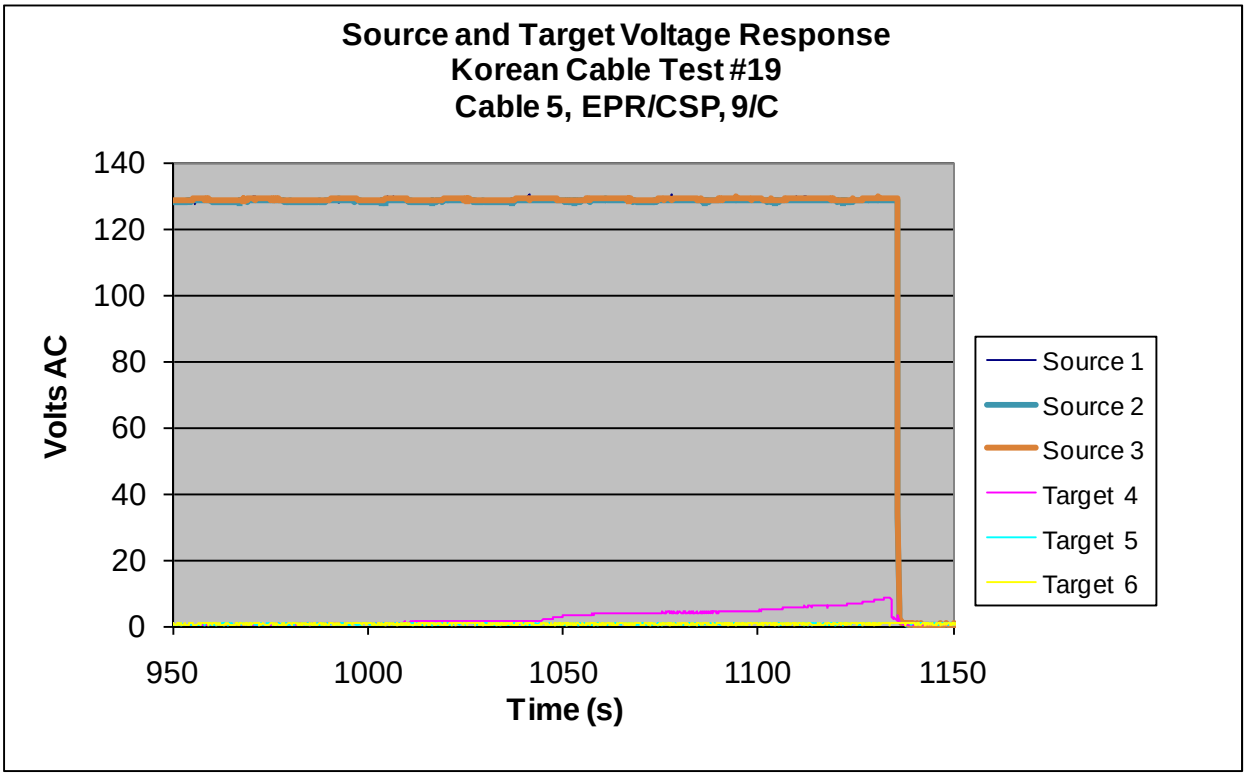


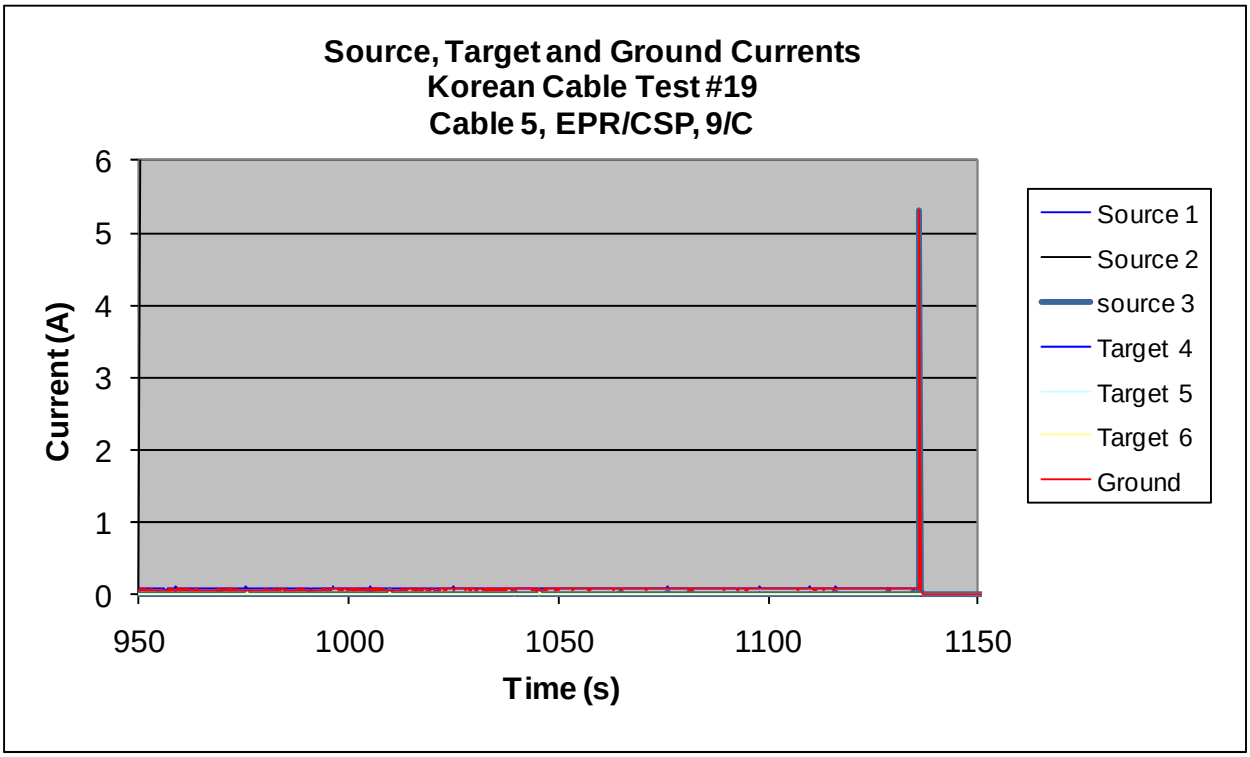
Cable conductor connections to SCDU during Test #19

The Penlight shroud temperature was initially set at 450C and held at that value until electrical failure of the cable occurred.

Summary of Observed Faulting Behavior during Korean Cable Test #19		
Time (s)	**Event**	**Comments**
393	Penlight On; set at 450C (12.6 kW/m2)	
1000-1136	Voltage on T4 begins increasing slightly	
1136	Fuse clears	Initial failure manifest as a fuse clear due to short to ground; 423C average cable temperature at center


Penlight Shroud and Cable Temperatures
Korean Cable Test #19
Cable 5, EPR/CSP, 9/C
First Cable
Failure (1136 s)
Shroud
TC 1
TC 2
TC 3
TC 4
Degrees-C
Seconds
600
500
400
300
200
100
0
0
500
1000
1500
2000
2500
3000
3500


Source and Target Voltage Response
Korean Cable Test #19
Cable 5, EPR/CSP, 9/C
Volts AC
140
120
100
80
60
40
20
0
950
1000
1050
1100
1150
Time (s)
Source 1
Source 2
Source 3
Target 4
Target 5
Target 6

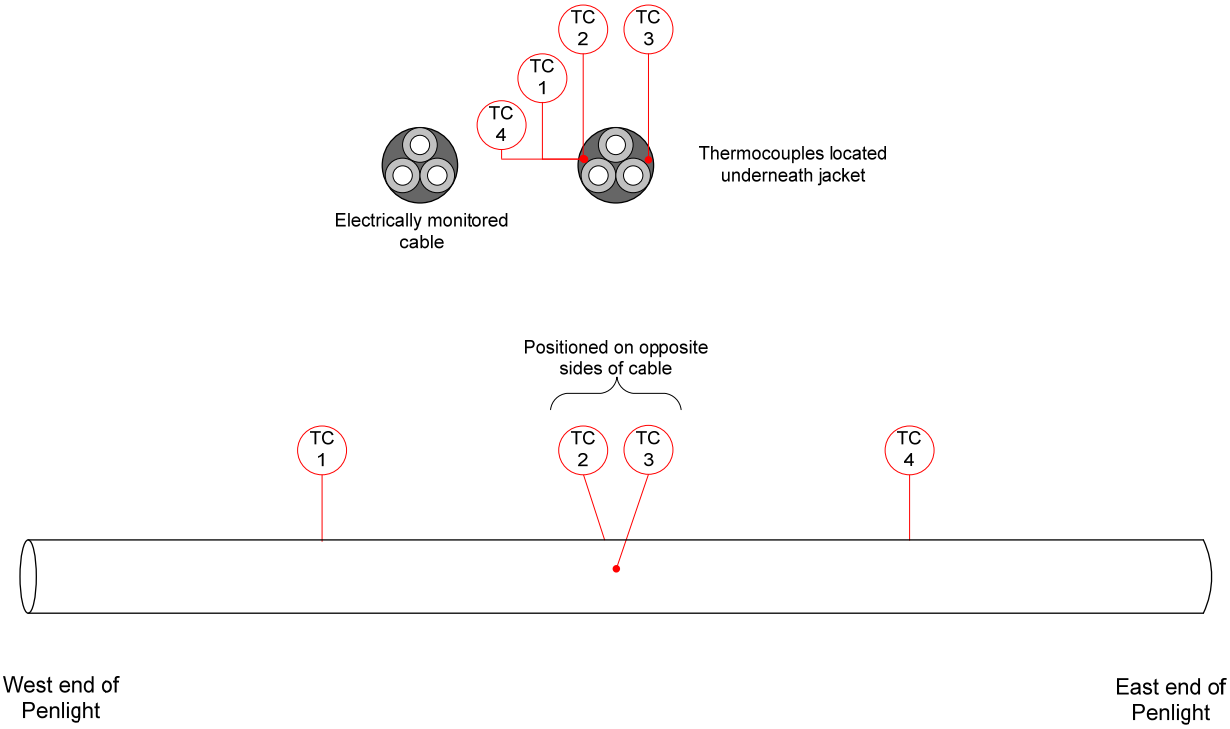

Source, Target and Ground Currents
Korean Cable Test #19
Cable 5, EPR/CSP, 9/C
Current (A)
6
5
4
3
2
1
0
950
1000
1050
1100
1150
Time (s)
Source 1
Source 2
source 3
Target 4
Target 5
Target 6
Ground

Korean Cable Test #20

Test conditions:

Cable: 3-conductor, 14 AWG, EPR insulated, CSP jacketed, power cable (Cable ID 13).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud set to temperature of 440C, nominal 11.9 kW/m^2 flux from shroud.
Electrical response monitoring: SCDU system using three circuit paths - one for each insulated conductor connected to S1, T5 and T6. SCDU circuit paths S2, S3, T4 and ground were not connected to the test cable. The cable tray was grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see maps).

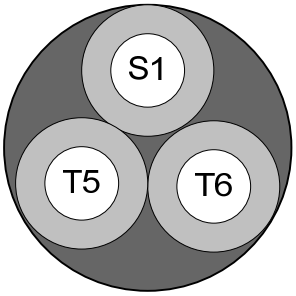
Two cables were included in Test #20, one electrically monitored, one thermally monitored. The test cables had a black jacket and black, white, and red conductor insulation.



Map for placement of thermocouples inserted within the thermally monitored cable during Test #20.

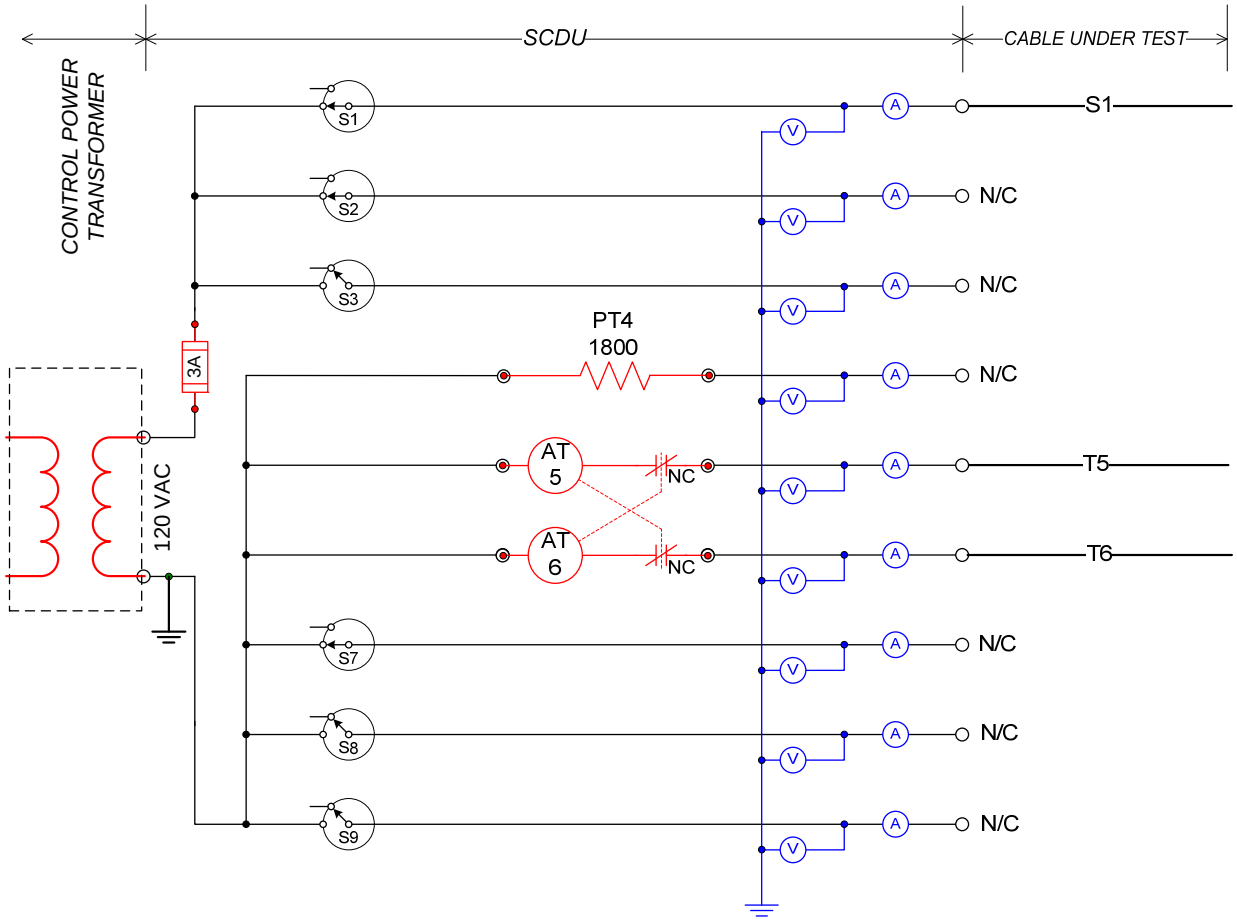
Thermo-couple Name	Location
TC1	Within cable just below cable jacket, to the West of the center position
TC2	Within cable just below cable jacket, at center position
TC3	Within cable just below cable jacket, opposite side from Cable 2, center position
TC4	Within cable just below cable jacket, to the East of the center position

Three of the seven available SCDU circuit paths were connected to the electrically monitored test cable.



SCDU channel assignments for electrically monitored cable

SCDU Channel	Test Cable
S1	Black
S2	
3 (Spare)	
T4	
T5	Red
T6	White
Ground	

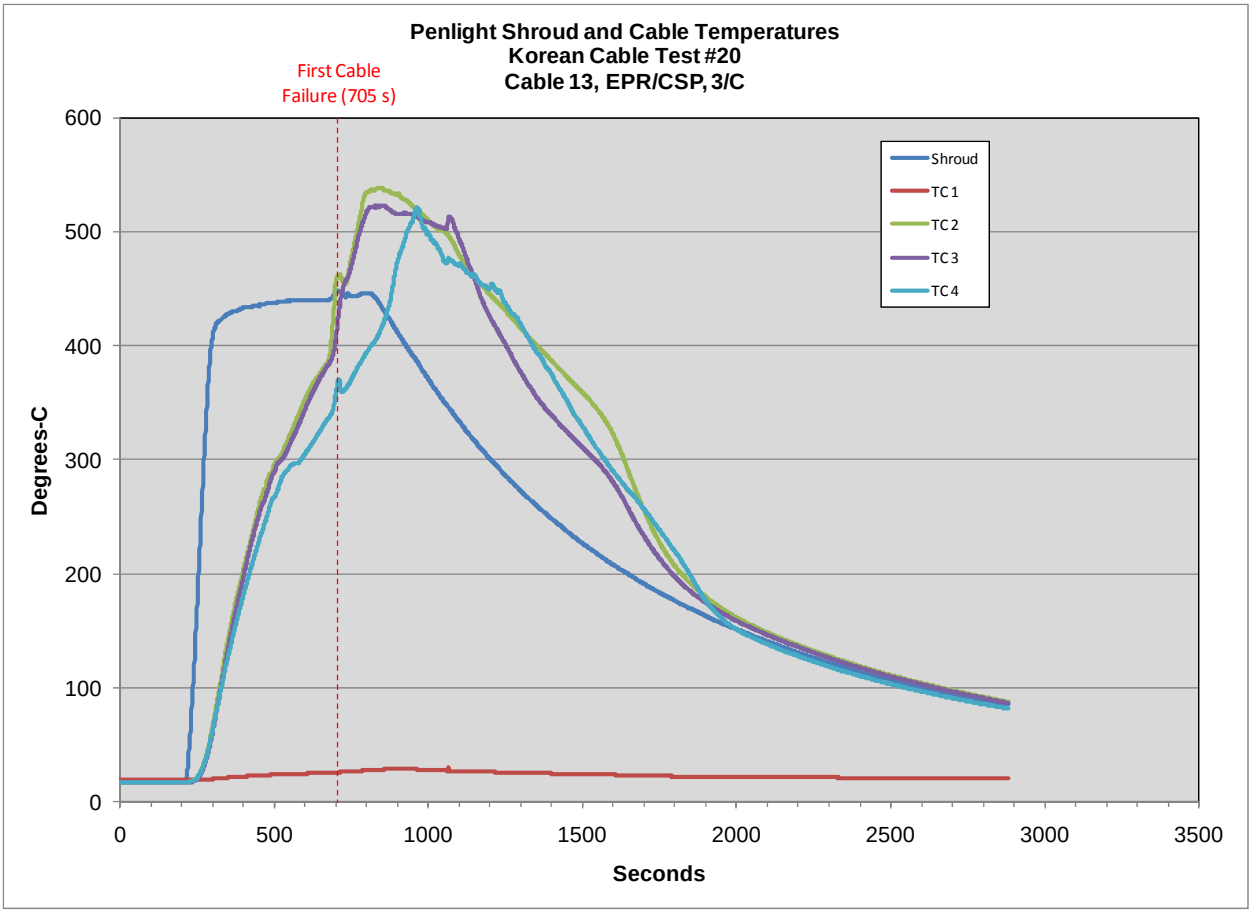


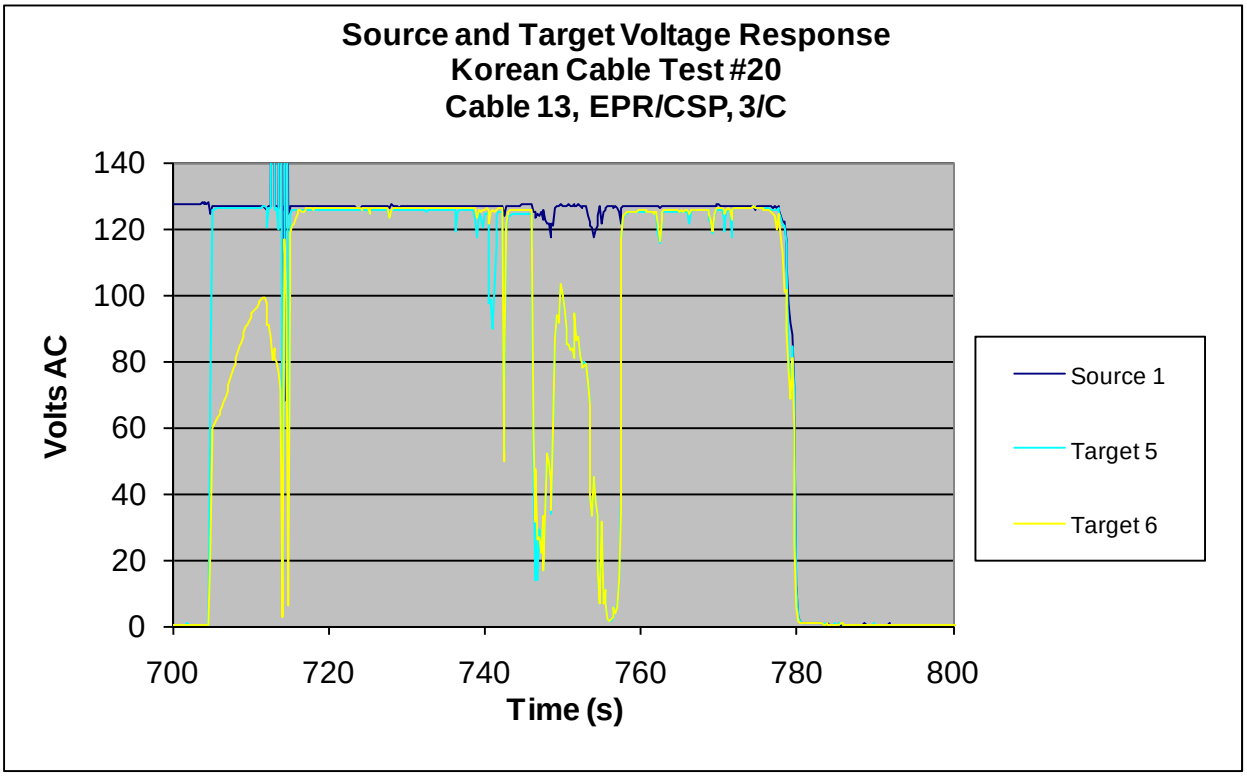
Cable conductor connections to SCDU during Test #20

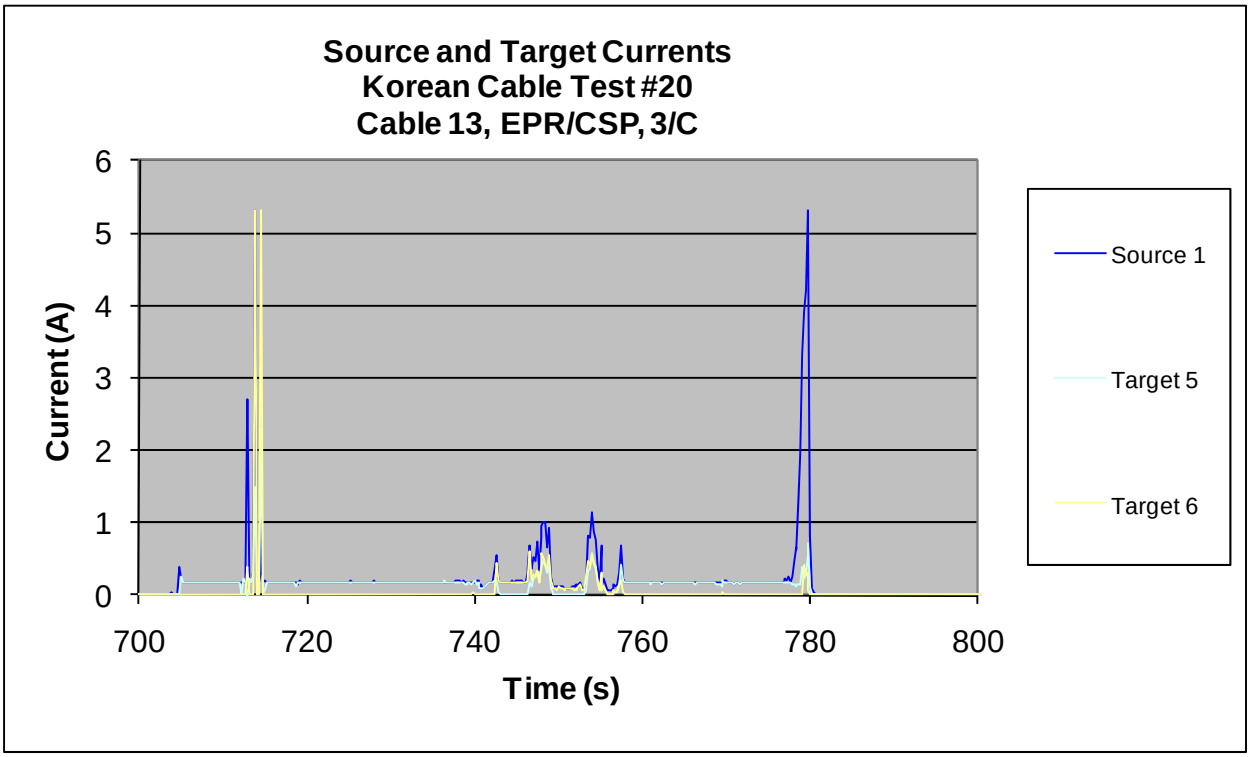
The Penlight shroud temperature was initially set at 440C and held at that value until electrical failure of the cable occurred.

Summary of Observed Faulting Behavior during Korean Cable Test #20		
Time (s)	**Event**	**Comments**
213	Penlight On; set at 440C (11.9 kW/m2)	
705-742	Spurious actuation of T5 due to hot short from S1	Initial failure manifest as a spurious actuation due to hot short (37 s duration); 438C average cable temperature
708-742	Hot short on T6 from S1	No spurious actuation because T6 is locked out by T5
742-746	Spurious actuation of T6	
742-746	Hot short on T5	
746-749	Chattering of T5 & T6 coils	Insufficient voltage for coil pickups
749-752	Spurious actuation of T6	
753-755	Chattering of T5 & T6 coils	
757-779	Spurious actuation of T5	

757-779	Hot short on T6	
780	Fuse clears	
Additional observations		
1	Cable thermocouple TC-1 did not perform as expected.	




Source and Target Voltage Response
Korean Cable Test #20
Cable 13, EPR/CSP, 3/C
Volts AC
140
120
100
80
60
40
20
0
700
720
740
760
780
800
Time (s)
Source 1
Target 5
Target 6

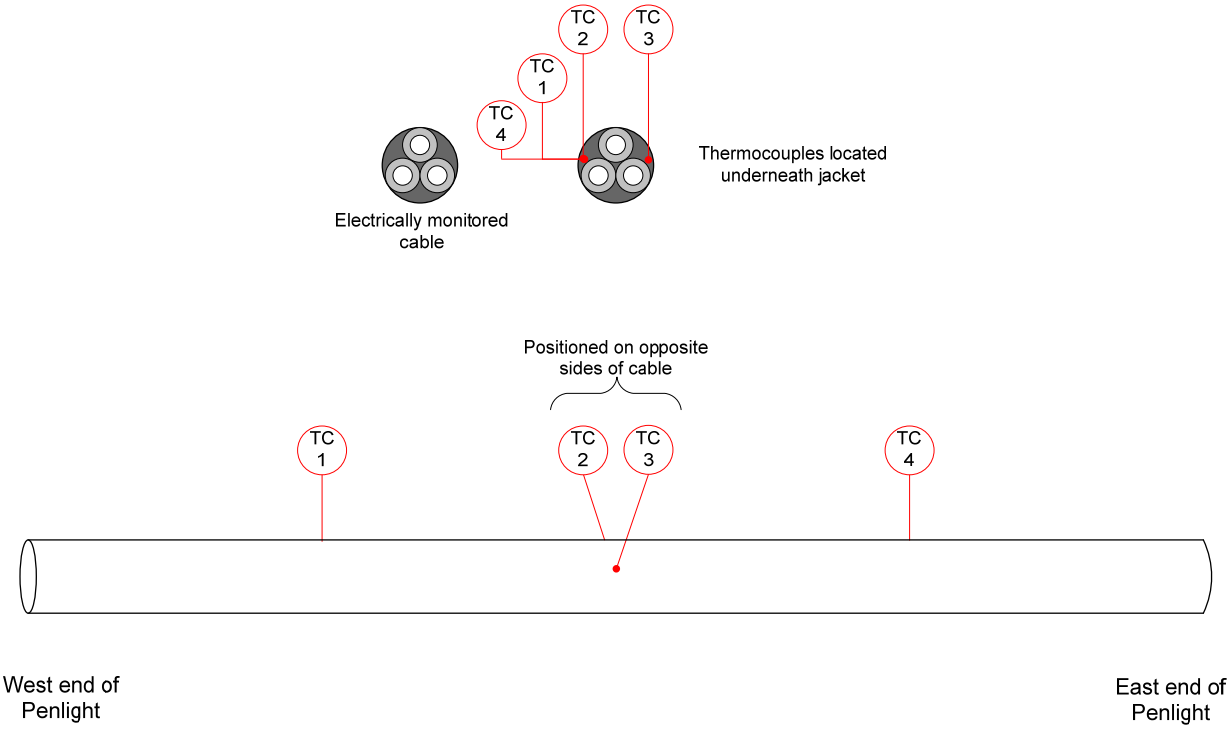

Source and Target Currents
Korean Cable Test #20
Cable 13, EPR/CSP, 3/C
Current (A)
6
5
4
3
2
1
0
700
720
740
760
780
800
Time (s)
Source 1
Target 5
Target 6

Korean Cable Test #21

Test conditions:

Cable: 3-conductor, 14 AWG, EPR insulated, CSP jacketed, power cable (Cable ID 13).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud set to temperature of 430C, nominal 11.3 kW/m^2 flux from shroud.
Electrical response monitoring: SCDU system using three circuit paths - one for each insulated conductor connected to S1, T5 and T6. SCDU circuit paths S2, S3, T4 and ground were not connected to the test cable. The cable tray was grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see maps).

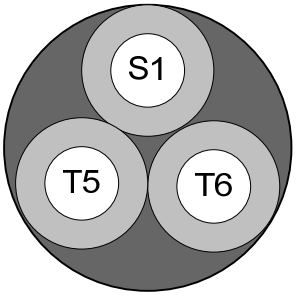
Two cables were included in Test #21, one electrically monitored, one thermally monitored. The test cables had a black jacket and black, white, and red conductor insulation.



Map for placement of thermocouples inserted within the thermally monitored cable during Test #21.

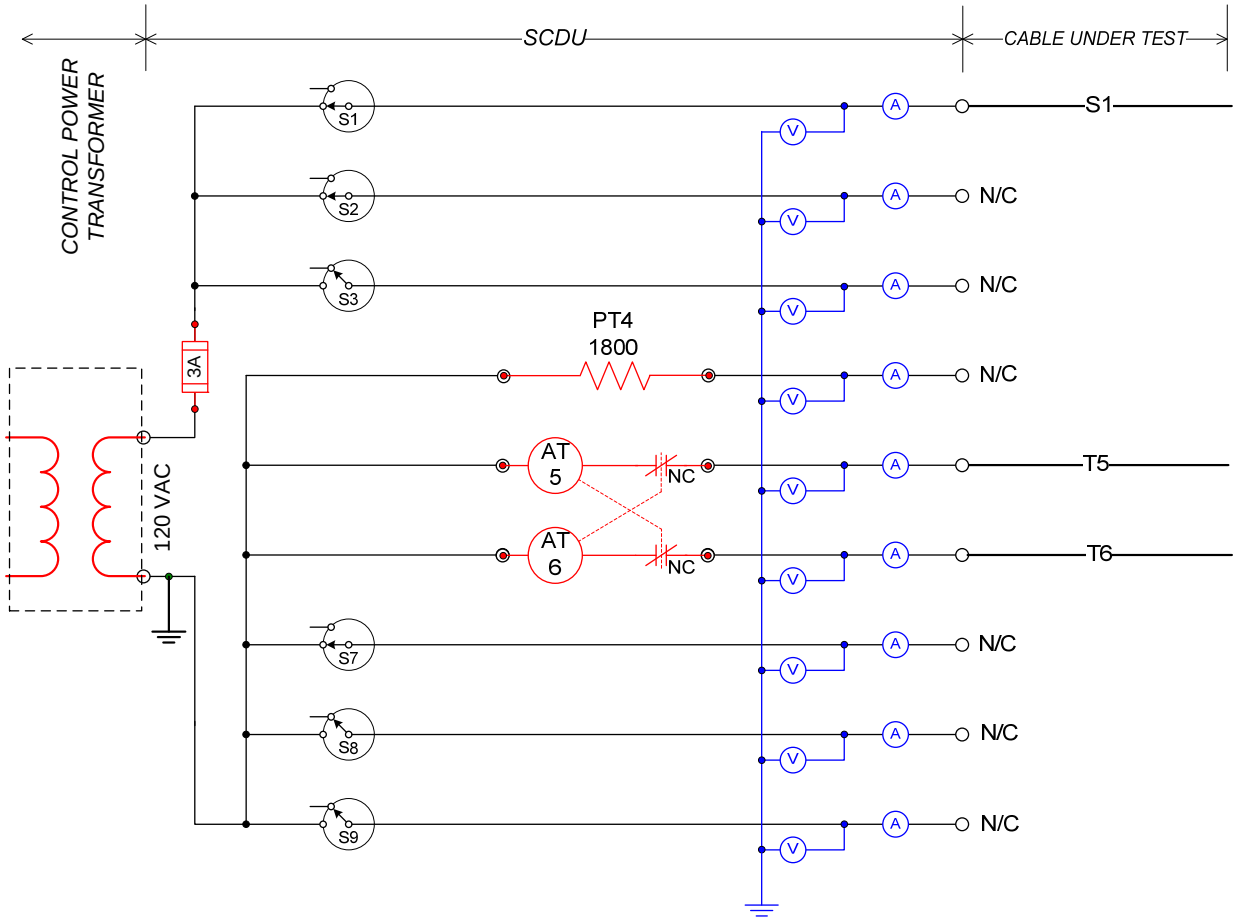
Thermo-couple Name	Location
TC1	Within cable just below cable jacket, to the West of the center position
TC2	Within cable just below cable jacket, at center position
TC3	Within cable just below cable jacket, opposite side from Cable 2, center position
TC4	Within cable just below cable jacket, to the East of the center position

Three of the seven available SCDU circuit paths were connected to the electrically monitored test cable.



SCDU channel assignments for electrically monitored cable

SCDU Channel	Test Cable
S1	Black
S2	
3 (Spare)	
T4	
T5	Red
T6	White
Ground	

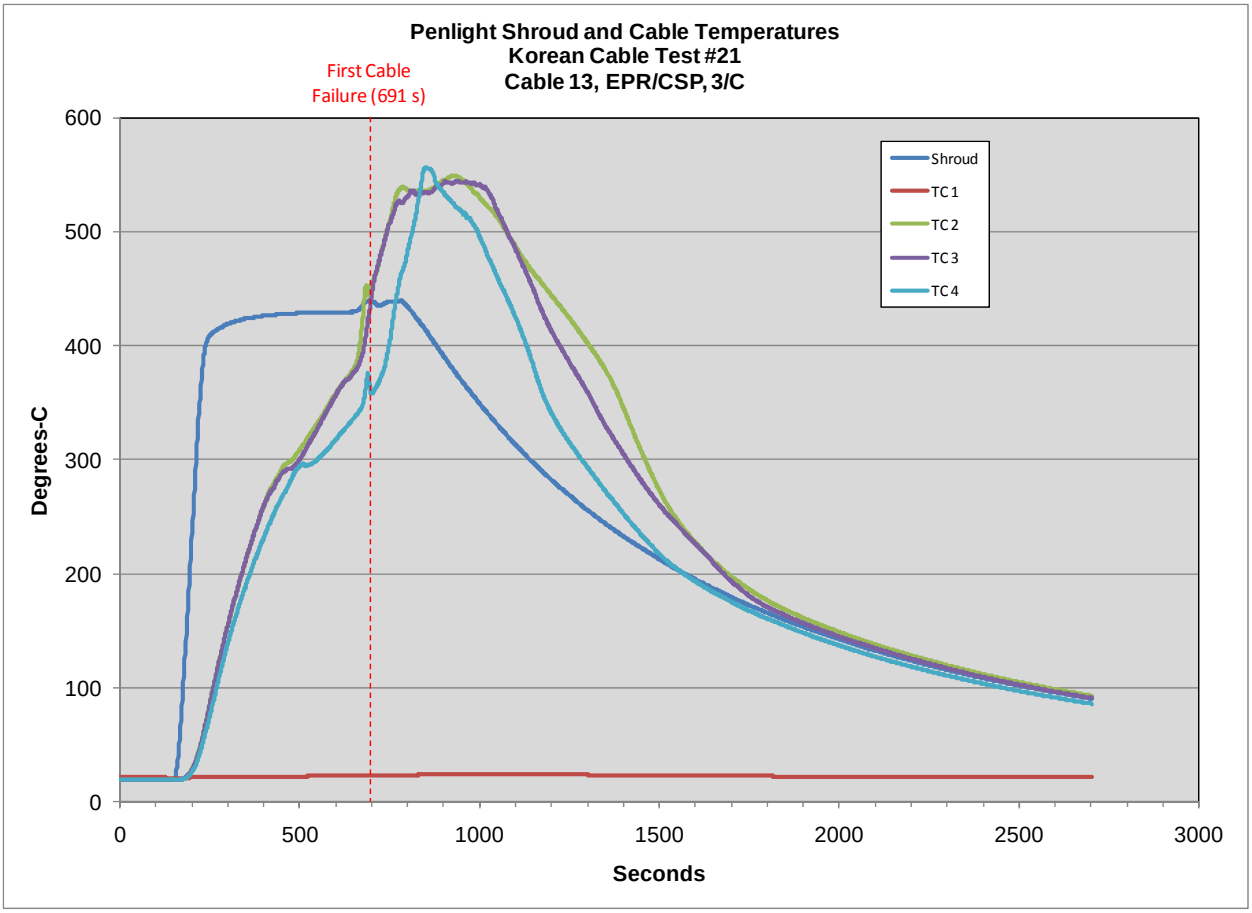


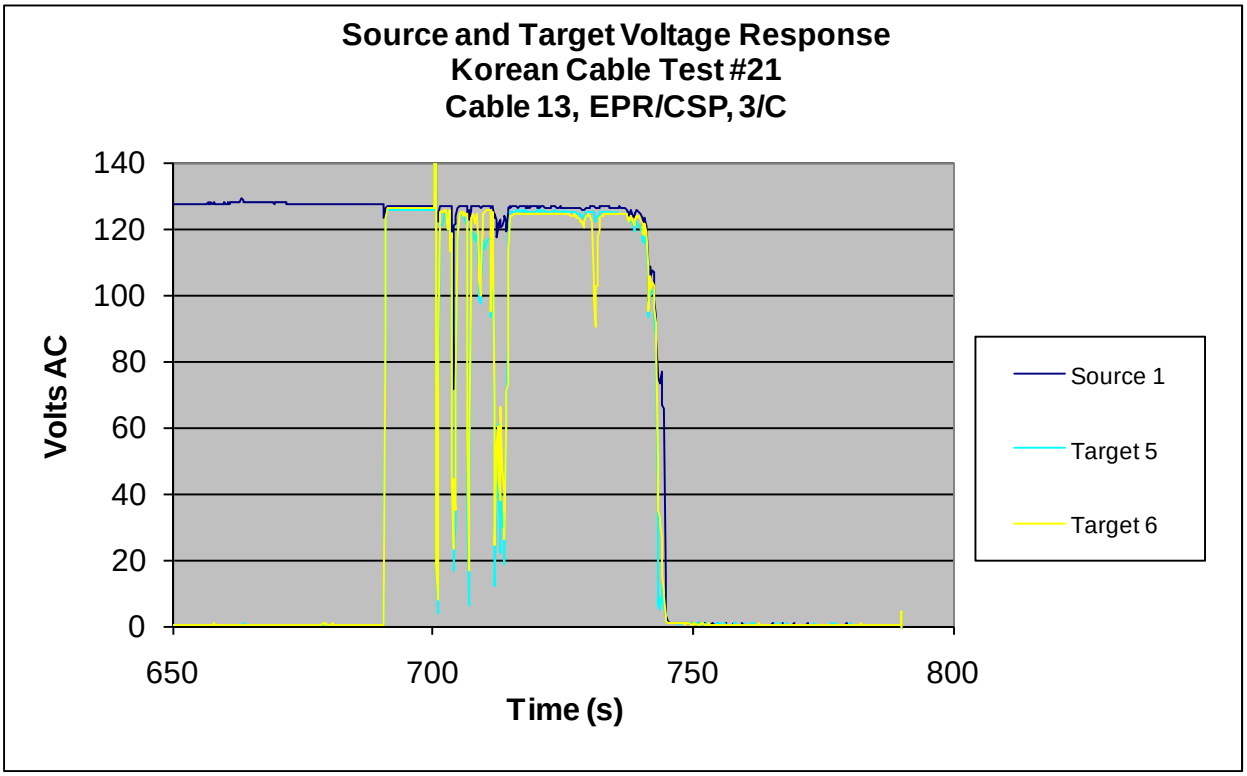
Cable conductor connections to SCDU during Test #21

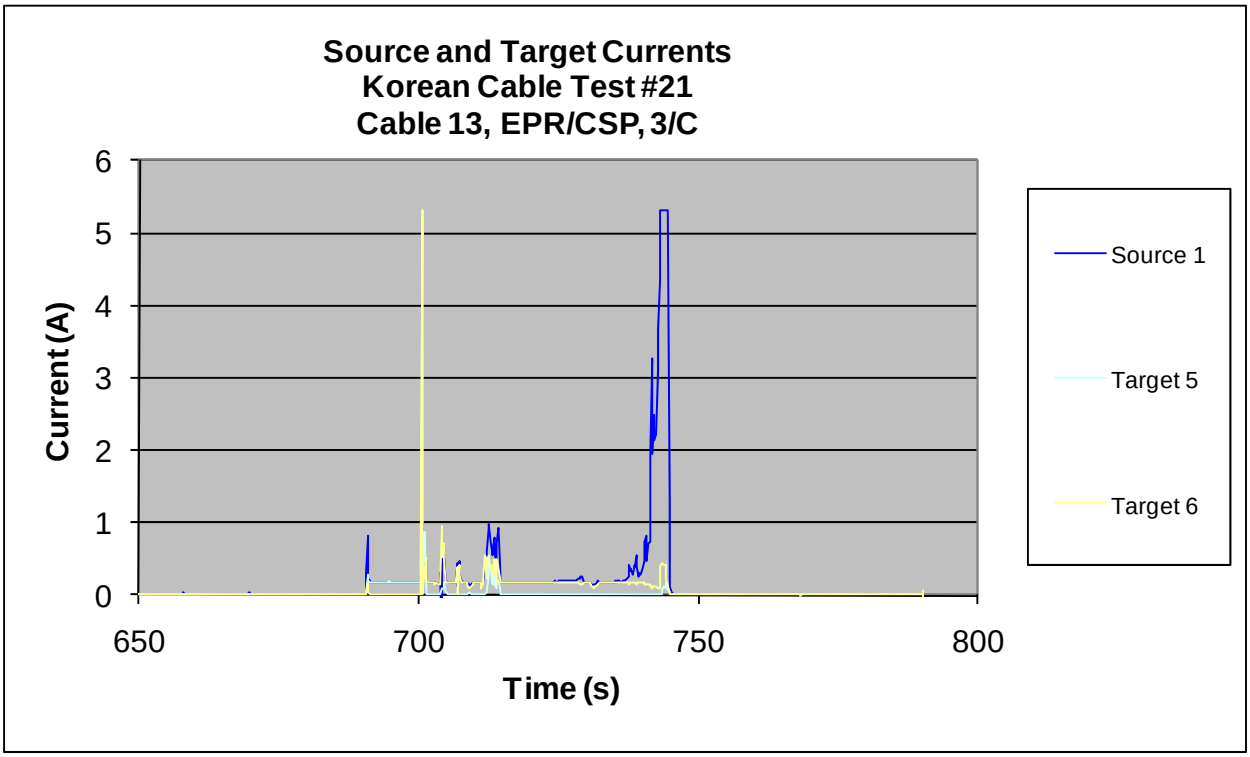
The Penlight shroud temperature was initially set at 430C and held at that value until electrical failure of the cable occurred.

Summary of Observed Faulting Behavior during Korean Cable Test #21		
Time (s)	**Event**	**Comments**
152	Penlight On; set at 430C (11.3 kW/m2)	
691-701	Spurious actuation of T5 due to hot short from S1	Initial failure manifest as a spurious actuation due to hot short (10 s duration); 437C average cable temperature
691-701	Hot short on T6 from S1	No spurious actuation because T6 is locked out by T5
701-743	Spurious actuation of T6	
701-743	Hot short on T5	
743-745	Chattering of T5 & T6 coils	Insufficient voltage for coil pickups
745	Fuse clears	

Additional observations	
1	Cable thermocouple TC-1 did not perform as expected.




Source and Target Voltage Response
Korean Cable Test #21
Cable 13, EPR/CSP, 3/C
Volts AC
140
120
100
80
60
40
20
0
650
700
750
800
Time (s)
Source 1
Target 5
Target 6

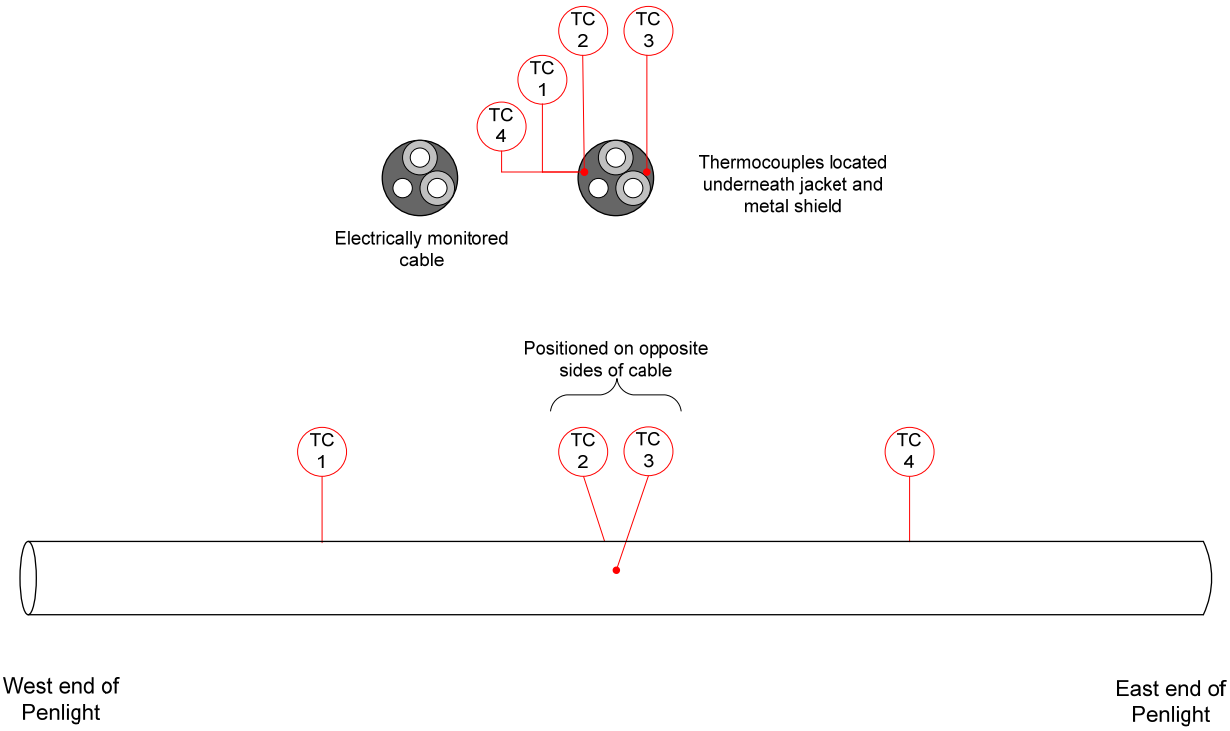

Source and Target Currents
Korean Cable Test #21
Cable 13, EPR/CSP, 3/C
Current (A)
6
5
4
3
2
1
0
650
700
750
800
Time (s)
Source 1
Target 5
Target 6

Korean Cable Test #22

Test conditions:

Cable: 2-conductor with bare drain wire, 16 AWG, EPR insulated, CSP jacketed, instrument cable (Cable ID 3).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud initially set to temperature of 440C, nominal 11.9 kW/m^2 flux from shroud.
Electrical response monitoring: SCDU system using three circuit paths - one for each insulated conductor connected to S1 and T5, the uninsulated drain wire was connected to the CPT ground return circuit path. SCDU circuit paths S2, S3, T4 and T6 were not connected to the test cable. The cable tray was grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see thermocouple map).

Two cables were included in Test #22, one electrically monitored, one thermally monitored. The test cables had a red jacket and black and white conductor insulation. The drain wire was not insulated.

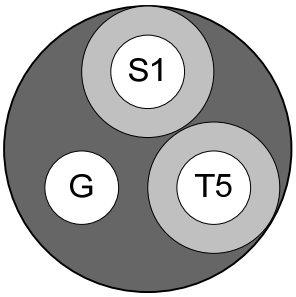


Map for placement of thermocouples inserted within the thermally monitored cable during Test #22.

Thermo-couple Name	Location
TC1	Within cable just below cable jacket and shield, to the West of the center position

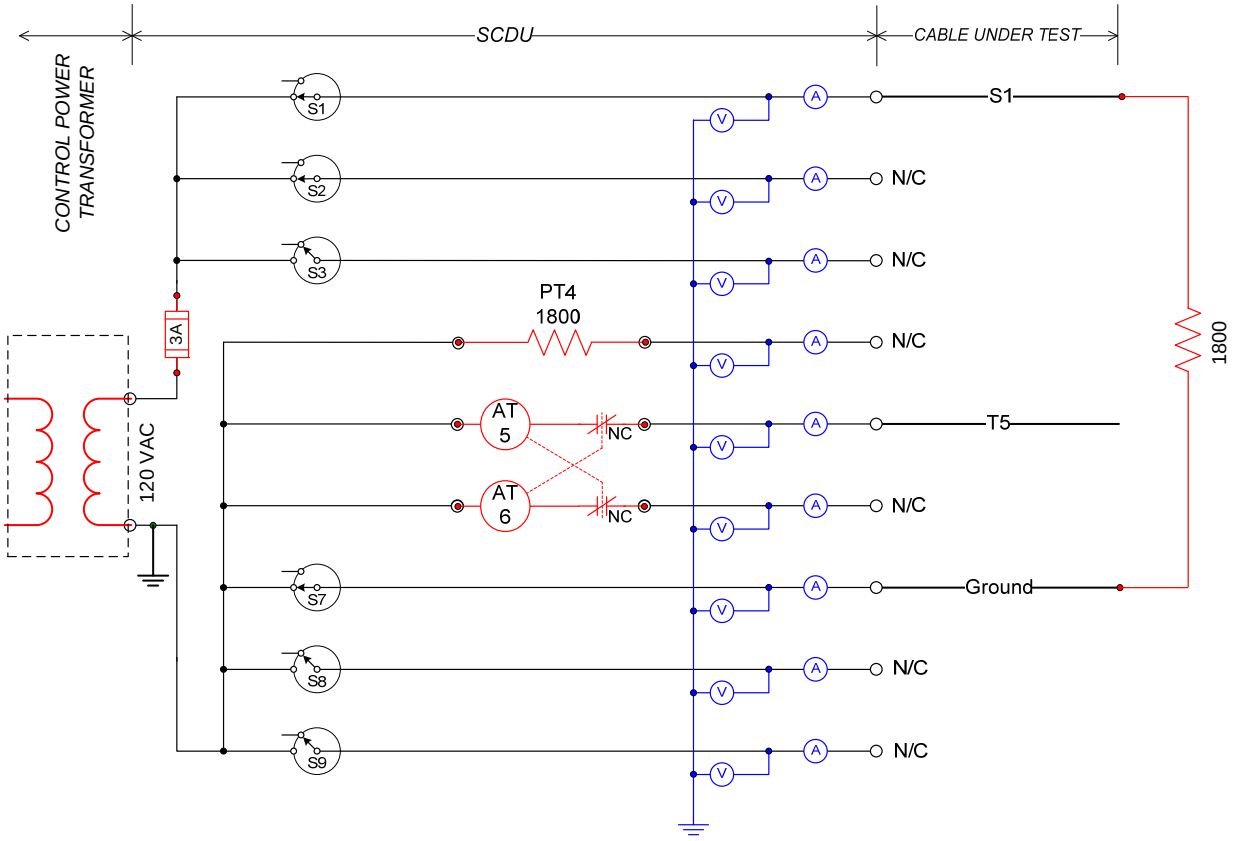
TC2	Within cable just below cable jacket and shield, at center position
TC3	Within cable just below cable jacket and shield, opposite side from Cable 2, center position
TC4	Within cable just below cable jacket and shield, to the East of the center position

Three of the seven available SCDU circuit paths were connected to the electrically monitored test cable.



SCDU channel assignments for electrically monitored cable

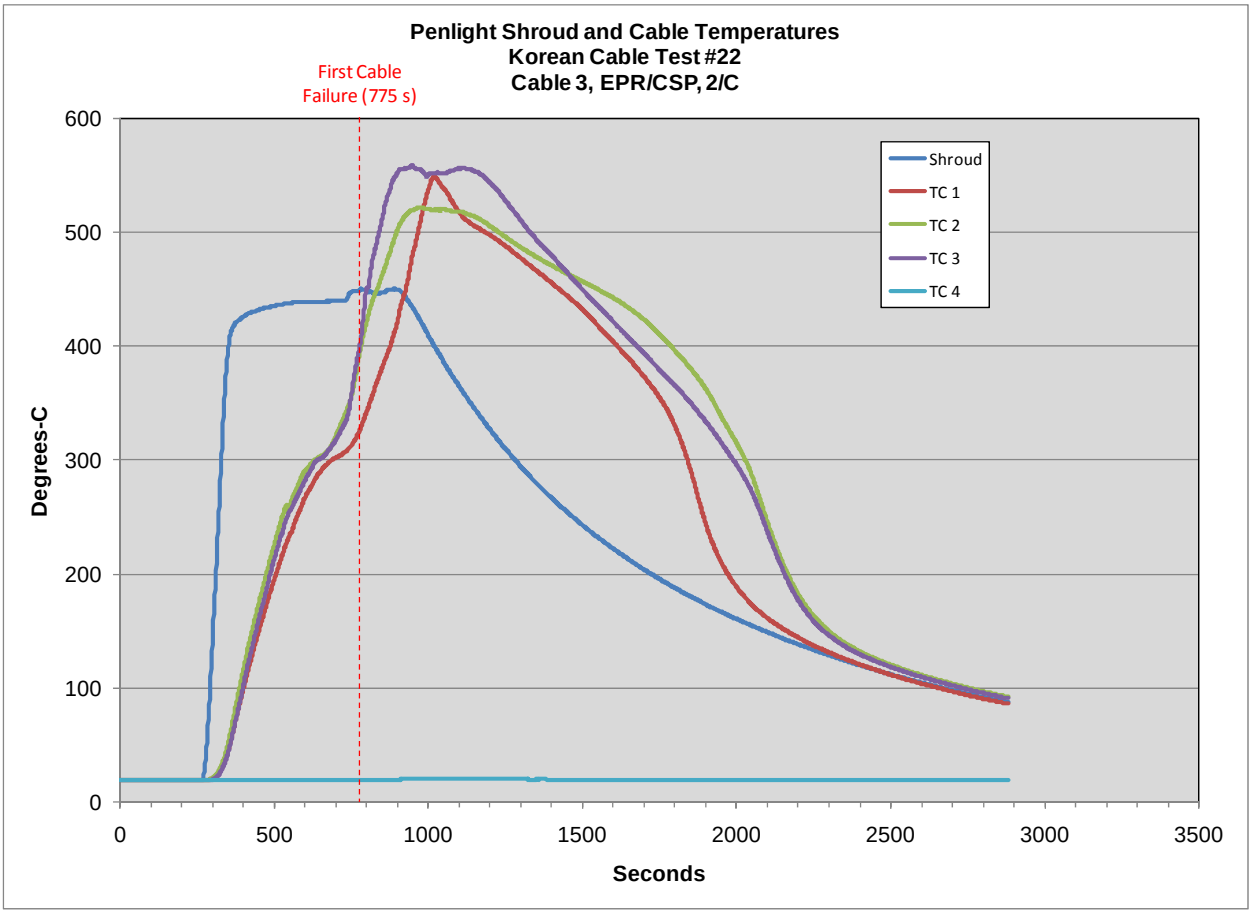
SCDU Channel	Test Cable
S1	Black
S2	
3 (Spare)	
T4	
T5	White
T6	
Ground	Drain wire

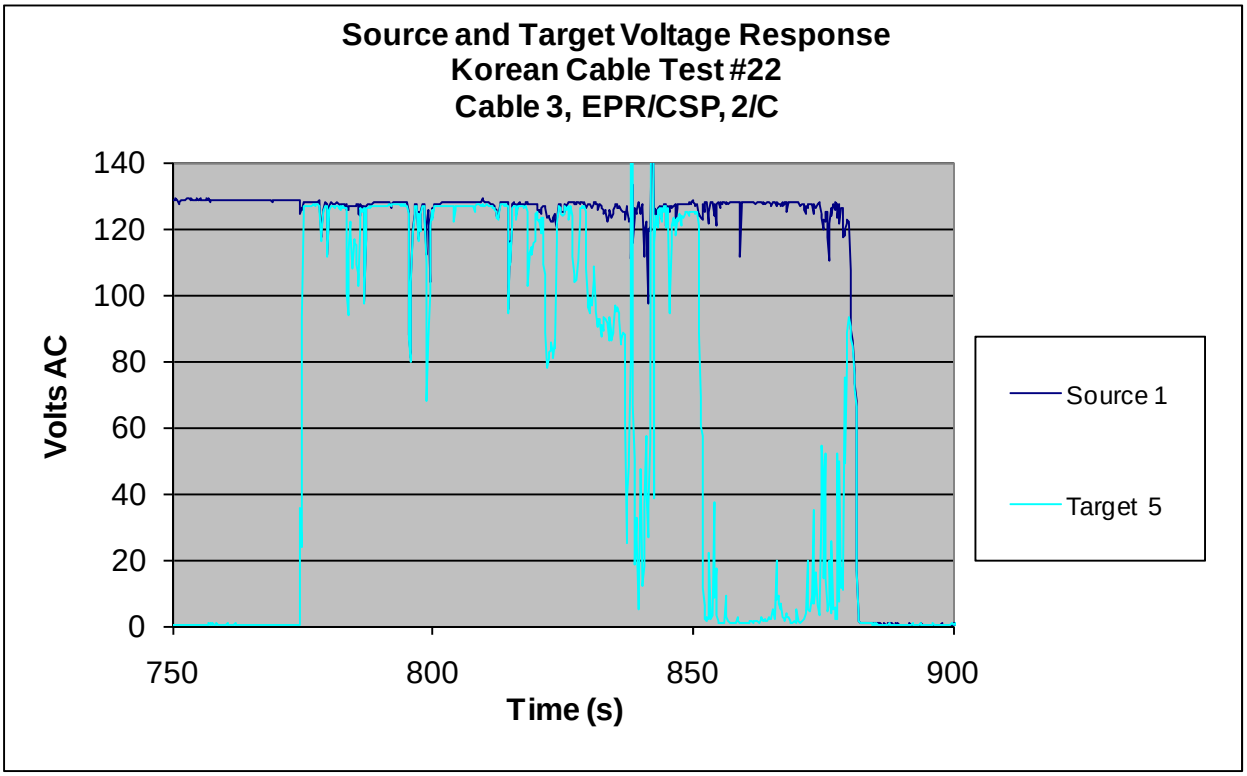


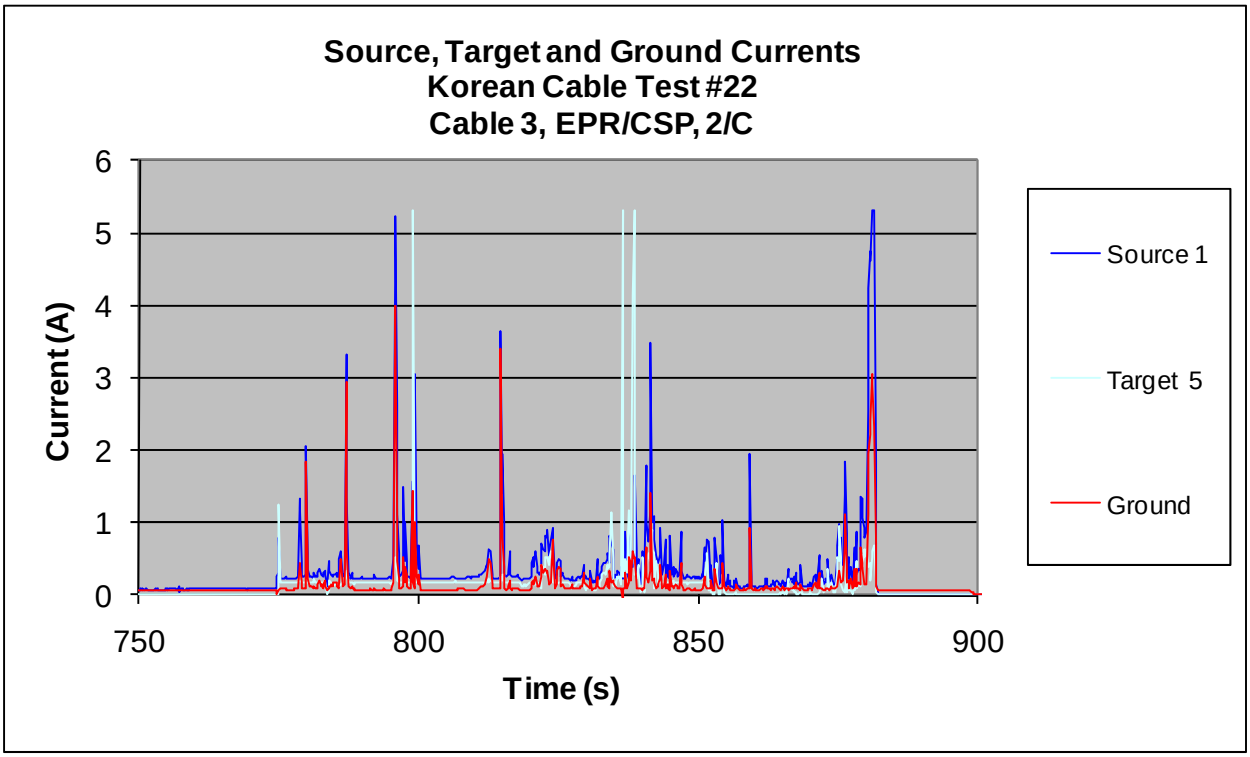
Cable conductor connections to SCDU during Test #22

The Penlight shroud temperature was initially set at 440C and held at that value until electrical failure of the cable occurred.

Summary of Observed Faulting Behavior during Korean Cable Test #22		
Time (s)	**Event**	**Comments**
269	Penlight On; set at 440C (11.9 kW/m2)	
775-831	Spurious actuation of T5 due to hot short from S1	Initial failure manifest as a spurious actuation due to hot short (56 s duration); 393C average cable temperature
831-842	T5 chattering	Insufficient voltage to pickup coil
842-851	Spurious actuation of T5 due to hot short from S!	
872-881	T5 chattering	
882	Fuse clears	
Additional observations		
1	Cable thermocouple TC-4 did not perform as expected.	


Penlight Shroud and Cable Temperatures
Korean Cable Test #22
Cable 3, EPR/CSP, 2/C
First Cable
Failure (775 s)
Shroud
TC 1
TC 2
TC 3
TC 4
Degrees-C
Seconds
600
500
400
300
200
100
0
0
500
1000
1500
2000
2500
3000
3500


Source and Target Voltage Response
Korean Cable Test #22
Cable 3, EPR/CSP, 2/C
Volts AC
140
120
100
80
60
40
20
0
750
800
850
900
Time (s)
Source 1
Target 5

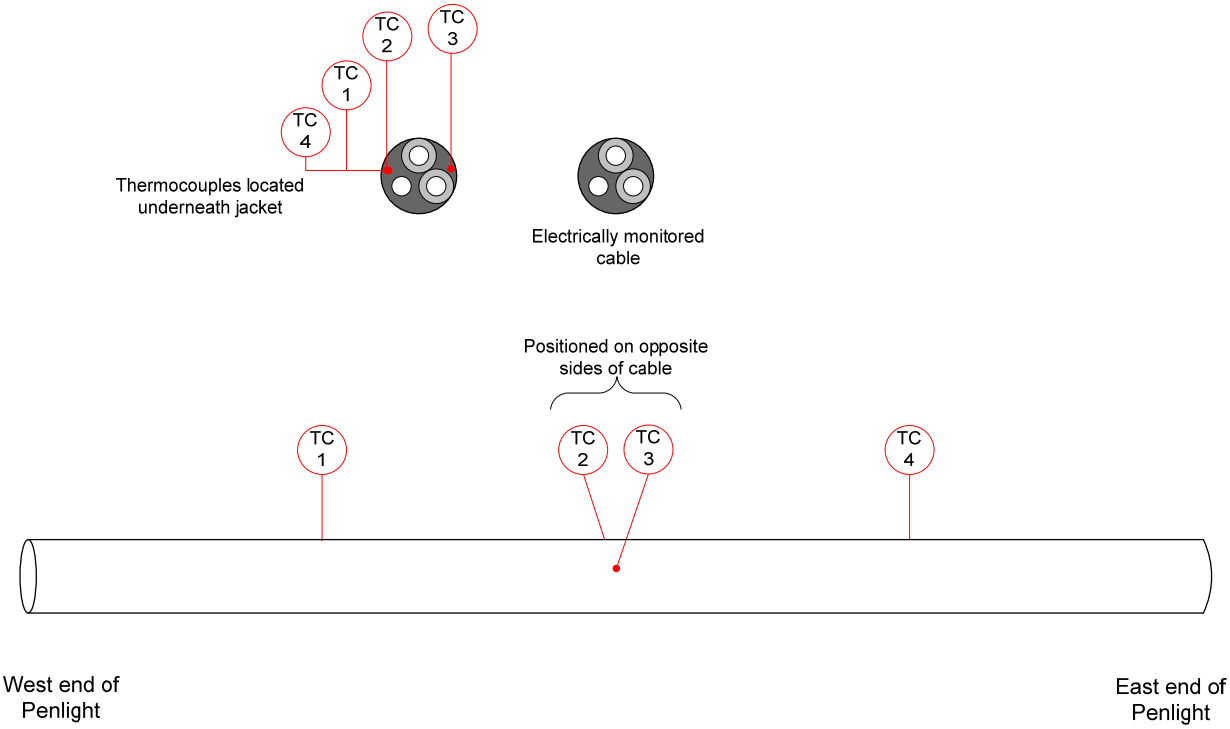

Source, Target and Ground Currents
Korean Cable Test #22
Cable 3, EPR/CSP, 2/C
Current (A)
6
5
4
3
2
1
0
750
800
850
900
Time (s)
Source 1
Target 5
Ground

Korean Cable Test #23

Test conditions:

Cable: 2-conductor with bare drain wire, 16 AWG, EPR insulated, CSP jacketed, instrument cable (Cable ID 3).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud initially set to temperature of 440C, nominal 11.9 kW/m^2 flux from shroud.
Electrical response monitoring: SCDU system using three circuit paths - one for each insulated conductor connected to S1 and T5, the uninsulated drain wire was connected to the CPT ground return circuit path. SCDU circuit paths S2, S3, T4 and T6 were not connected to the test cable. The cable tray was grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see thermocouple map).

Two cables were included in Test #23, one electrically monitored, one thermally monitored. The test cables had a red jacket and black and white conductor insulation. The drain wire was not insulated.

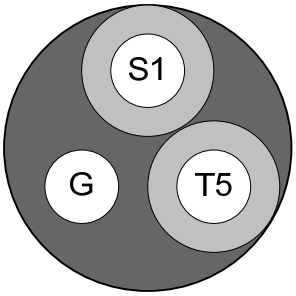


Map for placement of thermocouples inserted within the thermally monitored cable during Test #23. Note change in relative positions of thermally monitored and electrically monitored cables from previous tests.

Thermo-couple Name	Location

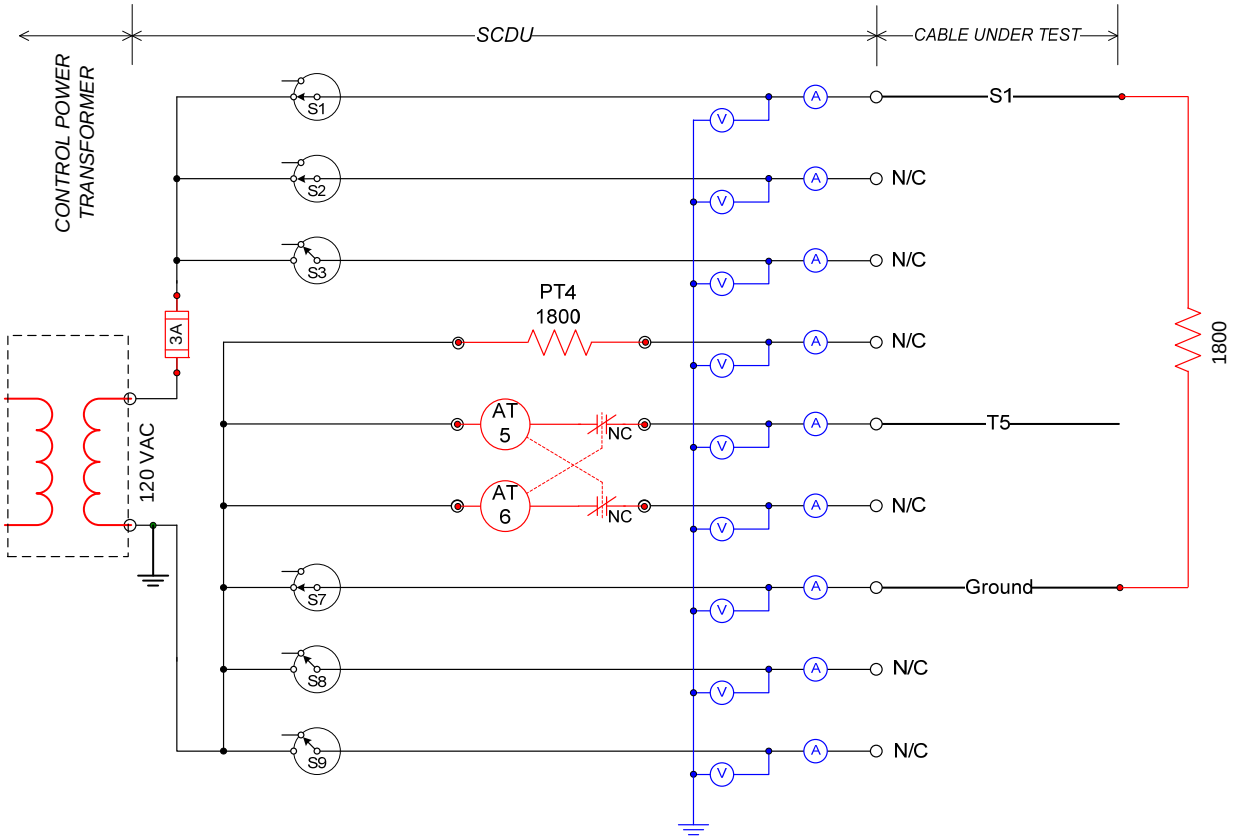
TC1	Within cable just below cable jacket and shield, to the West of the center position
TC2	Within cable just below cable jacket and shield, at center position
TC3	Within cable just below cable jacket and shield, opposite side from Cable 2, center position
TC4	Within cable just below cable jacket and shield, to the East of the center position

Three of the seven available SCDU circuit paths were connected to the electrically monitored test cable.



SCDU channel assignments for electrically monitored cable

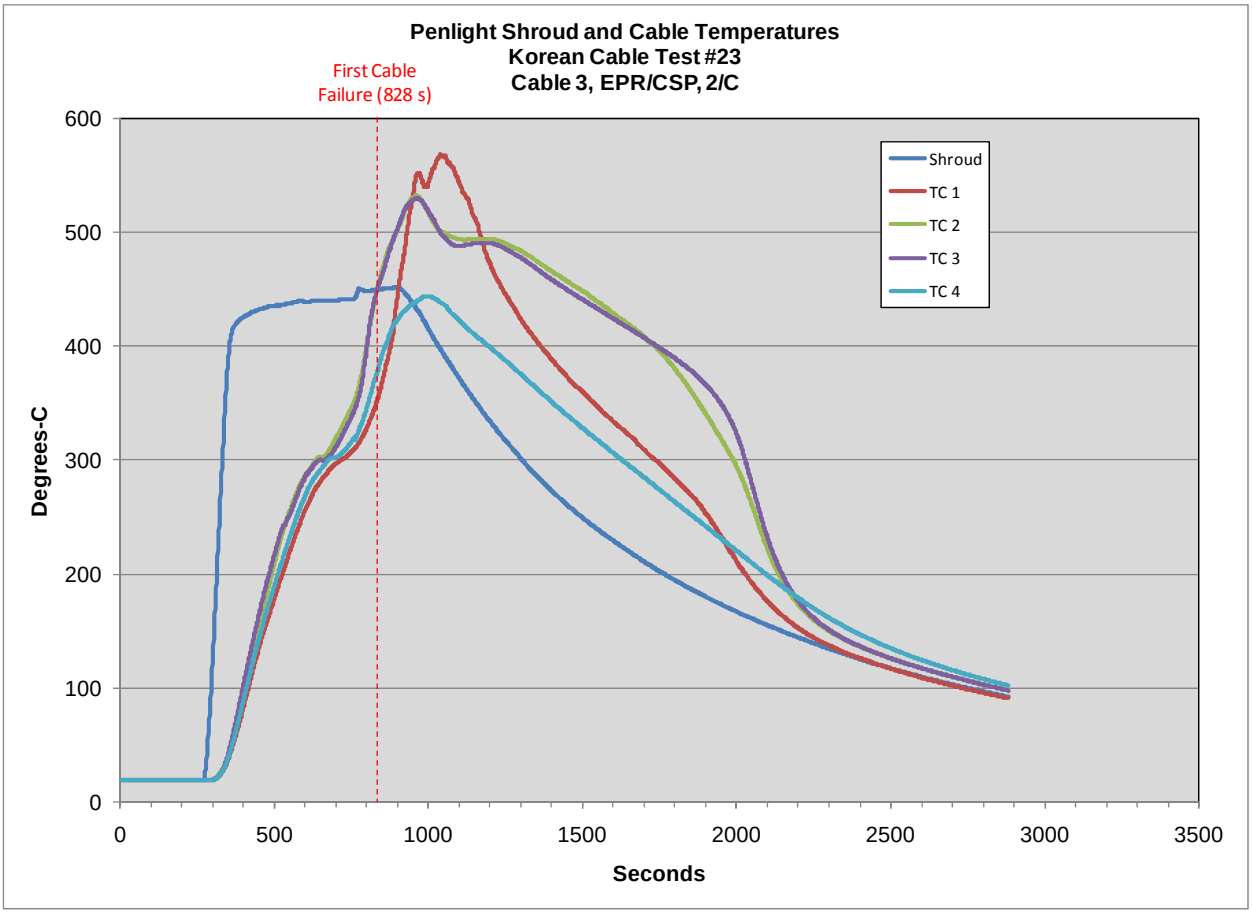
SCDU Channel	Test Cable
S1	Black
S2	
3 (Spare)	
T4	
T5	White
T6	
Ground	Drain wire

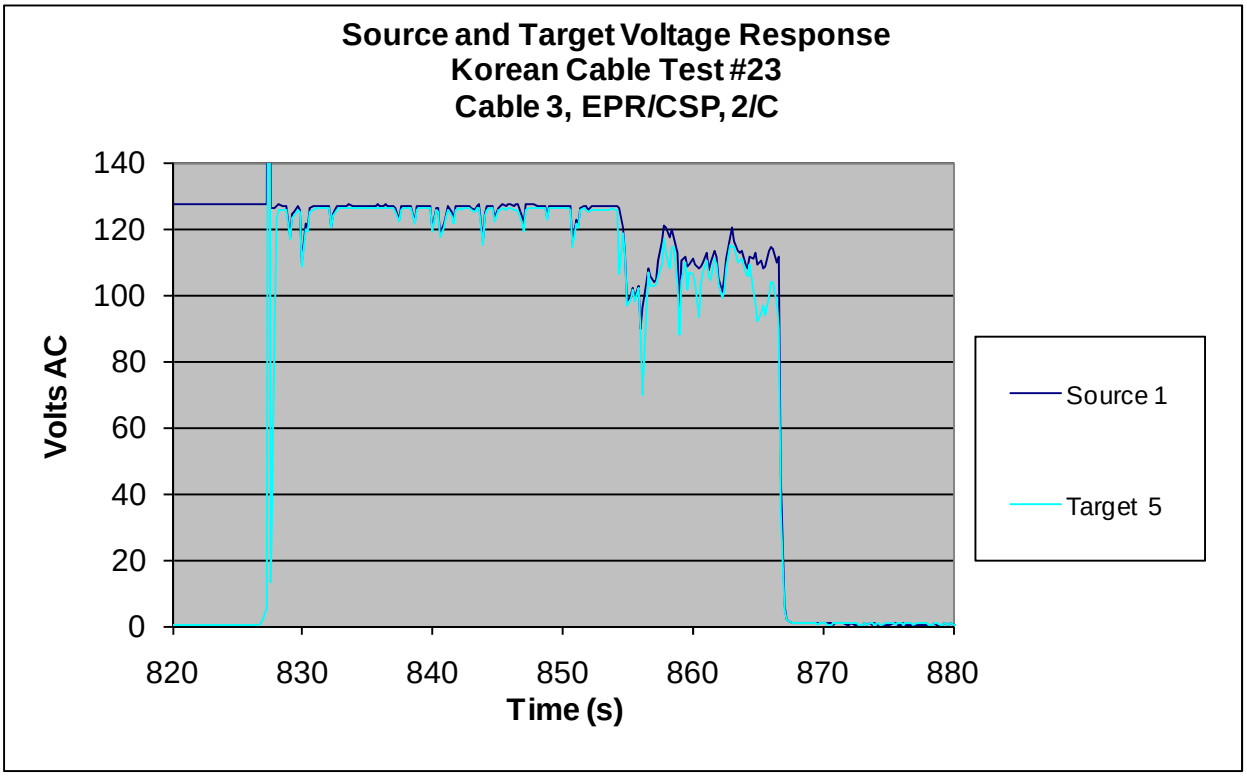


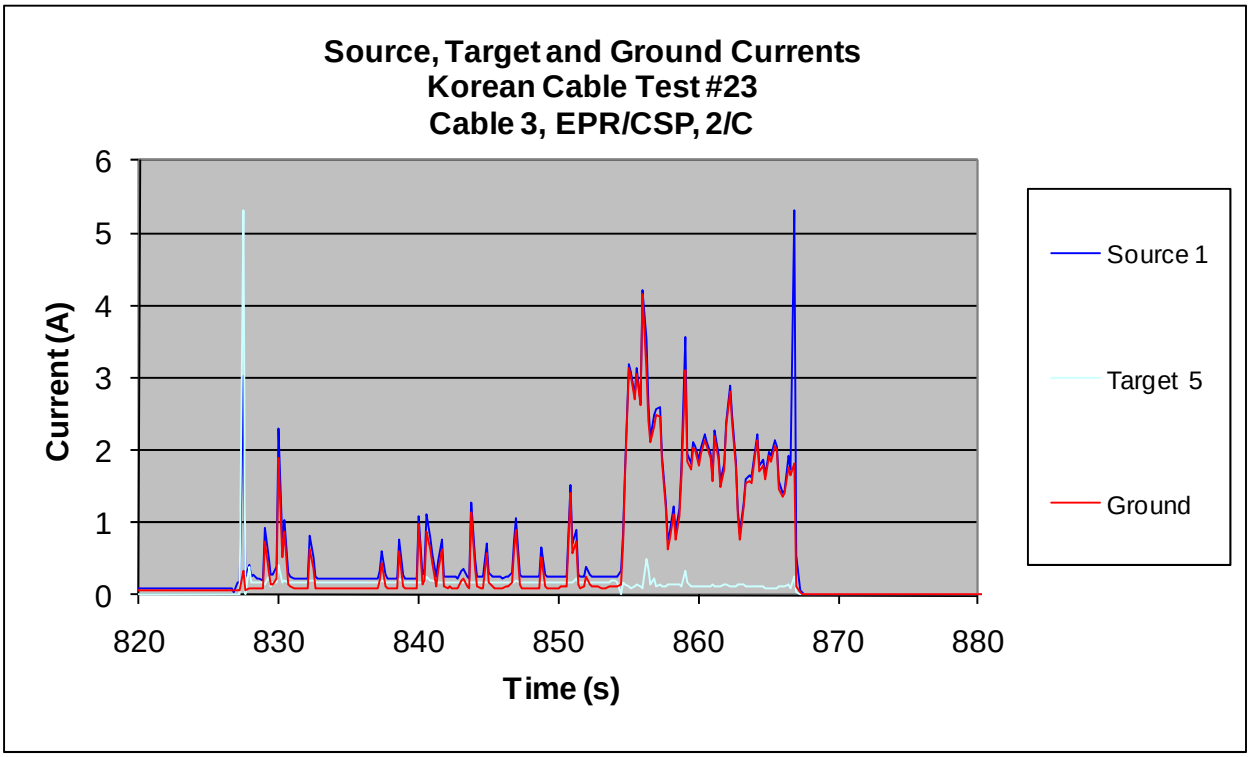
Cable conductor connections to SCDU during Test #23

The Penlight shroud temperature was initially set at 440C and held at that value until electrical failure of the cable occurred.

Summary of Observed Faulting Behavior during Korean Cable Test #23		
Time (s)	**Event**	**Comments**
273	Penlight On; set at 440C (11.9 kW/m2)	
828-867	Spurious actuation of T5 due to hot short from S1	Initial failure manifest as a spurious actuation due to hot short (39 s duration); 443C average cable temperature
867	Fuse clears	


Penlight Shroud and Cable Temperatures
Korean Cable Test #23
Cable 3, EPR/CSP, 2/C
First Cable
Failure (828 s)
Shroud
TC 1
TC 2
TC 3
TC 4
Degrees-C
Seconds
600
500
400
300
200
100
0
0
500
1000
1500
2000
2500
3000
3500


Source and Target Voltage Response
Korean Cable Test #23
Cable 3, EPR/CSP, 2/C
Volts AC
140
120
100
80
60
40
20
0
820
830
840
850
860
870
880
Time (s)
Source 1
Target 5

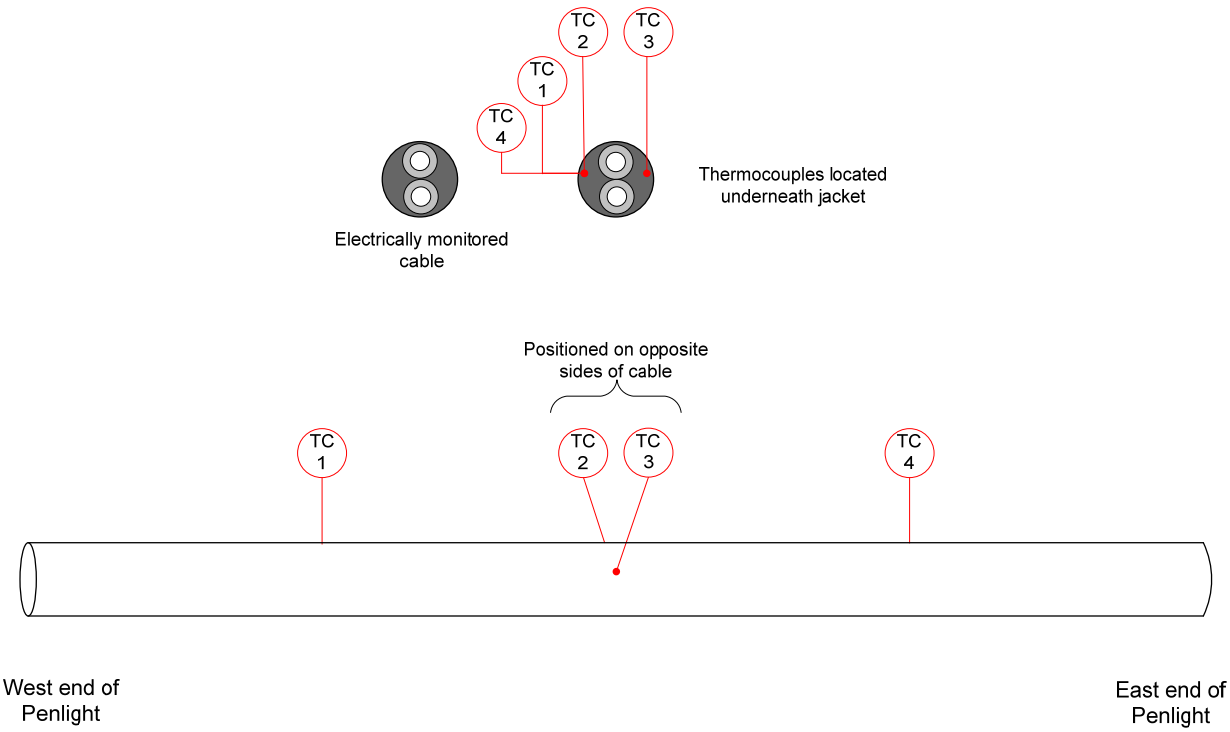

Source, Target and Ground Currents
Korean Cable Test #23
Cable 3, EPR/CSP, 2/C
Current (A)
6
5
4
3
2
1
0
820
830
840
850
860
870
880
Time (s)
Source 1
Target 5
Ground

Korean Cable Test #24

Test conditions:

Cable: 2-conductor without drain wire or shield, 16 AWG, EPR insulated, CSP jacketed, power cable (Cable ID 10).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud initially set to temperature of 440C, nominal 11.9 kW/m^2 flux from shroud.
Electrical response monitoring: SCDU system using two circuit paths - one for each insulated conductor connected to S1 and T5. SCDU circuit paths S2, S3, T4, T6 and ground were not connected to the test cable. The cable tray was grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see thermocouple map).

Two cables were included in Test #24, one electrically monitored, one thermally monitored. The cables had red jackets and black and white conductor insulation. This type of cable did not have a metal shield or drain wire.

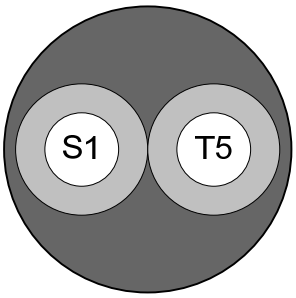


Map for placement of thermocouples inserted within the thermally monitored cable during Test #24.

Thermo-couple Name	Location
TC1	Within cable just below cable jacket, to the West of the center position
TC2	Within cable just below cable jacket, at center position

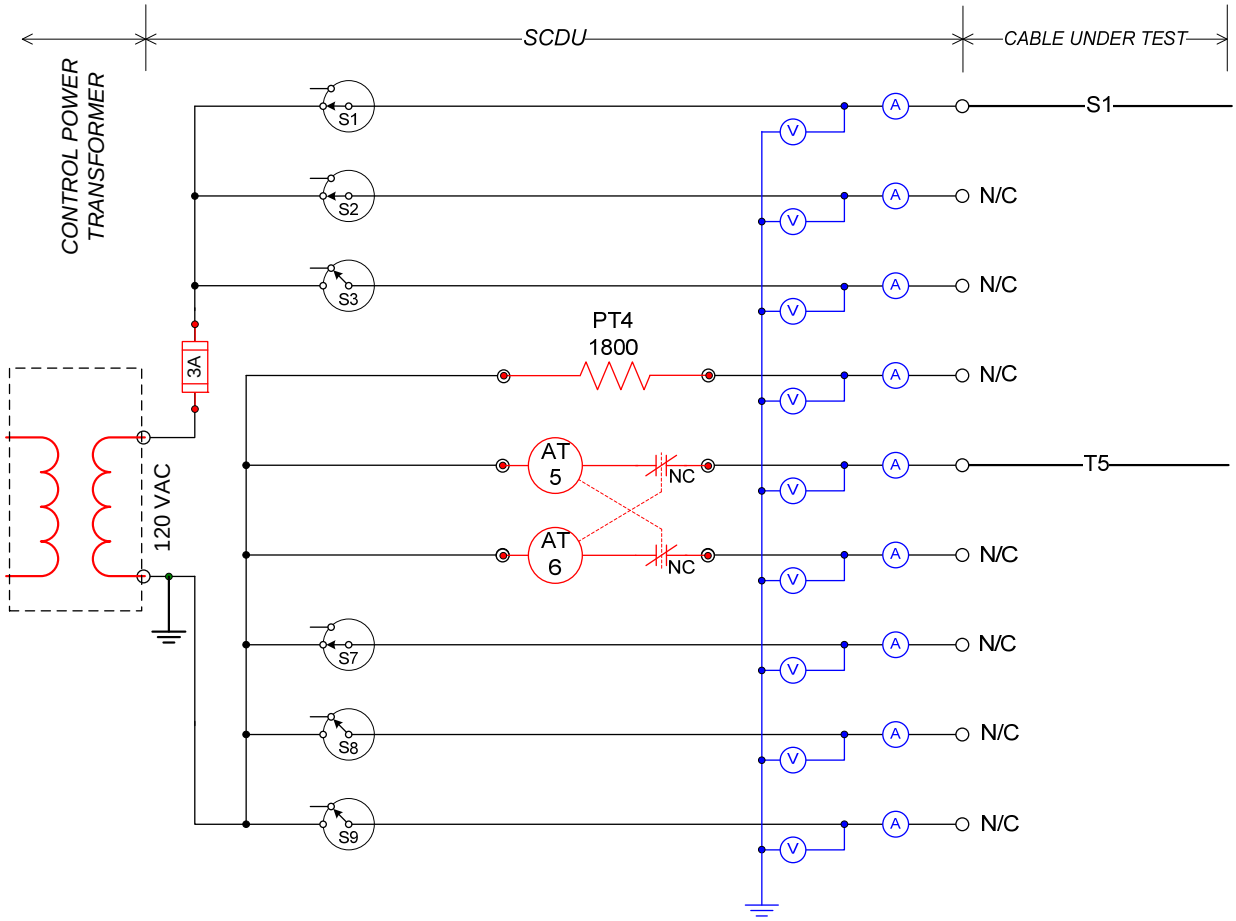
TC3	Within cable just below cable jacket, opposite side from Cable 2, center position
TC4	Within cable just below cable jacket, to the East of the center position

Two of the seven available SCDU circuit paths were connected to the electrically monitored test cable.



IRMS channel assignments for electrically monitored cable

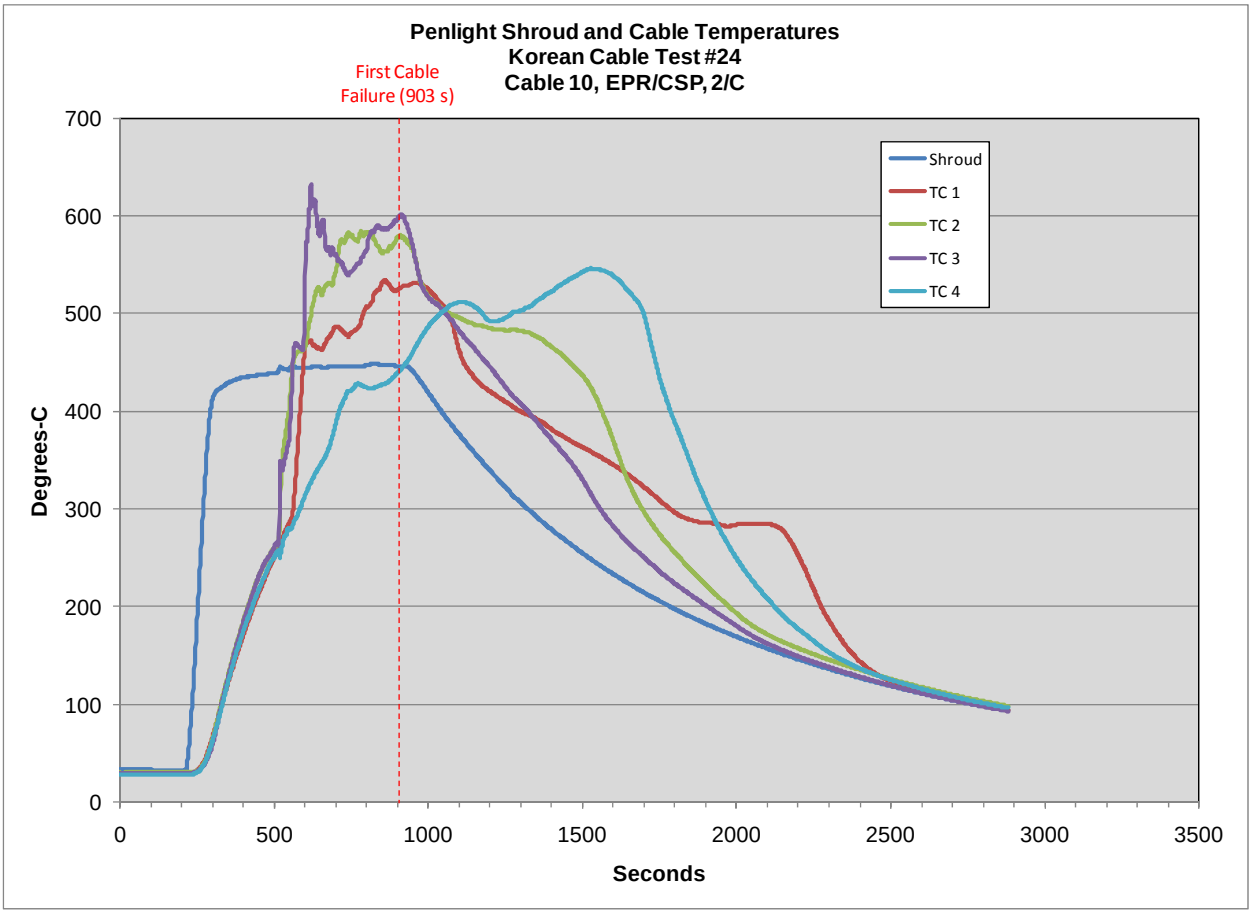
SCDU Channel	Test Cable
S1	Black
S2	
3 (Spare)	
T4	
T5	White
T6	
Ground	

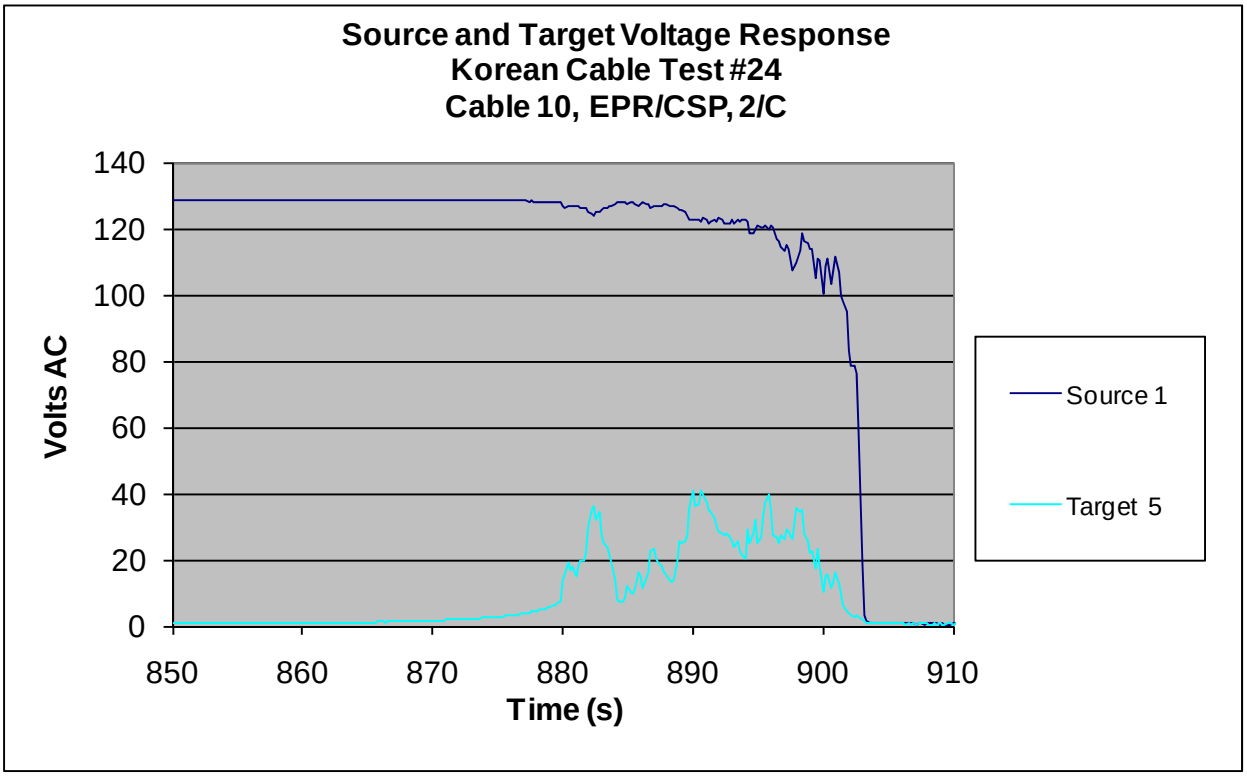


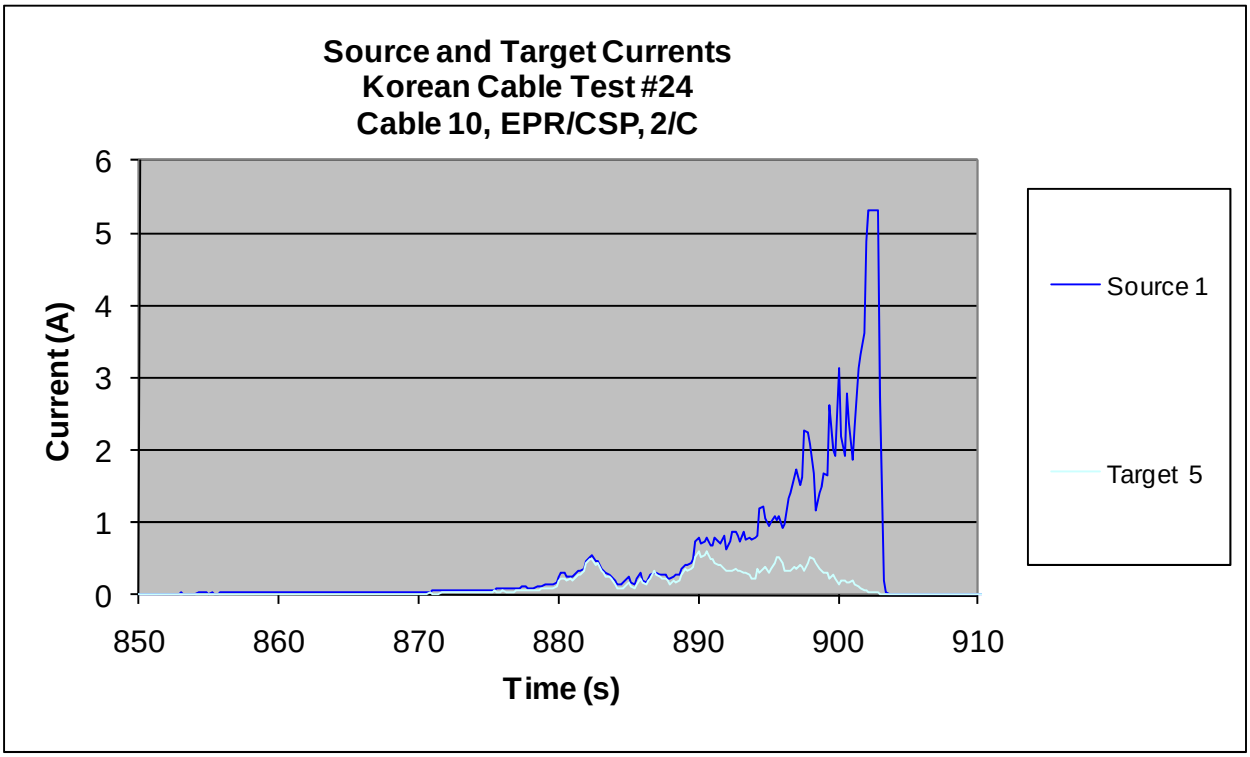
Cable conductor connections to SCDU during Test #24

The Penlight shroud temperature was initially set at 440C and held at that value until electrical failure of the cable occurred.

Summary of Observed Faulting Behavior during Korean Cable Test #24		
Time (s)	**Event**	**Comments**
214	Penlight On; set at 440C (11.9 kW/m2)	
879-902	Voltage on T5 increasing slightly, humming heard from MOV coil, no actuation occurred	Insufficient voltage to pickup coil
903	Fuse clears	Initial failure manifest as a short to ground; 588C average cable temperature at center


Penlight Shroud and Cable Temperatures
Korean Cable Test #24
Cable 10, EPR/CSP, 2/C
First Cable Failure (903 s)
Shroud
TC 1
TC 2
TC 3
TC 4
Degrees-C
Seconds
0
100
200
300
400
500
600
700
0
500
1000
1500
2000
2500
3000
3500


Source and Target Voltage Response
Korean Cable Test #24
Cable 10, EPR/CSP, 2/C
Volts AC
140
120
100
80
60
40
20
0
850
860
870
880
890
900
910
Time (s)
Source 1
Target 5

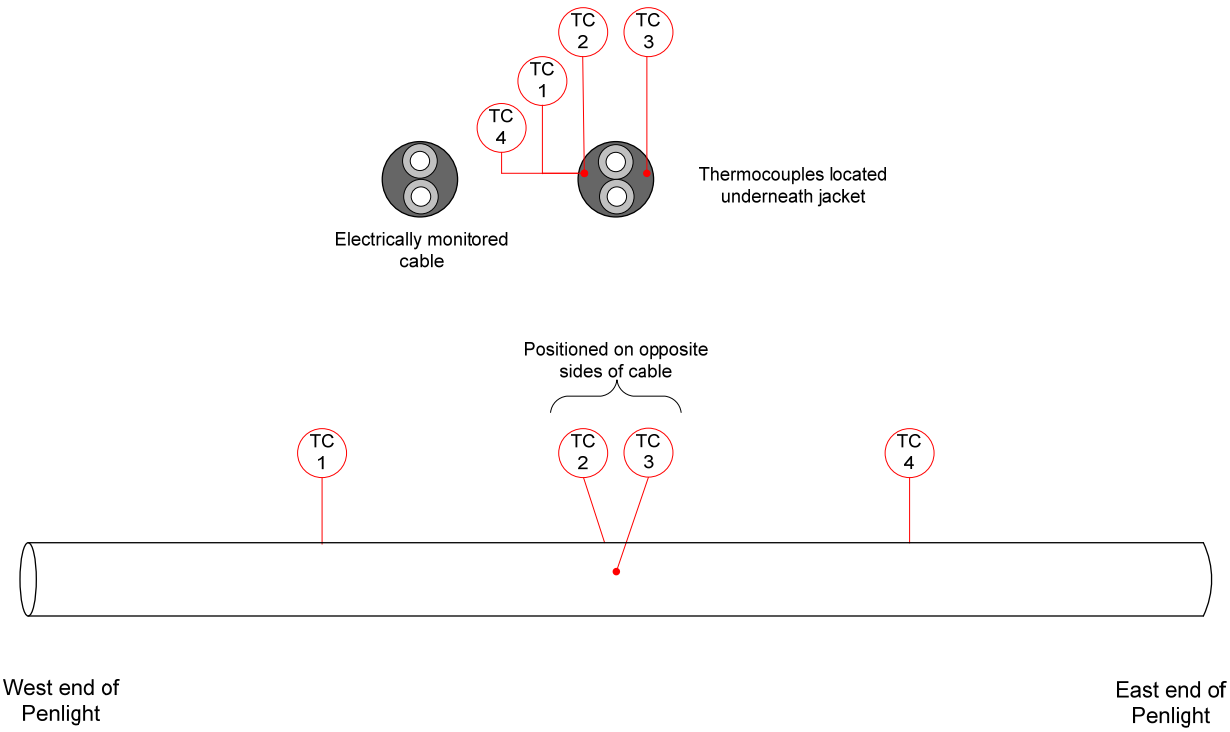

Source and Target Currents
Korean Cable Test #24
Cable 10, EPR/CSP, 2/C
Current (A)
6
5
4
3
2
1
0
850
860
870
880
890
900
910
Time (s)
Source 1
Target 5

Korean Cable Test #25

Test conditions:

Cable: 2-conductor without drain wire or shield, 16 AWG, EPR insulated, CSP jacketed, power cable (Cable ID 10).
Cable specimens present: One length of cable was monitored for electrical performance, a second length of cable monitored for temperature response, no other cable samples present.
Raceway: 12" B-Line Series 2 tray (part number 248P09-12-144) located centrally in the Penlight chamber with chamber end walls closed and un-heated.
Exposure conditions: Shroud initially set to temperature of 440C, nominal 11.9 kW/m^2 flux from shroud.
Electrical response monitoring: SCDU system using two circuit paths - one for each insulated conductor connected to S1 and T5. SCDU circuit paths S2, S3, T4, T6 and ground were not connected to the test cable. The cable tray was grounded.
Thermal response monitoring: Shroud temperature and four cable temperatures (see thermocouple map).

Two cables were included in Test #25, one electrically monitored, one thermally monitored. The cables had red jackets and black and white conductor insulation. This type of cable did not have a metal shield or drain wire.

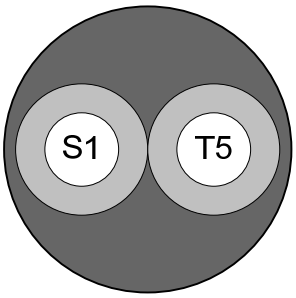


Map for placement of thermocouples inserted within the thermally monitored cable during Test #25.

Thermo-couple Name	Location
TC1	Within cable just below cable jacket, to the West of the center position
TC2	Within cable just below cable jacket, at center position

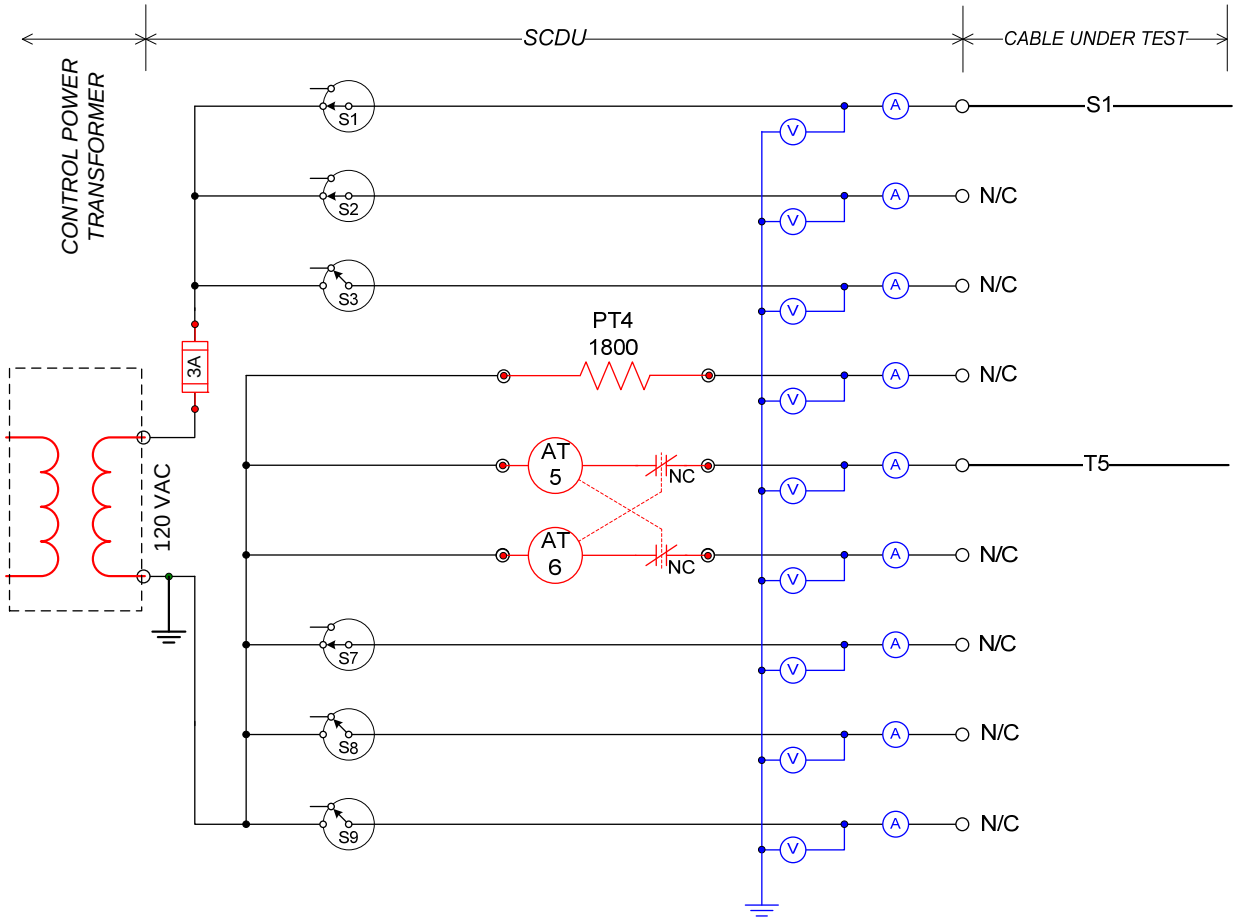
TC3	Within cable just below cable jacket, opposite side from Cable 2, center position
TC4	Within cable just below cable jacket, to the East of the center position

Two of the seven available SCDU circuit paths were connected to the electrically monitored test cable.



IRMS channel assignments for electrically monitored cable

SCDU Channel	Test Cable
S1	Black
S2	
3 (Spare)	
T4	
T5	White
T6	
Ground	

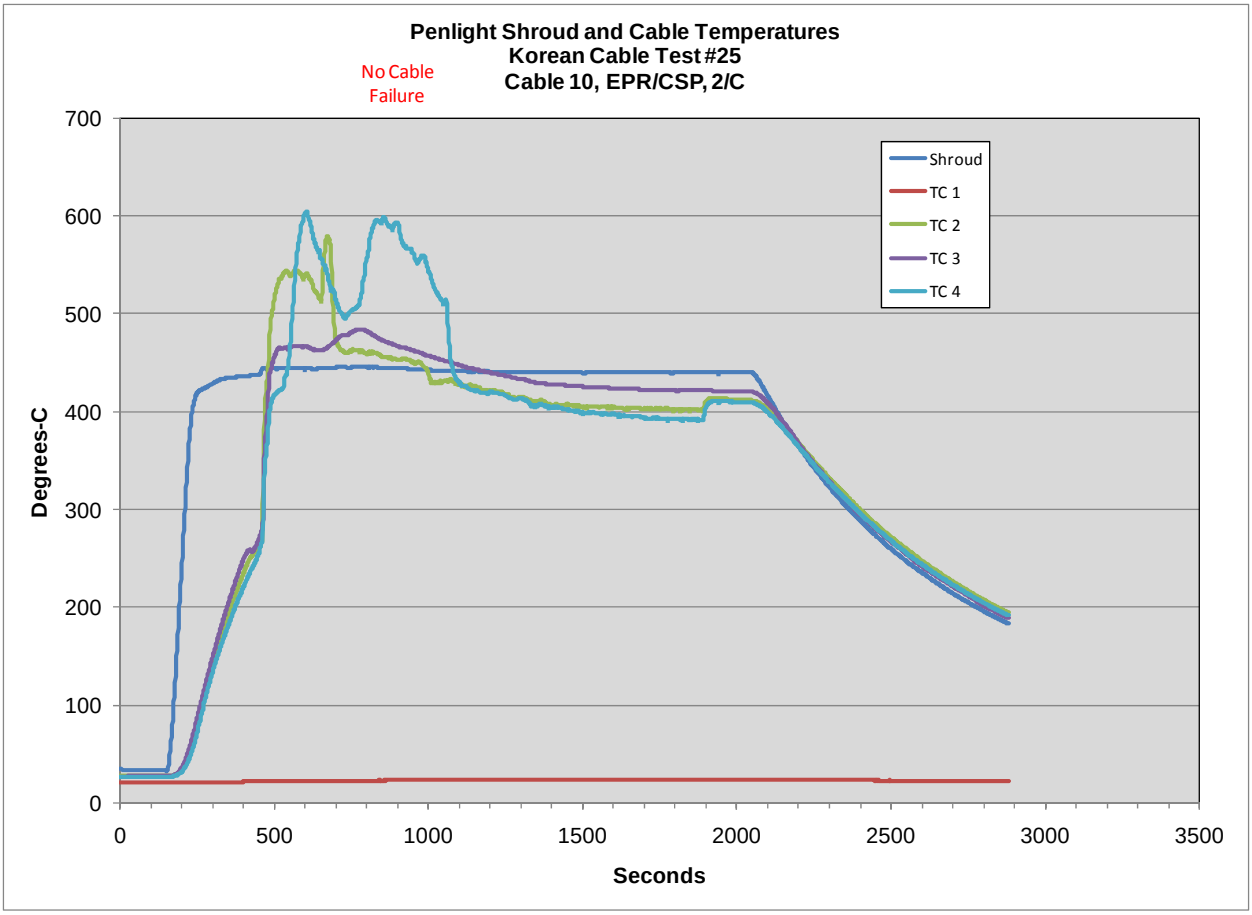


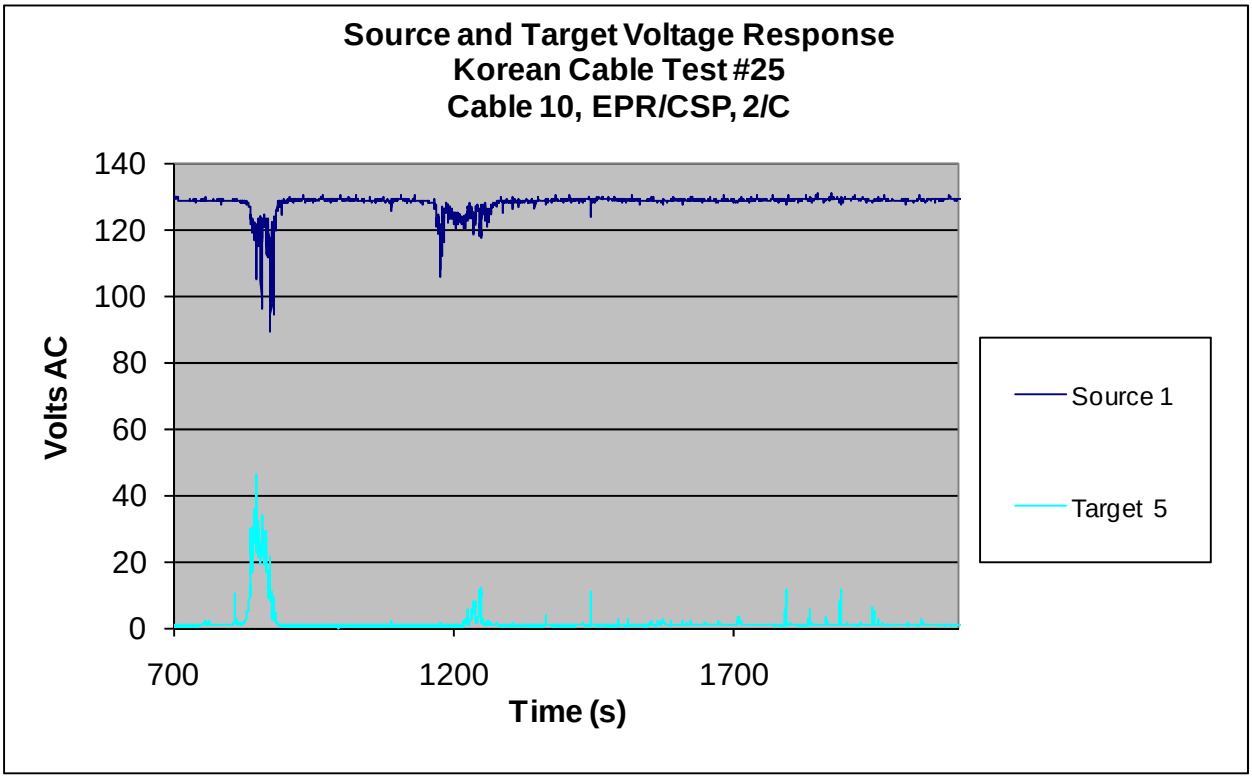
Cable conductor connections to SCDU during Test #25

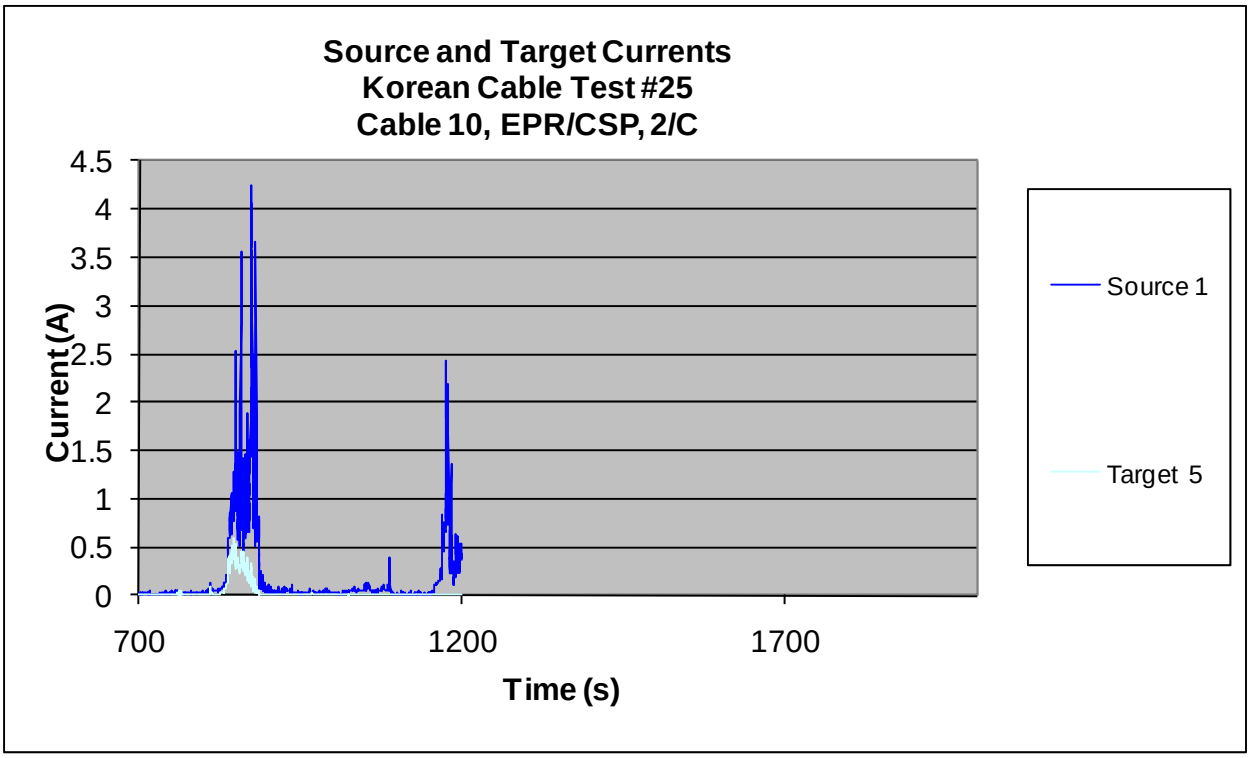
The Penlight shroud temperature was initially set at 440C and held at that value until electrical failure of the cable occurred.

Summary of Observed Faulting Behavior during Korean Cable Test #25		
Time (s)	**Event**	**Comments**
154	Penlight On; set at 440C (11.9 kW/m2)	
833-882	Voltage on T5 increasing slightly, humming heard from MOV coil, no actuation occurred	Insufficient voltage to pickup coil
1235-1240	Voltage on T5 increasing slightly, humming heard from MOV coil, no actuation occurred	
1245-1249	Voltage on T5 increasing slightly, no actuation occurred	
1891-1892	Voltage on T5 increasing slightly, no actuation occurred	
2053	Penlight shutdown	

Additional observations	
1	This cable did not fail electrically during the test.
2	Cable thermocouple TC-1 did not perform as expected.




Source and Target Voltage Response
Korean Cable Test #25
Cable 10, EPR/CSP, 2/C
Volts AC
140
120
100
80
60
40
20
0
700
1200
1700
Time (s)
Source 1
Target 5


Source and Target Currents
Korean Cable Test #25
Cable 10, EPR/CSP, 2/C
Current (A)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
700
1200
1700
Time (s)
Source 1
Target 5