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ONS-2018-016 10 CFR 50.55a(z)(1)

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ATTN: Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Duke Energy Carolina, LLC (Duke Energy)
Oconee Nuclear Station, Units 1, 2 and 3
Docket Numbers 50-269, 50-270, 50-287
Renewed License Numbers DPR-38, DPR-47, and DPR-55

Subject: Duke Energy Responses to Request for Additional Information (RAI); Request for Alternative to Codes and Standards Requirements Pursuant to 10 CFR 50.55a(z) to Satisfy 10 CFR 50.55a(h)(2) Associated with Bronze Tape Wrapped Emergency Power Cables in Use at the Oconee Nuclear Station

References:

1. Duke Energy Letter to the NRC, "Request for Alternative to Codes and Standards Requirements pursuant to 10 CFR 50.55a(z) to satisfy 10 CFR 50.55a(h)(2) associated with Bronze Tape Wrapped Emergency Power Cables in Use at the Oconee Nuclear Station," dated February 15, 2016.
2. NRC Email, "Request for Additional Information - Oconee Nuclear Station - Proposed Alternatives to Cable Separation Requirements," from Audrey Klett (NRC) to Chris Wasik (Duke Energy), dated February 1, 2018.

By letter dated February 15, 2016, Duke Energy Carolinas, LLC. (Duke Energy), submitted a request to the U.S. Nuclear Regulatory Commission (NRC) for the use of alternatives to portions of Institute of Electrical and Electronic Engineers (IEEE) Standard 279-1971, "Criteria for Protection Systems for Nuclear Power Stations," for specific configurations at the Oconee Nuclear Station, Units 1, 2, and 3 (Reference 1).

By email dated February 1, 2018, the NRC requested additional information associated with the Reference 1 Duke Energy submittal. The enclosure to this letter provides Duke Energy's response to the NRC request.

There are no regulatory commitments associated with this letter.

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NRR

Should you have any questions regarding this submittal, please contact Stephen C. Newman, Lead Nuclear Engineer, Oconee Regulatory Affairs, at (864) 873-4388.

Sincerely,

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Enclosure - Duke Energy Response to NRC Request for Additional Information cc (w/enclosure):

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ENCLOSURE

Duke Energy Response to NRC Request for Additional Information

RAI 1

During routine discussions with the NRC's licensing project manager for Oconee in summer 2017, the licensee indicated that it has completed the modifications discussed in the proposed alternative. Therefore, the staff requests the licensee to confirm the status of the modifications discussed in the application and discuss any impacts or needed changes or clarifications to the proposed alternatives as a result.

Duke Energy Response to RAI 1

The modifications identified in Attachment 1 (Commitment Table) of the February 15, 2016, submittal have been completed; consequently, Duke Energy no longer requests NRC approval of the temporary "as-is" configurations discussed in Sections 4.1, 4.2 and 4.3 of the February 15, 2016, submittal.

Attachment 1 to this RAI response contains a revision to the enclosure from the February 15, 2016, 10 CFR 50.55a(z)(1) relief request. The enclosure was revised to remove verbiage that requested Staff acceptance of the temporary "as-is" configurations while the noted station modifications were completed.

Attachment 2 of the February 15, 2016, submittal contained Duke Energy's responses to NRC questions on cable fault testing. These questions and responses were discussed in a public meeting on December 15, 2015, and were provided with the February 15, 2016, submittal as a convenience. The information in Attachment 2 of that submittal remains valid; however, Attachment 2 is not repeated as a part of this RAI response.

Section 6 of the February 15, 2016, submittal, "Risk Insights," has not been revised, even though the completed modifications associated with the Fant and CT4 cables in the KHU Equipment Gallery and PSW Cable areas would drive the original CDF/LERF risk increase value of 2E-11 even lower.

RAI 2

In Sections 4.2.3 and 4.3.2 of the licensee's application, the licensee requested the NRC to allow acceptance of the "as-is" configuration of the normally de-energized 13.8-kV power feed from the KHS to the PSW building as an alternative configuration to meeting the requirements of 10 CFR 50.55a(h)(2). The staff notes that the phrasing of this request would include Trench 3; however, in Section 6 of the application, the licensee states that Trench 3 is not addressed by the submittal. Therefore, the staff requests the licensee to clarify that the scope of the request in Sections 4.2.3 and 4.3.2 does not include Trench 3 and is only applicable to the length of cable present in the applicable areas (i.e., KHS Mechanical Equipment Gallery and the PSW Building Cable Spreading Area).

Duke Energy Response to RAI 2

The format of the original submittal was to evaluate cable configurations in each of the three discrete areas of interest. In other words, the submittal sections are location-based and not cable-based. The three areas of interest are: the PSW Building Cable Spreading Area, the KHS Mechanical Equipment Gallery and the PSW System Ductbank Manholes. Discussions as presented within the submittal are limited to the cables and potential cable interactions only within the specific areas of interest.

Potential cable interaction concerns within Trench 3 were rectified via modifications prior to the February 15, 2016, submittal. Thus, Trench 3 is not a location that is included within the scope of the submittal.

RAI 3

As discussed in the audit plan dated January 4, 2018 (ML18004A012), the staff reviewed OSC-11504, "Medium Voltage Cable Testing Analysis," during its audit.

(a) The staff determined that its safety evaluation will rely on the following information contained in this document: (1) Cable testing parameters considered in Section 4.0 of main body; (2) Engineering Report on Medium Voltage Cable Testing at KEMA Labs provided in Appendix C; and (3) MPR Induced Voltage Analysis provided in Attachment 6. Therefore, the staff requests the licensee to provide this information in a supplement to the application.

(b) Regarding the proposed alternatives for the PSW System Ductbank Manholes (MH-1 through MH-6, "as-is" configuration), the staff identified during its audit of OSC-11504, that Attachment 6 of this document states that the control cable is armored and shielded with armor grounded at both ends of cable and the shield floating (not grounded) [Page 1 of MPR Calculation No. 0079-0191-CALC-002] and that the total length of the power and control cables between Keowee and Oconee is approximately **2000 meters (6562 feet)** [emphasis added, Page No. 3 of MPR Calculation No. 0079-0191-CALC-002]. OSC-11504 also states that the power and control cables are routed in near vicinity of each other for a distance of **approximately 300 feet** [emphasis added] before the routing of the cables diverge away from each other [Page No. 3 of MPR Calculation No. 0079-0191-CALC-002]. OSC-11504 states that the edge-to-edge separation of the power and control cables along this 300 foot length is 3 inches.

In its application, the licensee mentioned that the potential for power cable to control cable interaction in the manholes represents a small portion of the overall cable run total **(approx. 180 feet out of 4500 feet)** [emphasis added]. The staff requests the licensee to explain and justify the differences between the application and OSC-11504 with regard to the length of cable subject to interaction, and any other differences between cable configurations considered in Attachment 6 of OSC-11504 and the actual cable configurations, including any grounding differences of armor and shields as considered in Attachment 6 versus what is actually installed in the field.

(c) In order to conclude that the proposed alternative provides an adequate level of safety and quality, the staff needs to confirm that the grounding of armor and shield of various cables minimizes the interactions between the power and control and instrument cables. Therefore, the staff requests the licensee to provide the general criteria considered for grounding the shields and armor of all power, control, and instrument cables associated with the proposed alternative involving the "as-is" configuration.

(d) In order to conclude that the proposed alternative provides an adequate level of safety and quality, the staff needs to confirm that the faults in the power cables would also not impact the instrument cables routed in parallel to power cables. Therefore, the staff requests the licensee to confirm that the results of induced control voltage analysis provided in Attachment 6 [Page No. 1 of MPR Calculation No. 0079-0191-CALC-002] of OSC-11504 would also apply to instrument cables with no significant difference.

Duke Energy Response to RAI 3(a)

The RAI requested the following document excerpts from OSC-11504 Rev.1, "Medium Voltage Cable Testing Analysis." The respective page(s) / page sections have been excerpted from the calculation and provided as the following attachments to this RAI response:

- Section 4.0 of Main Body (Calculation) — Attachment 3A
- Appendix C (Engineering Report on Medium Voltage Cable Testing at KEMA Labs) — Attachment 3B
- Attachment 6 (MPR Induced Voltage Analysis) — Attachment 3C

Duke Energy Response to RAI 3(b)

The testing documented in OSC-11504 was conducted to (1) determine if a multi-phase fault can propagate from a single-phase fault in the cable configuration in question and to (2) determine if the medium voltage would be directly induced on adjacent control cable via arcing of the fault. OSC-11504, Attachment 6 was generated to evaluate noise observed during line-to-ground fault testing to determine if the noise observed on the cables would be consequential to the actual plant configuration. This calculation concluded that properly grounded cable armor would attenuate and shield the conductor from noise and therefore the noise observed is inconsequential.

With regards to cable lengths, three (3) distances are called out in RAI 3(b):

1. Approximately 2000 meters (6562 ft.) -- This is the total length of the cables as an input to calculate self-inductance. This value reflects the entire control cable length from Keowee to Oconee for cables routed via the PSW Ductbank.

2. Approximately 300 ft. -- The PSW Ductbank is comprised of concrete-encased conduit segments with intermediate manholes between the segments. Segment 7 is the segment of ductbank between the last manhole (MH6) and the PSW Building. This segment, in the original implementation, contained the off-site system feeder referred to as "Fant" in the submittal and calculation. As noted in OSC-11504 Section 4, this segment was selected as the study case for the Attachment 6 analysis. This is based on this segment having orders of magnitude higher current for the test configuration and therefore was used to model the length of concurrently routed power / control cable. This length was used in the calculation as the value for the cable length where mutual inductance between power and control cables occurs in segment 7.

3. Approximately 180 ft. -- This is the summation of distance in the PSW Ductbank where the power and control cables are routed in the ductbank manholes. This represents the length of cable which is routed without any additional intervening barriers (i.e. conduit) beyond those integrated into the cable.

With regards to the element of the question concerning differences between the application and the analysis in OSC-11504, several conservativisms were noted in OSC-11504 Section 4 and Attachment 6:

- use of the most limiting cable separation,
- cable shield and twist were conservatively not included in the model (would have had additional attenuation leading to a reduction in induced voltage) and

- a conservatively high line-ground fault current.

As noted in Attachment 1, the Fant Feeder is now routed to the PSW Building in its own dedicated buried raceway and is no longer routed through Segment 7.

With regards to the element of the question concerning the grounding of armor and shields, Attachment 6 credited the armor as grounded on both ends and excluded any benefits from the presence of the shield. As discussed further in RAI 3 (c), this configuration is consistent with actual configuration for the armor, and conservative to the configuration for the shield.

Duke Energy Response to RAI 3(c)

The general criteria at Oconee Nuclear Station for cable termination for instrumentation and control cables, including armor and shield conductors, is provided in generic cable termination drawings. These drawings state [in summary]:

> Armor is being used on most cables as both mechanical and fire protection in much the same manner as conduit is used to provide these functions. The difference is that generally the armored cables will be installed in cable trays for support instead of being self-supporting. In general, armored cable must have their armors grounded at each termination point to the station ground bus.
>
> Instrument cables are provided with one or more shields. As a precaution against ground loops, the grounding of these shields shall adhere to the instructions given as to which end of the cable is grounded.

The general criteria for termination of medium voltage power cables are provided in specifications. These provide clear criteria for: (a) how to bond the ground strap to the metallic shield of the cable, (b) the ground conductor size and (c) a requirement that cable shields shall be grounded at each termination. In addition, it clarifies that metallic raceways (including cable armor) shall be bonded at each end.

Duke Energy Response to RAI 3(d)

The analysis performed in Attachment 6 of OSC-11504 only included the attenuation factor for the grounded cable armor. Both the instrument and control cables in the subject configuration have grounded cable armor. The instrument cable utilized is shielded paired cable, which includes twisted pairs with each pair individually shielded. As noted in the 3(c) response, the shield is bonded at one end. These attenuation features are not included in the analysis and would provide additional margin beyond the analyzed configuration. Therefore, based on the significant noise rejection features, the results of the analysis in Attachment 6 bound the design of both the instrument and control cables.

RAI 4

The staff requests the licensee to provide the grounding criteria for the armor and shield of the power, control, and instrument cables, relating to the proposed alternatives for the KHS Mechanical Equipment Gallery and PSW Building Cable Spreading Area.

Duke Energy Response to RAI 4

The general criteria are the same as those provided in response 3 (c).

RAI 5

The staff requests the licensee to provide electrical single line diagrams that show the interconnections of the following switchgears and transformers discussed in the application: CT 4 transformer, KPF switchgear, 1TC switchgear, CX transformer, B6T switchgear, PX13 transformer, and PCB-9.

Duke Energy Response to RAI 5

The requested equipment can be found on the following drawings provided in Attachment 2:

- KPF Breakers are found on K-700 coordinates E-7, 8, and D-7, 8,
- CX transformer (Keowee Aux Power feeder) is found on K-702 coordinates K-8 and K-700 coordinates H-13,
- PCB-9 (Keowee 230KV Switchyard breaker) is found on O-800 coordinates E-8,
- Switchgear 1TC-4 (Keowee Aux Power feeder CX) is found on O-702 coordinates H-4,
- CT-4 (Emergency Power Transformer fed from Keowee Underground) one-line and three-line diagrams are found on O-800-D coordinates E-3 and I-8, respectively,
- B6T (PSW Switchgear) is found on O-6700 coordinates G-5; Interconnections to KPF breakers are shown at coordinates L-5, and
- PX13 (4KV/600V transformer and Load Center) are shown on O-6707.

ATTACHMENT 1

Associated with Response to RAI 1

1. SYSTEMS/COMPONENTS AFFECTED

This request pertains to medium voltage single conductor bronze armor cables related to operation of the Keowee Hydroelectric Stations' (KHS) 13.8 kV and 4.16 kV underground power paths and the 13.8 kV Protected Service Water (PSW) power paths from KHS and areas where they are routed in proximity to certain Keowee safety-related control cables.

Specifically, the medium voltage power cables affected are the:

- Six (6) 13.8 kV Keowee Underground (KUG) feeder cables to CT-4;
- Three (3) 4.16 kV KHS Auxiliary CX transformer power feeder cables;
- Six (6) 13.8 kV B6T and B7T Feeder cables from the KHS to the PSW switchgear building; and
- Six (6) 4.16 kV feeder cables from PSW Switchgear B6T to 600 VAC PSW Loadcenter PX13 transformer.

The specific areas[1] associated with this request are the:

- PSW System ductbank manholes,[2]
- KHS Mechanical Equipment Gallery,
- PSW Building Cable Spreading Area.

A description of each cable's composition and its application at the Oconee Nuclear Station is given below:

<u>Cable Type 1</u>:

- Cable Description: Single conductor cable, 750 kcmil conductor, 260 mils insulation with two overlapping 10 mil layers of bronze armor shielding.
- Used On: KHS underground path to the PSW switchgear building and the PSW 4 kV switchgear to 600 V PSW Load Center.
- System Nominal Operating Voltage: 13.8 kV phase-to-phase or 8 kV phase-to-ground and 4.16 kV phase-to-phase or 2.4 kV phase-to-ground.

<u>Cable Type 2</u>:

- Cable Description: Single conductor cable, 250 kcmil conductor, 140 mils insulation with two overlapping 10 mil layers of bronze armor shielding.

[1] The control cable circuits in the buried underground concrete trench (i.e., Trench 3) have been relocated and are no longer included as part of this evaluation.
[2] Within the PSW ductbank, power and control cables are routed through separate concrete encased conduits. The area of interest is with the power/control cables located in the PSW ductbank manholes (along the PSW ductbank) which are not contained in individual conduits.

- Used On: Underground (Trench 3) path plant feed to KHS station service transformer CX from ONS Unit 1.
- System Nominal Operating Voltage: 4.16 kV phase-to-phase or 2.4 kV phase-to-ground.

2. APPLICABLE REGULATORY REQUIREMENT

10 CFR 50.55a(h)(2), *"Protection Systems,"* states: "For nuclear power plants with construction permits issued after January 1, 1971, but before May 13, 1999, protection systems must meet the requirements in IEEE Std. 279–1968, "Proposed IEEE Criteria for Nuclear Power Plant Protection Systems," or the requirements in IEEE Std. 279–1971, "Criteria for Protection Systems for Nuclear Power Generating Stations," or the requirements in IEEE Std. 603–1991, "Criteria for Safety Systems for Nuclear Power Generating Stations, and the correction sheet dated January 30, 1995. For nuclear power plants with construction permits issued before January 1, 1971, protection systems must be consistent with their licensing basis or may meet the requirements of IEEE Std. 603–1991 and the correction sheet dated January 30, 1995."

Although the ONS construction permit was issued prior to January 1, 1971, the current licensing bases is that ONS will satisfy Section 4.2 of IEEE Std. 279-1971 for the Oconee Emergency Power and Emergency Core Cooling systems. NRC acceptance of the IEEE Std. 279-1971 single failure criteria is documented in three (3) 1976 safety evaluations associated with changes to the Emergency Core Cooling System model which conformed to the requirements of 10 CFR 50.46. IEEE Std. 279-1971, Section 4.2, "Single Failure Criterion," requires, in part, that any one single failure within the protection system shall not prevent the proper protective action at the system level when required (Reference 8.2). The potential for not satisfying the single failure criteria (based on the requirements of 10 CFR 50.55a(h)) due to interactions between cables in certain cable transition areas is the specific issue addressed by this request. Options available to Duke Energy under this circumstance include 10 CFR 50.55a(z).

10 CFR 50.55a(z) states:

"Alternatives to the requirements of paragraphs (b) through (h) of this section or portions thereof may be used when authorized by the Director, Office of Nuclear Reactor Regulation, or Director, Office of New Reactors, as appropriate. A proposed alternative must be submitted and authorized prior to implementation. The applicant or licensee must demonstrate that:

(1) Acceptable level of quality and safety. The proposed alternative would provide an acceptable level of quality and safety; or

(2) Hardship without a compensating increase in quality and safety. Compliance with the specified requirements of this section would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety."

This request seeks NRC approval in accordance with 10 CFR 50.55a(z)(1) as a part of the resolution of the concerns identified in the Unresolved Item discussed in Section 3 below."

3. REASON FOR REQUEST

A June 27, 2014 NRC letter (Reference 8.8) identified an Unresolved Item (URI) regarding a concern that postulated short circuits and/or ground faults in electrical cabling located in an underground concrete raceway could potentially impact the functionality of the emergency power system which is required to mitigate certain design basis events. The NRC inspection team subsequently requested assistance from the Office of Nuclear Reactor Regulation (NRR) by means of a Task Interface Agreement (TIA), to review the Oconee Nuclear Station emergency power system licensing bases to determine the acceptability of the design (Reference 8.9) with respect to Oconee's current licensing basis.

Duke Energy has taken several anticipatory actions (i.e., plant modifications) to address the concerns identified in the URI. This submittal requests NRC review and approval under the provisions of 10 CFR 50.55a(z)(1) of certain alternatives to codes and standards. Duke Energy believes that these proposed alternatives address the concerns associated with the URI and that they provide an acceptable level of quality and safety.

The previously referenced URI is associated with a single failure compliance question with IEEE Std. 279-1971. Specifically, the issue is associated with a potential of a power cable fault that causes an adverse interaction with control cables in close proximity to the faulted power cable. This request addresses the NRC concerns by proposing permanent modification to the plant licensing basis. In summary, to address NRC concerns with single failure capabilities ONS requests:

1. Permanent acceptance of the current configuration in the PSW ductbank manholes and the 13.8 kV B6T and B7T Feeder cables from the KHS to the PSW switchgear building based on cable design, operation and testing.
2. Acceptance of the application of Paragraph 6.1.4 of IEEE Std. 384-1992, "Limited Hazard Areas," as a means of providing acceptable cable separation in certain modified areas of the plant. The classification is appropriate because these are areas containing power cables, but without any Hazard Area drivers being present (e.g., missiles, high energy lines etc.).

The description details and justifications for the 10 CFR 50.55(a)(z)(1) request are given below:

3.1 Description of Affected Locations

As part of a 2014 Component Design Basis Inspection (CDBI), a question was raised by an inspection team whether this bronze tape on medium voltage power cables in Trench 3 can be credited as armor when evaluating failures per IEEE Std. 279-1971, Section 4.2, and thus whether credit can be taken for its single failure mitigation properties. As described below, the plant areas within the scope of this submittal are the PSW system ductbank manholes, Keowee Mechanical Equipment Gallery, and the PSW building Cable Spreading Area.

3.1.1 PSW System Ductbank Manholes

The PSW system is designed as a standby system for use under emergency conditions. The PSW system provides added "defense in-depth" protection by serving as a backup to certain existing safety systems. The PSW system is provided as an alternate means to achieve and maintain safe shutdown conditions for one, two or three units following certain postulated scenarios. The PSW system also reduces fire risk by providing a diverse power supply to power safe shutdown equipment in accordance with the National Fire Protection Association (NFPA) 805 safe shutdown analyses.

As noted above, the defense-in-depth function of the PSW system provides a diverse means to achieve and maintain safe shutdown by providing secondary side decay heat removal, Reactor Coolant System (RCS) pump seal cooling, RCS primary inventory control, and RCS boration for reactivity management following plant scenarios that disable the 4.16 kV essential electrical power distribution system. The PSW electrical system is designed to provide power to PSW mechanical and electrical components as well as other system components needed to establish and maintain a safe shutdown condition. The system is designed to supply the necessary loads and is electrically independent from the Oconee station electrical distribution system and the SSF. No credit is taken in the safety analyses for PSW system operation following design basis events. The PSW System can be supplied power from an offsite transmission feed or the KHS.

A separate PSW electrical equipment structure (PSW Switchgear Building) is provided for major PSW electrical equipment. Normal power is provided from the Central Tie Switchyard via a 100 kV transmission line to a 100/13.8 kV PSW substation located adjacent to Oconee Nuclear Station and then via a 13.8 kV feeder (Fant Line) that enters the PSW building via a direct buried route independent of other cables.

Alternate QA-1 power is available from each Keowee Hydroelectric Generating unit as an electrical source to the PSW building. The route from KHS to PSW consists of an underground 13.8 kV power cable feeder connecting Keowee output breakers KPF-11 and KPF-12 located in KHS to transformers CT6 and CT7 located in the PSW building. The Keowee switchgear circuit breaker and bus arrangement provides the capability of aligning either the Keowee Unit 1 or Unit 2 generators to the CT6 and/or CT7 transformers.

The KHS to PSW 13.8 kV power feed initially routes from Keowee through an underground trench (along with the CT-4 underground feeder), and then diverts into a separate ductbank / manhole system before reaching the CT-4 blockhouse. The PSW ductbank system from the underground trench to the PSW building consists of underground duct with six intervening manholes. The underground duct segments connecting the manholes consist of separate PVC conduits surrounded by concrete fill. The manholes are designed with the control cables routed across the bottom in a cable tray and the power cables racked above the floor on separate supports. The manhole closest to the underground trench is designated Manhole-1 (MH-1) and the manhole closest to the PSW building is designated MH-6. The KHS to PSW 13.8 kV power feed is the Technical Specification credited powerpath but it is not the normal power feed for this system. These cables are typically energized only during PSW system powerpath surveillance testing that is performed on a quarterly basis (~33 hours/year total).

In addition to the power feeds, the PSW ductbank system contains low voltage Instrumentation & Control (I&C) cables consisting of supervisory functions for both KHUs, one train of KHU emergency start (safety-related), one train switchyard isolation complete (safety-related), PCB-9 control, and PSW KPF breaker control.

Power and control cable routing in the PSW ductbank manholes is consistent with Duke Energy design specifications (Reference 8.13).

3.1.2 <u>KHS Mechanical Equipment Gallery</u>

The KHS Mechanical Equipment gallery contains motor control centers, cooling water strainers, governors, and Keowee Power Feeder (KPF) Switchgear KPF-1 and KPF-2. In addition, cabling for the CT-4 underground feeder, the KHS to PSW underground feeder, the KHS to PSW Switchgear (KPF) line side cable bus, the feeder from switchgear 1TC to transformer CX, and adjacent safety-related control cables, all route through the area.

Power and control cable routing in the KHS Mechanical Equipment Gallery is consistent with Duke Energy design specifications (Reference 8.13).

3.1.3 <u>PSW Building Cable Spreading Area</u>

The PSW building Cable Spreading Area is a section of the PSW switchgear building into which the cables discussed in the previous sections enter from the PSW ductbank system. In addition, there are low voltage I&C cables consisting of supervisory functions for both KHUs, one train of KHU emergency start cables (safety-related), one train switchyard isolation complete (safety-related), PCB-9 control, and breaker control for the PSW KPF switchgear. This area also contains PSW power and control cables.

Power and control cable routing in the PSW Building Cable Spreading Area is consistent with Duke Energy design specifications (Reference 8.13).

4. PROPOSED ALTERNATIVE AND BASIS FOR USE

This request is specific to the applications identified herein and is not intended to be a blanket request for approval of the use of IEEE Std. 384-1992 at ONS.

4.1 PSW System Ductbank Manholes[3]

Current Configuration:

The KHS to PSW 13.8 kV power feed initially routes from Keowee through an underground trench and then diverts into a separate ductbank/manhole system before reaching the CT-4 blockhouse. The PSW ductbank system from the underground trench to the PSW building consists of an underground duct with six intervening manholes. The manhole closest to the underground trench is designated Manhole-1 (MH-1) and the one closest to the PSW switchgear building is designated Manhole-6 (MH-6). The feed from the KHS to PSW is normally not energized.

The PSW ductbank system also contains low voltage Instruments & Controls (I&C) cables routed in separate ductbank conduits consisting of supervisory functions for both KHUs, one train of KHU emergency start, one train switchyard isolation complete, PCB-9 control, and breaker control for the PSW KPF switchgear. In addition, future station changes may route a second channel of KHU Emergency Start and Switchyard Isolation Complete via the PSW ductbank.

Proposed Alternate Method:

Pursuant to 10 CFR 50.55a(z), Duke Energy requests:

1. For manholes 1 through 6, Duke Energy requests to modify the ONS licensing basis pursuant to 10 CFR 50.55a(z) to allow acceptance of the "as-is" configuration of the normally de-energized 13.8 kV KHS to the PSW building power feed as an alternative configuration to meeting the requirements of 10 CFR 50.55a(h)(2).

[3] The KHS to PSW power cables in the PSW ductbank are routed through individual concrete encased conduits that are separate from the I&C cables and conduit within the same ductbank. The area of concern for interaction is within the PSW ductbank manholes, where power cables and I&C cables are not contained within individual conduits.

An acceptable level of quality and safety is demonstrated via the following:

- satisfactory cable crush test results (refer to Section 5),
- satisfactory cable fault test results (refer to Section 5),
- the potential for power cable to control cable interaction in the manholes represents a small portion of the overall cable run total (~180 feet out of ~4500 feet),
- robust power cable design and cables procured to QA-1 standards which minimizes the likelihood of cable interactions,
- the KHS to PSW power cables are not normally energized which minimizes the likelihood of cable interactions; for a PSW event, these cables would only be energized if the Fant Line is unavailable,
- high impedance grounding system limits fault current (KHS-PSW feeder) and minimizes the effect of any cable interaction should a fault occur,
- station power cables are evaluated as described in UFSAR Section 18.3.14, "Insulated Cables and Connections Aging Management Program," and
- the cables are housed in a steel-reinforced concrete ductbank/manhole engineered to withstand earthquakes, tornado missiles, and to minimize water entry.

4.2 KHS Mechanical Equipment Gallery

Current Configuration:

The KHS Mechanical Equipment gallery contains motor control centers, cooling water strainers, governors, and the Keowee Power Feeder (KPF) Switchgear KPF-1 and KPF-2. In addition, cabling for the CT-4 underground feeder, the KHS to PSW underground feeder, the KHS to PSW Switchgear (KPF) line side cable bus, the feeder from switchgear 1TC to transformer CX, and adjacent Keowee unit control cables all route through the area.

Proposed Alternate Method:

1. Modification of the ONS licensing basis pursuant to 10 CFR 50.55a(z) to accept a completed modification to the separation requirements for a Limited Hazard Area as noted by IEEE Std. 384-1992, Paragraph 6.1.4 with respect to the CX auxiliary power feed to the KHS, the KHS underground emergency power feeder to CT-4, the PSW KPF switchgear line side cable bus, and adjacent control cables, is requested as an alternative configuration to meeting the requirements of 10 CFR 50.55a(h)(2).

   Adoption of the IEEE Std. 384-1992, Limited Hazard Area classification, is due to the area containing power cables without any Hazard Area drivers present (e.g., missiles, high energy lines etc.). The incorporation of this standard into the licensing basis is limited to Paragraph 6.1.4 and is only for the scope of cables specified in this section.

Following guidance from IEEE Std. 384-1992, the openly routed medium voltage bronze armor power cables and low voltage Keowee control cables require separation of three feet horizontally and five feet vertically, which is not achieved at all locations in the Keowee Mechanical Equipment Gallery. Where open distance is not achieved, enclosures have been provided for the medium voltage power cables and low voltage control cables.

By providing a fully metallic enclosed raceway to meet the enclosed raceway separation distance, the requirement of the IEEE Std. 384-1992 standard is met and sufficient physical separation between the power and control circuits is achieved. By fully and separately enclosing the medium voltage power cables and the low voltage control cables, the IEEE Std. 384-1992 required separation distance is reduced to one inch in each direction, which is maintained with the design.

2. Modification of the ONS licensing basis pursuant to 10 CFR 50.55a(z) to allow acceptance of the "as-is" configuration of the normally de-energized 13.8 kV power feed from the KHS to the PSW building as an alternative configuration to meeting the requirements of 10 CFR 50.55a(h)(2).

An acceptable level of quality and safety is demonstrated via the following:

- satisfactory cable crush test results (refer to Section 5),
- satisfactory cable fault test results (refer to Section 5),
- modifications to meet enclosed raceway separation requirements for a Limited Hazard Area as noted by IEEE Std. 384-1992, paragraph 6.1.4, "Limited Hazard Area of IEEE Std 384-1992," (Reference 8.3)[as endorsed in RG 1.75].
- robust power cable design and cables procured to QA-1 standards which minimizes the likelihood of cable interactions,
- KHS power cables (CT-4 and KPF) are not normally energized which minimizes the likelihood of cable interactions; for a PSW event, these cables would only be energized if the Fant Line is unavailable.
- high impedance grounding system limits fault current (KPF and CT-4) and minimizes the effect of any cable interaction should a fault occur,
- limited exposure distance (approximately 100 feet) which minimizes the opportunity of cable interactions,
- station power cables are evaluated as described in UFSAR Section 18.3.14, "Insulated Cables and Connections Aging Management Program," and
- the cables are protected from the environment in that they are in the KHS powerhouse and not exposed to environmental hazards.

4.3 PSW Building Cable Spreading Area

Current Configuration:

The PSW Building Cable Spreading Area is a section of the PSW building into which the cables discussed in the previous sections enter from the PSW ductbank system. In addition to the power feeds, low voltage I&C cables consisting of supervisory functions for both KHUs, one train of KHU emergency start cables, one train switchyard isolation complete, PCB-9 control, and breaker control for the PSW KPF switchgear also enter the PSW building via these ductbanks. Additionally, power and control cables for other PSW functions are present.

Proposed Alternate Method:

1. Modify the ONS licensing basis pursuant to 10 CFR 50.55a(z) to accept a completed modification to meet the separation requirements for a Limited Hazard Area as noted by IEEE Std. 384-1992, Paragraph 6.1.4, with respect to the normally energized Fant line power supply feeder, normally energized feeder from switchgear B6T to PX13 transformer, and adjacent KHS control cables as an alternative configuration to meeting the requirements of 10 CFR 50.55a(h)(2).

   Adoption of the IEEE Std. 384-1992, Limited Hazard Area classification, is due to the area containing power cables without any Hazard Area drivers present (e.g., missiles, high energy lines etc.). The incorporation of this standard into the licensing basis is limited to Paragraph 6.1.4 and is only for the scope of cables specified in this section.

   Following guidance from IEEE Std. 384-1992, the openly routed medium voltage power cables and low voltage control cables require separation of three feet horizontally and five feet vertically, which is not achieved at all locations in the PSW cable spreading area. Where open distance is not achieved, enclosures have been provided for the medium voltage power bronze armor cables and low voltage control cables.

   By providing a fully metallic enclosed raceway to meet the enclosed raceway separation distance, the requirement of the IEEE Std. 384-1992 standard is met and sufficient physical separation between the power and control circuits is achieved. By fully and separately enclosing the medium voltage power cables and the low voltage control cables, the IEEE Std. 384-1992 required separation distance is reduced to one inch in each direction, which is maintained with the design. Adoption of IEEE Std. 384-1992 is limited to Paragraph 6.1.4 and is only for the scope of cables specified in this section.

2. Modify the ONS licensing basis pursuant to 10 CFR 50.55a(z) to allow acceptance of the as-is configuration of the normally de-energized 13.8 kV power feed from KHS to the PSW building as an alternative configuration to meeting the requirements of 10 CFR 50.55a(h)(2).

An acceptable level of quality and safety is demonstrated via the following:

- satisfactory cable crush test results (refer to Section 5),
- satisfactory cable fault test results (refer to Section 5),
- modifications to meet enclosed raceway separation requirements for a Limited Hazard Area as noted by IEEE Std. 384-1992, paragraph 6.1.4, (Reference 8.3)[as endorsed in RG 1.75],
- robust power cable design and cables procured to QA-1 standards which minimizes the likelihood of cable interactions,
- KHS power cables are not normally energized which minimizes the likelihood of cable interactions; for a PSW event, these cables would only be energized if the Fant Line is unavailable
- high impedance grounding system limits fault current (KHS-PSW feeder) which minimizes the likelihood of cable interactions,
- station power cables are evaluated, as described in UFSAR Section 18.3.14, "Insulated Cables and Connections Aging Management Program," and
- the cables are housed in a protected area engineered to withstand earthquakes, tornado missiles, and to minimize water entry.

5. CABLE TESTING

Duke Energy conducted testing to validate that the bronze armored emergency power cable design provides an acceptable level of quality and safety. This testing was conducted in two phases, cable crush testing and cable fault testing. Test results demonstrate the cables provide an acceptable level of quality and safety and that a single failure of a bronze armored medium voltage power cable will not result in a consequential loss of safety functions performed by adjacent low voltage control cables.

Phase One - Cable Crush Testing

The first phase performed testing based on Underwriters Laboratory (UL)1569 'Metal Clad Cables' crush and impact tests of the medium voltage cables and was completed in February 2015. The phase one testing compared the bronze armor cables to galvanized steel interlocked armored cables with respect to their physical protection based on UL1569 testing sections 24 (impact testing), 25 (increasing crush), and 26 (direct burial crush). All of the cable types tested, including the medium voltage cables installed at the ONS, confirmed that the cable configuration with bronze armor provides adequate protection to perform consistently with armored cable based on UL 1569, Sections 24, 25, and 26. The results of this testing were provided to the NRC on May 11, 2015 (Reference 8.5).

Phase Two - Cable Fault Testing

The second phase of the testing involved inducing a fault on a single conductor medium voltage bronze armor power cable while monitoring for any effects on adjacent power and control cables. The fault testing (described below) further validates the engineering analyses which have concluded that the power cables subject to a single phase-to-ground fault will not propagate to a multi-phase fault and will not adversely interact with the low voltage control cables leading to consequential functional failures of redundant trains.

From November 2-6, 2015, a series of cable fault tests were conducted for Duke Energy at KEMA Laboratories in Pennsylvania. These tests were also observed by NRC Staff. Duke Energy commissioned the tests to determine the potential impacts of electrical fault in a medium voltage power cable with bronze armor. The test inputs which demonstrate the worst case bounding inputs and required critical parameters are documented in a calculation (Reference 8.12).

The primary purpose of the cable fault testing was to determine if a single cable failure (phase-to-ground fault) on a single medium voltage power cable will propagate to a multi-phase fault and damage adjacent cables. A secondary purpose was to determine if low voltage control cables installed near the faulted cable would be damaged and if unacceptable voltage would be induced on the low voltage conductors. Four (4) different configurations were tested five (5) times each.

The test setups used were configured in a manner to maximize the potential for a single cable phase-to-ground fault to propagate into a multi-phase fault. Test voltages, phase fault currents and associated durations, bound the Oconee plant values for the cables of concern. The tests were conducted on bronze armored medium voltage cables of same specifications as existing plant cables located in the following areas:

- 13.8 kV KHS Underground Path (KHS to Transformer CT-4),
- 13.8 kV PSW Underground Path (KHS to PSW Switchgear),
- 13.8 kV Fant Path (Manhole 6 to PSW Switchgear),
- 4.16 kV KHS Underground Path (Breaker 1TC-04 to KHS Transformer CX).

Test Methodology:

For each test configuration, a single power cable was prepared by cutting a triangular flap in the cable jacket and drilling a small hole through the cable bronze metallic shield, insulation semicon, insulation and conductor semicon to the conductor. The jacket flap was placed back and secured to the cable jacket with tape. The hole through the metallic shield was not to be repaired and tape was not installed over the area where the hole is drilled. This approach is conservative with respect to the type of test being performed. Since the cable insulation and metallic shield system was compromised, this resulted in a single phase-to-ground fault to immediately occur when the cable is energized. A small copper wire was inserted into the hole to facilitate the cable fault.

The position and orientation of the cable fault was such that if the bronze tape metallic shield and cable jacket were penetrated by the fault, the effects of the fault would directly impinge on the adjacent power cable. The power cables were arranged in a triangular bundle(s) and held in close contact by cable cleats which were mounted to a cable tray. This was a conservative orientation since any increase in distance would reduce the severity of consequential damage (if any) of electrical faults on adjacent cables.

Instrument & Control (I&C) cables were also installed in the cable tray attached to the cable tray with stainless steel ty-wraps parallel to the cable at nominal spacing. The I&C cable interlocked steel armor and underlying shielding were grounded on both ends. The I&C cable conductors were not energized but were monitored during the test for induced voltage. The I&C cables were repositioned closer (control cable separation from power cables varied from 5" to no gap spacing) to the power cable to obtain additional data for conservatism.

The testing laboratory replicated the critical parameters of the Oconee power systems response, including generator/power source neutral grounding arrangement (resistance or solidly grounded), voltages and phase-to-ground fault currents, and fault durations that included relay response and breaker opening times. The test was also configured to replicate multi-phase faults if fault extended to other phase cables. The primary test parameters were fault currents and voltage on the faulted cable and the overall fault duration.

Conduct of Testing:

The testing was performed using a laboratory procedure and results were compiled and documented in a test report. Subsequently, Duke Energy evaluated the test program lab, procedure, and results; and determined the commercial grade dedication of the testing was acceptable as a QA product. Each test article configuration was tested at least five (5) times. After each test, the following parameters were inspected:

1. Verified that a single phase-to-ground fault did not result in a multi-phase fault through visual inspection line current data and/or cable electrical testing. Breaching of the metallic shield and jacket of the faulted cable was acceptable. Scorching or other damage to the jacket, metallic shield and insulation of the adjacent cables was acceptable provided the initial phase-to-ground fault did not propagate to a multi-phase fault.

2. Verified that a power cable fault did not result in medium voltage being imposed on I&C cable conductors by review of the voltage monitored by the test laboratory data acquisition system. Scorching or other damage to the I&C cable jacket, armor or underlying shields and tapes was acceptable provided the underlying conductor insulation was undamaged as verified by visual inspection and/or cable electrical testing.

Test Results:

- None of the test cases resulted in cable damage that propagated to a multi-phase fault.
- In some of the tests, the adjacent power cable had a superficial indentation at the fault location but no jacket or shield damage occurred.
- In one of the five 4 kV cable fault tests, there was damage that penetrated the adjacent power cable's outer jacket and bronze tape shield; however, the internal insulation remained intact and no phase-to-phase fault occurred. Follow-up testing of this cable showed the cable passed a 30-minute withstand test at 7.0 kV.
- In each test case, the cable jacket and bronze tape performed its function of protecting the adjacent conductors and not allowing a fault to propagate (based on visual inspection of the test specimen).
- In each test case there was no observable damage to the control cables in the tray section adjacent to the faulted power cables.
- Low voltage levels observed on control cables determined to be inconsequential, based on 3rd party review of test results and finite element model of a full length configuration.

On November 18, 2015, in a public meeting with NRC staff, Duke Energy outlined its plans to submit a licensing action to address cable separation issues. At that time, NRC questions on the testing were developed in preparation for a follow-up public meeting with Duke Energy on December 15, 2015. These questions were emailed to Duke Energy on December 8 and 10, 2015. Duke Energy's responses to these questions were shared at the December 15, 2015, public meeting.

6. RISK INSIGHTS

Note: The following section is not part of the basis for acceptance but is being provided for risk insight purposes.

A risk analysis (Reference 8.7) was performed to determine the potential risk impact of the current plant configuration with respect to cable separation in the locations of concern. The risk analysis determined the potential risk impact of the current plant configuration with respect to cable separation in the following three (3) locations:

- PSW System Ductbank Manholes 1-6,
- KHS Mechanical Equipment Gallery,
- PSW Building Cable Spreading Area.

Note that the Reference 8.7 analysis also addresses an additional location (Trench 3) which is not addressed in this submittal. For each location, an estimate of the increase in core damage frequency (CDF) and large early release frequency (LERF), above that which would exist if the DC control cables were not co-located with the AC power cables, was developed. The analysis considered the following aspects:

- Frequency of cable faults,

- Probability that a fault is a multi-phase or high energy arc fault (HEAF),
- Probability of a large imposed voltage on one or both Oconee vital 125 VDC trains,
- Probability of failure of one or both Oconee vital 125 VDC trains, given an imposed voltage,
- Probability of failure of mitigation strategies.

Each of the above aspects is described briefly below:

Frequency of Cable Faults:

The analysis used generic industry data (Reference 8.10) on cable faults as a starting point to determine the likelihood of a fault on an energized medium voltage power cable. Reference 8.10 gives a failure rate of 7.2E-04/year per 500 feet of cable for pink EPR cables (the type used at Oconee). Although the EPRI data may be considered representative of general pink EPR medium voltage underground cable failure rates, this data includes cables of the "Uni-Shield" design which has a reduced-diameter, no external insulating jacket, and a much different / compromised shield. In the EPRI data, the much more vulnerable "Uni- Shield" design failures are included with the standard-shield pink-EPR cables. Further parsing of the EPRI data indicates that all but 3 out of 15 (or 20%) of the pink EPR cable failures were of the "Uni-Shield" design.

Since the cables in the locations of concern are not of that design, the cable failure frequency was reduced by a factor of five to 1.44E-04/year per 500 feet of cable for this Oconee-specific evaluation. For each location, this value was then adjusted to account for the length of cable in that location, and the amount of time the cable is energized.

The following tables provide an overview of the results of this adjustment for each location. The frequency contribution from each set of cables is the product of the number of cables, the base frequency, the length adjustment and the hours per year divided by 8760 hours:.

Manholes 1-6 ≈ 180 feet (Total)				
# of Cables	Hours/Year Energized	Length Adjustment	Frequency per Cable	Frequency Contribution
6	32.8	0.36	1.94E-07	1.2E-06
			Total Frequency	1.2E-06

KHS Equipment Gallery ≈ 100 feet				
# of Cables	Hours/Year Energized	Length Adjustment	Frequency per Cable	Frequency Contribution
6	99.0	0.2	3.25E-07	1.95E-06
3	8760	0.2	2.88E-05	8.64E-05
6	32.8	0.2	1.08E-07	6.47E-07
			Total IE Frequency	8.9E-05

PSW Cable Area ≈ 90 feet (Total)				
# of Cables	Hours/Year Energized	Length Adjustment	Frequency per Cable	Frequency Contribution
6	8760	0.18	2.59E-05	1.56E-04
6	32.8	0.18	9.71E-08	5.83E-07
			Total Frequency	1.6E-04

<u>Probability that a Fault is a Multi-Phase or High Energy Arc Fault (HEAF):</u>

Although the expected result of a fault across the insulation is a ground fault to the bronze tape shielding, it cannot absolutely be ruled out that a multi-phase fault could occur. However, this failure mode is unlikely since, as discussed above, the fault across the insulation would have to penetrate the grounded bronze shielding of the faulted cable, and then penetrate the grounded bronze shielding and the insulation of an adjacent cable, all prior to the actuation of the protection system, in order to fault to another phase. Duke Energy is not aware of any mechanism that could cause a fault to behave in this manner. Consider Eaton Corporation White Paper TP08700001E "Fault Characteristics in Electrical Equipment" published in 2011 (Ref. 8.11), which provides data on the likelihood of multi-phase faults. The paper summarizes data collected in IEEE Std. 493 'Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems.' IEEE Std. 493 examined the total number of faults that occurred over a sample of equipment, and compared the quantity of those involving ground with those that did not and calculated a percentage of each type of fault relative to the total. This paper concludes "This IEEE 493 standard is stating that for a cable, it is nearly 100 times more likely (99% divided by 1%) for a cable fault to be a ground fault versus a fault not involving ground." Based on this, a 1.0E-02 probability has been assigned that, given a cable fault occurs, it is a multi-phase fault.

Probability of a Large Imposed Voltage on One or Both Oconee Vital 125 VDC trains:

Duke Energy did not identify any specific data that addresses the likelihood that a HEAF on one of medium voltage power cables in the vicinity of the DC control cables would induce a large voltage on those control cables. However, reasonable engineering judgment based on the design of the DC control cables (i.e., interlocked, grounded, stainless steel armor, multiple ground planes, etc.), supports the conclusion that the likelihood of this scenario would be very low. This is supported by the cable testing and analysis described above, where no significant voltage was impressed on any of the DC control cables in any of the tests. A value of 5E-02 was used for this likelihood. The value selected is considered bounding and worst case, based upon the testing showing no adverse impact.

Probability of Failure of One or Both Oconee Vital 125 VDC Trains, Given an Imposed Voltage:

It would take a significant failure (i.e., failures of multiple distribution panels on multiple trains) of the Oconee 125 VDC system, caused by an imposed voltage on that system from the fault, to impact the ability to safely shut down the units. However, the probability of a loss of all 125 VDC power at Oconee is low, given the design of the cables in these manholes (which have grounded bronze tape for AC power cables or interlocked steel armor for the DC control cables), the design of the manholes themselves (which have grounded uni-strut supports), and the design of the DC system (which has multiple ground planes in the marshalling cabinets, and in the Oconee DC system itself).

Lastly, the 125 VDC system at Oconee is designed to maintain defense-in-depth and safety margin by two independent trains, such that an induced failure of one train should not impact the other. Thus, while failure of a single train of DC power is unlikely, failure of both trains is even less likely. A value of 1.0E-02 has been used for the likelihood of the failure of a single train of 125 VDC power, while a value of 4.0E-03 has been used for the likelihood of failure of both trains of 125 VDC power, which includes a common cause element. These values are considered bounding and worst case, again, based on the results of the cable testing.

Probability of Failure of Mitigation Strategies:

Even in the event of a complete loss of normal and emergency offsite power and loss of the 125 VDC system, there is still equipment available for mitigating the event. It is clear that mitigating strategies are limited in the case of a loss of all DC power, due to the significant loss of normal safety equipment control and control room indication.

However, the Standby Shutdown Facility (SSF) which is designed to provide the ability to maintain the plant in a safe condition, is still available, providing further defense-in-depth and safety margin.

The SSF is completely independent normal plant systems (including 125 VDC power). Electrical power to the SSF is provided by a dedicated diesel generator, while DC control power to the SSF is provided by a dedicated battery and battery charger. In the event of a failure of the SSF DG, power can be provided by an additional offsite source (i.e., the 13.8 kV power feed from the Central Tie Switchyard through the PSW system, that is not affected by any failures in manholes 1 through 6). Note that although the PSW system itself can potentially provide additional mitigation capability (i.e., auxiliary feedwater, seal injection), no credit has been taken in this analysis for those system. Mitigating strategies in the case of a loss of only a single train of DC are much more robust, since one train of normal plant safety equipment and indication would remain available, in addition to the SSF. Failure probabilities for the mitigating strategies of 3.4E-03, given loss of a single train of 125 VDC, and 2.2E-02 given a loss of both trains of 125 VDC, have been calculated based on portions of the Oconee PRA model.

Conclusions:

The analysis shows that the overall CDF/LERF increase for the three (3) cable locations is approximately 2E-11/year. The CDF/LERF increase for manholes 1 through 6, whose configuration is proposed to remain "as-is," is less than 1E-13/year, which is many orders of magnitude below what is typically considered risk significant. The CDF/LERF increases from the PSW cable spreading area and the KHS Mechanical Equipment Gallery are approximately 1E-11/year and 5E-12/year, respectively. These locations have relatively short lengths of cable, but do have some normally energized AC power cables. Again, these values are several orders of magnitude below what is typically considered risk significant, and will be reduced even further with completion of the proposed modifications.

8. REFERENCES

8.1 NRC Regulatory Guide 1.75, Criteria for Independence of Electrical Safety Systems, Revision 3 (ADAMS Accession Number ML043630448).

8.2 IEEE Std. 279-1971, "IEEE Standard: Criteria for Protection Systems for Nuclear Power Generating Stations."

8.3 IEEE Std. 384-1992, "IEEE Standard Criteria for Independence of Class 1E Equipment and Circuits."

8.4 Oconee Nuclear Station Updated Final Safety Analysis Report (UFSAR), Revision 24, effective date of contents 12/31/14. UFSAR Chapters/Sections consulted:

- Section 3.1.1.1, Design of Structures, Components, Equipment, and Systems – Conformance with NRC General Design Criteria.

- Section 8.2.1.3.1, Electric Power – Off-site Power System – System Description – 230 kV Switching Station – 230 kV Switching Station Degraded Grid Protection
- Section 8.3.1.1.1, Electric Power – Onsite Power Systems – AC Power Systems – System Descriptions – Keowee Hydro Station
- Section 8.3.1.4.6, Electric Power – Onsite Power Systems – AC Power Systems – Independence of Redundant Systems – Cable Installation and Separation
- Section 8.3.2.1.3, Electric Power – Onsite Power Systems – DC Power Systems – System Descriptions – 125 Volt DC Keowee Station Power System
- Section 9.7.3.2, Auxiliary Systems – Protected Service Water System – System Description – Electrical
- Section 9.7.3.5.1, Auxiliary Systems – Protected Service Water System – System Description – Civil/Structural – Building Structures
- Chapter 15, Accident Analyses.
- Chapter 18, Section 18.3.14 - Insulated Cables and Connections Aging Management Program Aging Management Programs and Activities.

8.5 Duke Energy Letter to the Nuclear Regulatory Commission, "TIA 2014-05, Potential Unanalyzed Condition Associated with Emergency Power System," dated 5/11/2015.

8.6 Duke Energy Letter to the Nuclear Regulatory Commission, "Supplemental Information on TIA 2014-05, Potential Unanalyzed Condition Associated with Emergency Power System," dated 8/7/2014.

8.7 OSC-11478 "Oconee Medium Voltage Cable Separation Risk Assessment," Revision 1.

8.8 NRC Letter to Duke Energy, "Oconee Nuclear Station – NRC Component Design Bases Inspection Report 05000269/2014007, 05000270/2014007, and 05000287/2014007," dated June 27, 2014, (ADAMS Accession No. ML14178A535).

8.9 NRC Memorandum, Director of Reactor Safety to Deputy Director, Division of Policy and Rulemaking, Office of Nuclear Reactor Regulation, "Request for Technical Assistance Regarding Oconee Nuclear Station Design Analysis for Single Failure and the Integration of Class 1E Direct Current Control Cabling in Raceways With High Energy Power Cabling (TIA 2014-05)," dated October 16, 2014, (ADAMS Accession No. ML14290A136).

8.10 "Plant Support Engineering: Failure Models and Data Analysis for Nuclear Plant Medium Voltage Cables for Consideration in Preventive Maintenance and Strategic Replacement," EPRI, December 2009.

8.11 Eaton Corporation White Paper TP08700001E, "Fault Characteristics in Electrical Equipment", September 2011.

8.12 OSC-11504, "Medium Voltage Cable Testing Analysis," Revision 1.

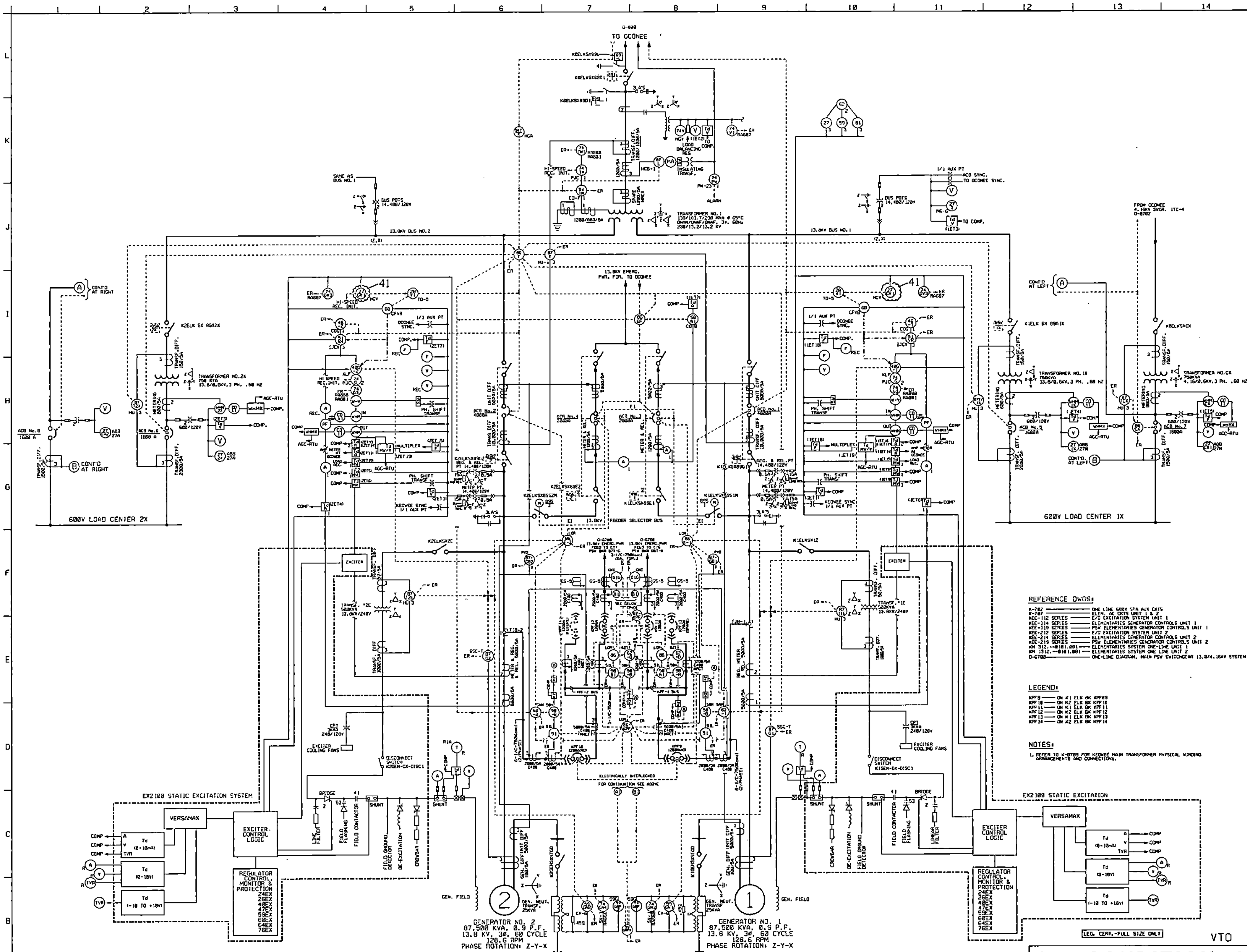
8.13. Duke Energy Design Specification OSS-0218.00-00-0019, "Cable and Wiring Separation Criteria," Revision 17.

ATTACHMENT 2

Associated with Response to RAI 5

The requested equipment can be found on the drawings contained in this attachment:

- KPF Breakers are found on K-700 coordinates E-7, 8, and D-7, 8,
- CX transformer (Keowee Aux Power feeder) is found on K-702 coordinates K-8 and K-700 coordinates H-13,
- PCB-9 (Keowee 230KV Switchyard breaker) is found on O-800 coordinates E-8,
- Switchgear 1TC-4 (Keowee Aux Power feeder CX) is found on O-702 coordinates H-4,
- CT-4 (Emergency Power Transformer fed from Keowee Underground) one-line and three-line diagrams are found on O-800-D coordinates E-3 and I-8, respectively,
- B6T (PSW Switchgear) is found on O-6700 coordinates G-5; Interconnections to KPF breakers are shown at coordinates L-5, and
- PX13 (4KV/600V transformer and Load Center) are shown on O-6707.



REFERENCE DWGS:

K-702 —— ONE LINE 600V STA AUX CKTS
K-707 —— ELEM. AC CKTS UNIT 1 & 2
KEE-112 SERIES —— E/D EXCITATION SYSTEM UNIT 1
KEE-114 SERIES —— ELEMENTARIES GENERATOR CONTROLS UNIT 1
KEE-119 SERIES —— PSW ELEMENTARIES GENERATOR CONTROLS UNIT 1
KEE-212 SERIES —— E/D EXCITATION SYSTEM UNIT 2
KEE-214 SERIES —— ELEMENTARIES GENERATOR CONTROLS UNIT 2
KEE-219 SERIES —— PSW ELEMENTARIES GENERATOR CONTROLS UNIT 2
KM 312.--0101.001 —— ELEMENTARIES SYSTEM ONE-LINE UNIT 1
KM 1312.--0101.001 —— ELEMENTARIES SYSTEM ONE LINE UNIT 2
O-6700 —— ONE-LINE DIAGRAM, MAIN PSW SWITCHGEAR 13.8/4.16KV SYSTEM

LEGEND:

KPF9 —— ON K1 ELK BK KPF09
KPF10 —— ON K2 ELK BK KPF10
KPF11 —— ON K1 ELK BK KPF11
KPF12 —— ON K2 ELK BK KPF12
KPF13 —— ON K1 ELK BK KPF13
KPF14 —— ON K2 ELK BK KPF14

NOTES:

1. REFER TO K-0709 FOR KEOWEE MAIN TRANSFORMER PHYSICAL WINDING ARRANGEMENTS AND CONNECTIONS.

VTO

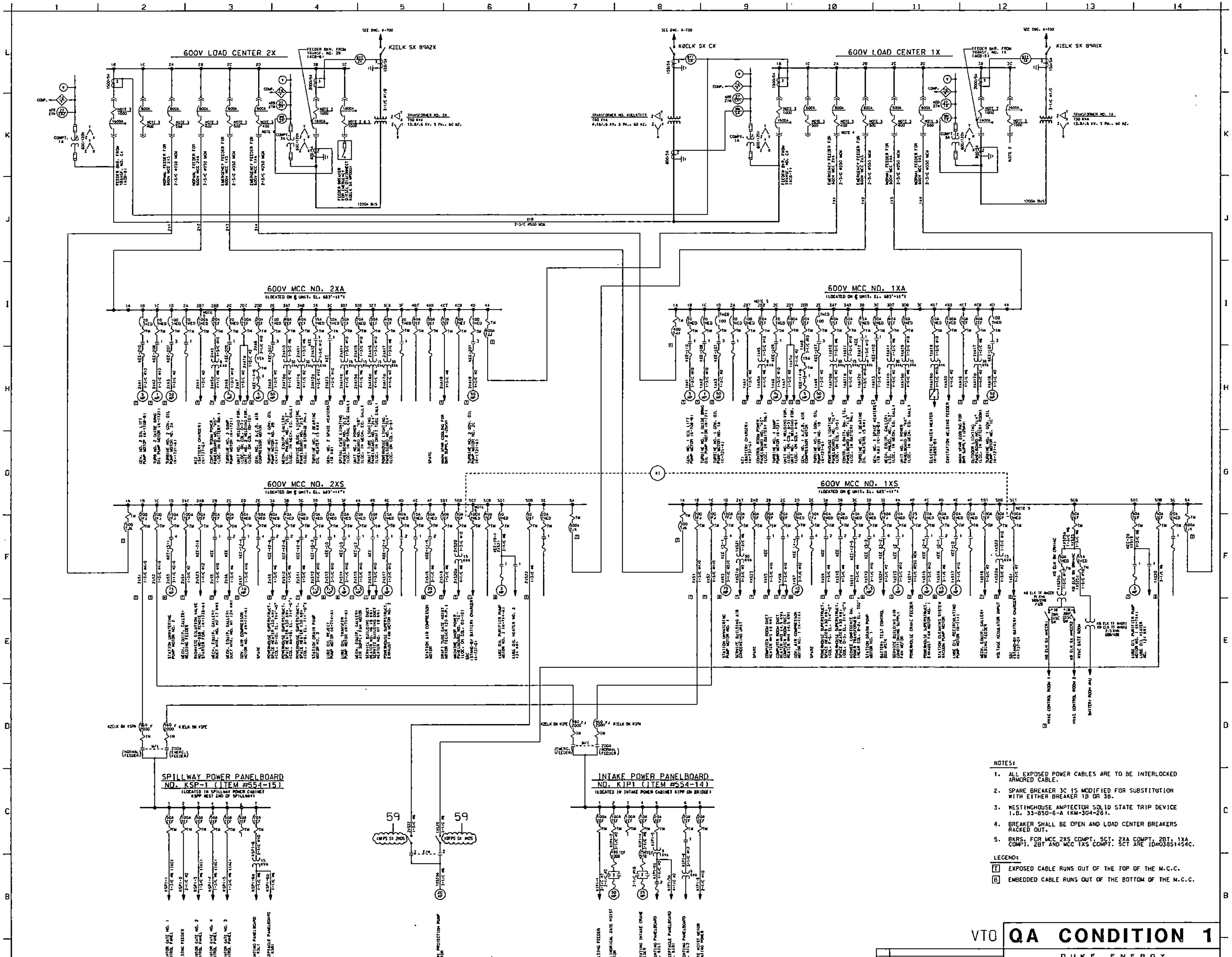
QA CONDITION 1

DUKE ENERGY
KEOWEE HYDRO STATION

ONE LINE DIAGRAM
RELAYS & METERS
13.8-230KV

NO.	REVISIONS
41	REV PER EC411331
40	AS-BUILT PER EC95361
39	PIP #O-14-8264, EO. EX. G.21

SCALE | DWG. NO. K-0700 | REV. 41



NOTES:

1. ALL EXPOSED POWER CABLES ARE TO BE INTERLOCKED ARMORED CABLE.
2. SPARE BREAKER 3C IS MODIFIED FOR SUBSTITUTION WITH EITHER BREAKER 1B OR 3B.
3. WESTINGHOUSE AMPTECTOR SOLID STATE TRIP DEVICE I.B. 33-850-6-A (KM-304-28).
4. BREAKER SHALL BE OPEN AND LOAD CENTER BREAKERS RACKED OUT.
5. BKRS. FOR MCC 2XS COMPT. 5CT, 2XA COMPT. 2BT, 1XA COMPT. 2BT AND MCC 1XS COMPT. 5CT ARE ID#03851454C.

LEGEND:

[T] EXPOSED CABLE RUNS OUT OF THE TOP OF THE M.C.C.
[B] EMBEDDED CABLE RUNS OUT OF THE BOTTOM OF THE M.C.C.

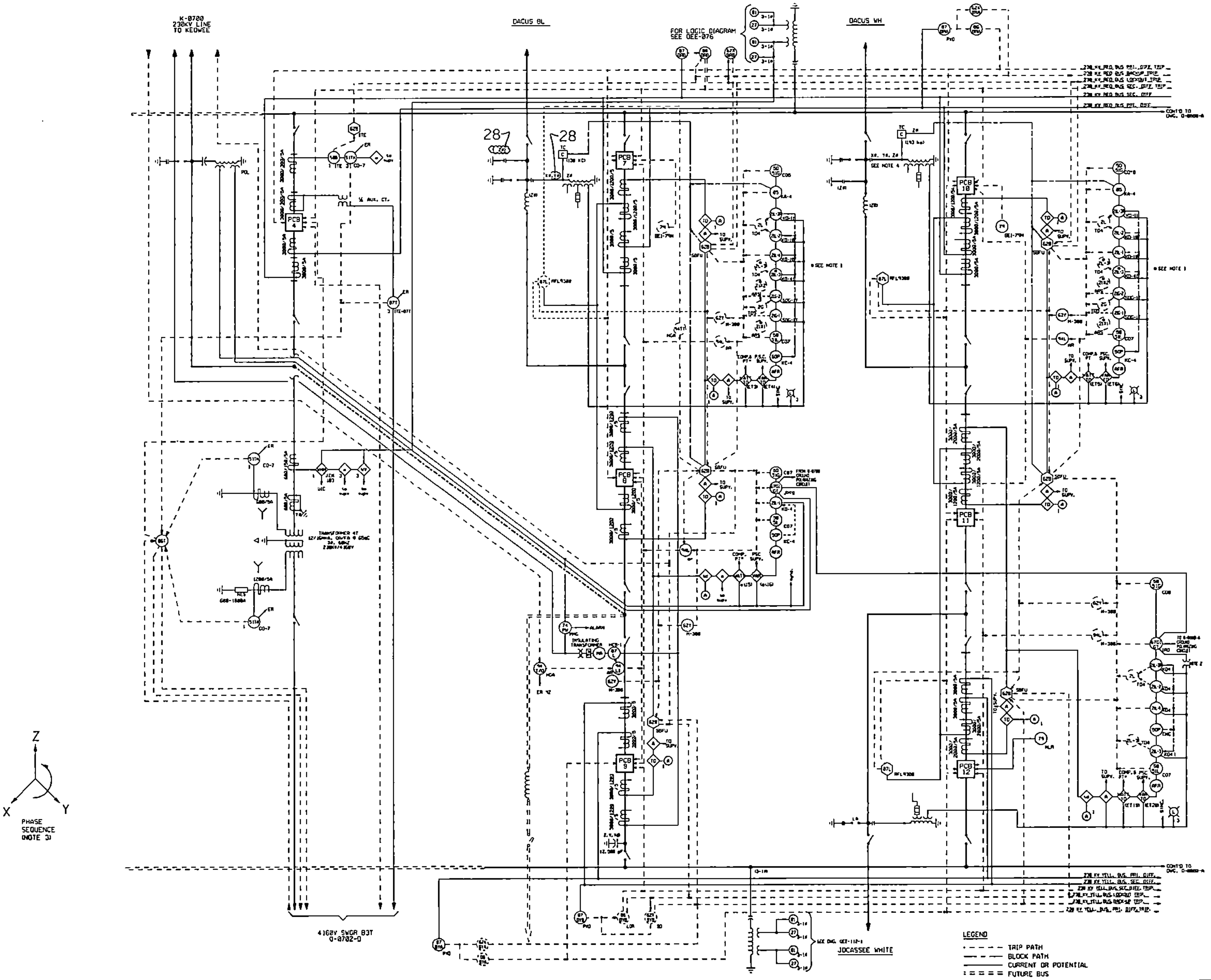
VTO **QA CONDITION 1**

NO.	REVISIONS
59	REV PER EC410251
58	AS-BUILT PER EC405185
57	REVISED PER EC95361 & EC403861
56	AS-BUILT PER EC95361
55	REV PER 407320
54	REV PER 407058
53	ED. EX. G.21, PIP 12-10099

DUKE ENERGY
KEOWEE STATION

ONE LINE DIAGRAM
600 VOLT
STATION AUXILIARY CIRCUITS

SCALE NTS | DWG. NO. K-0702 | REV. 59



LEGEND

- TRIP PATH
- BLOCK PATH
- CURRENT OR POTENTIAL
- FUTURE BUS
- TEMPORARY BUS/TEMPORARY EQUIP.
- INSTALLED EQUIPMENT

NOTES:

1. RELAYS 2L-3, 21L-3, 21X1 AND 21X2 HAVE BEEN ABANDONED IN PLACE.
2. ZERO SEQUENCE SUMMING POTENTIAL TRANSFORMER.
3. FACING THE FRONT OF A BREAKER, A CUBICLE, OR AN ENCLOSURE, PHASE ORIENTATION IS Z-Y-X (A-B-C, 1-2-3) WITH CONDUCTOR COLOR CODE BK-WH-RD LEFT TO RIGHT, TOP TO BOTTOM, AND FRONT TO REAR. PHASE ROTATION IS COUNTER-CLOCKWISE.
4. 12,500 pF CVT WITH CARRIER ON Z PHASE ONLY.

VTO

ABANDON COMPONENTS RELATED

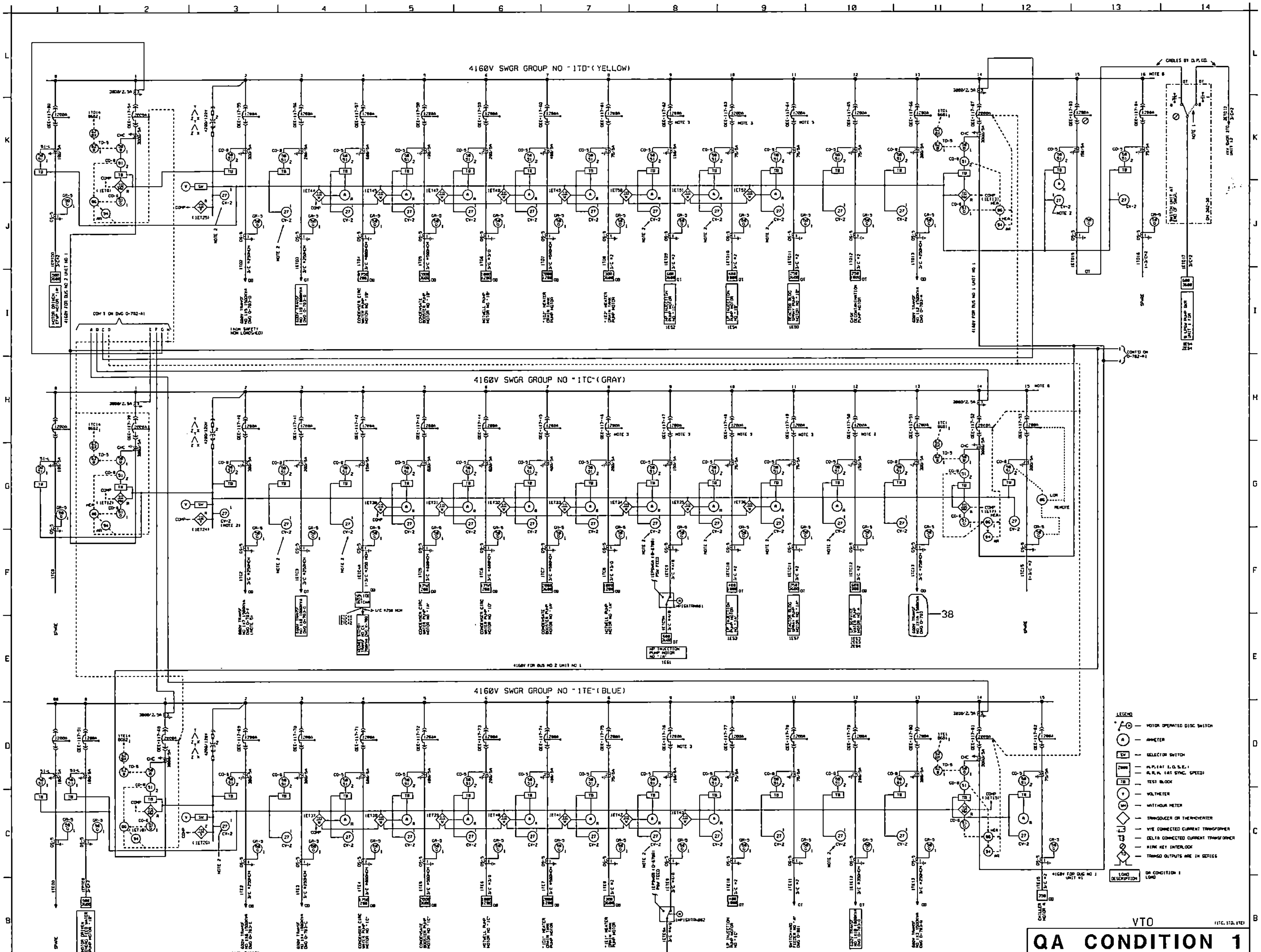
QA CONDITION 1

NO.	REVISIONS
28	AS-BUILT PER EC107383
27	REV PER EC112917
26	AS-BUILT PER EC107383, EC107384
25	AS-BUILT PER EC112284
24	AS-BUILT PER EC107362
23	EC0000112282
22	FF3801A2, EC98789
21	PIP #12-10146, ED. EX. G.10
20	EC102850

DUKE ENERGY
OCONEE NUCLEAR STATION - UNIT 0

ONE LINE DIAGRAM
RELAYS & METERS
230 kV SWITCHYARD
PCBs #4 & #7 THRU #12

SCALE NONE | DWG. NO. O-0800 | REV. 28



REFERENCE DRAWINGS:

0-6708 —— ONE LINE DIAG. SWGR. 861

NOTES:

1. THE NO LOAD MANUAL TRANSFER SWITCH IS EQUIPPED WITH KIRK INTERLOCK ARRANGEMENT SUCH THAT BREAKERS 1TD-15 & 2TD-12 (DWG O-1702) MUST BE IN OPEN POSITION BEFORE TRANSFER SWITCH CAN BE OPERATED
2. UNDERVOLTAGE RELAYS REMOVED AND TRIP CIRCUIT DISCONNECTED FROM CASE.
3. ALL 4KV 1200A BKRS. ARE INTERCHANGEABLE WITH THE EXCEPTION OF 1TC UNITS 9, 10, 11 & 12 1TD UNITS 9, 10, 11 1TE UNITS 9 THESE BREAKERS ARE ONLY INTERCHANGABLE AMONG THEMSELVES BECAUSE THEY HAVE INTERNAL RESISTORS FOR PROPER OPERATION OF THEIR COIL MONITOR RELAYS.

NOTES CONT'D

4.
5. BREAKER WILL AUTOMATICALLY RECLOSE FOLLOWING LOAD SHED AND SET TIME DELAY.
6. IN COMPARTMENT 1TC-15 AND 1TD-16 CABLE LANDING ADAPTER PLATES MAY NOT BE SUPPLIED IN COMPARTMENT. PERFORM FIELD WALKDOWN BEFORE UTILIZING SPARE COMPARTMENT.
7. NOT USED

ERN: 0X00088V

(1TC, 1TD, 1TE)

QA CONDITION 1

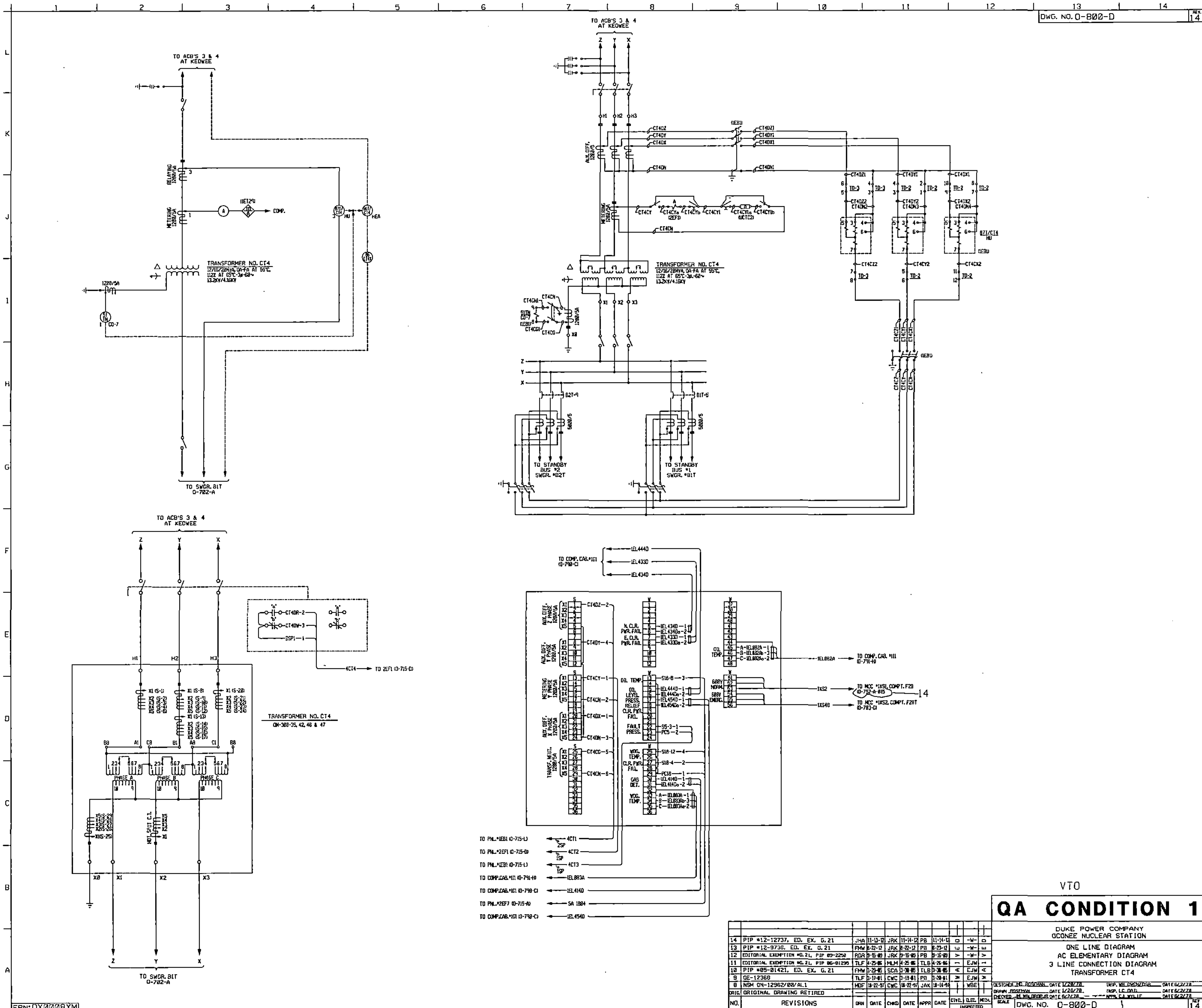
NO.	REVISIONS
38	REV PER EC409724
37	ISSUED PER EC400077
36	PIP #14-3899, ED. EX. G.21

DUKE POWER COMPANY
OCONEE NUCLEAR STATION UNIT 1

ONE LINE DIAGRAM
6900V & 4160V STA AUXILIARY SYS

SCALE | DWG. NO. 0-702 | REV. 38

DWG. NO. 0-800-D REV. 14



VTO

QA CONDITION 1

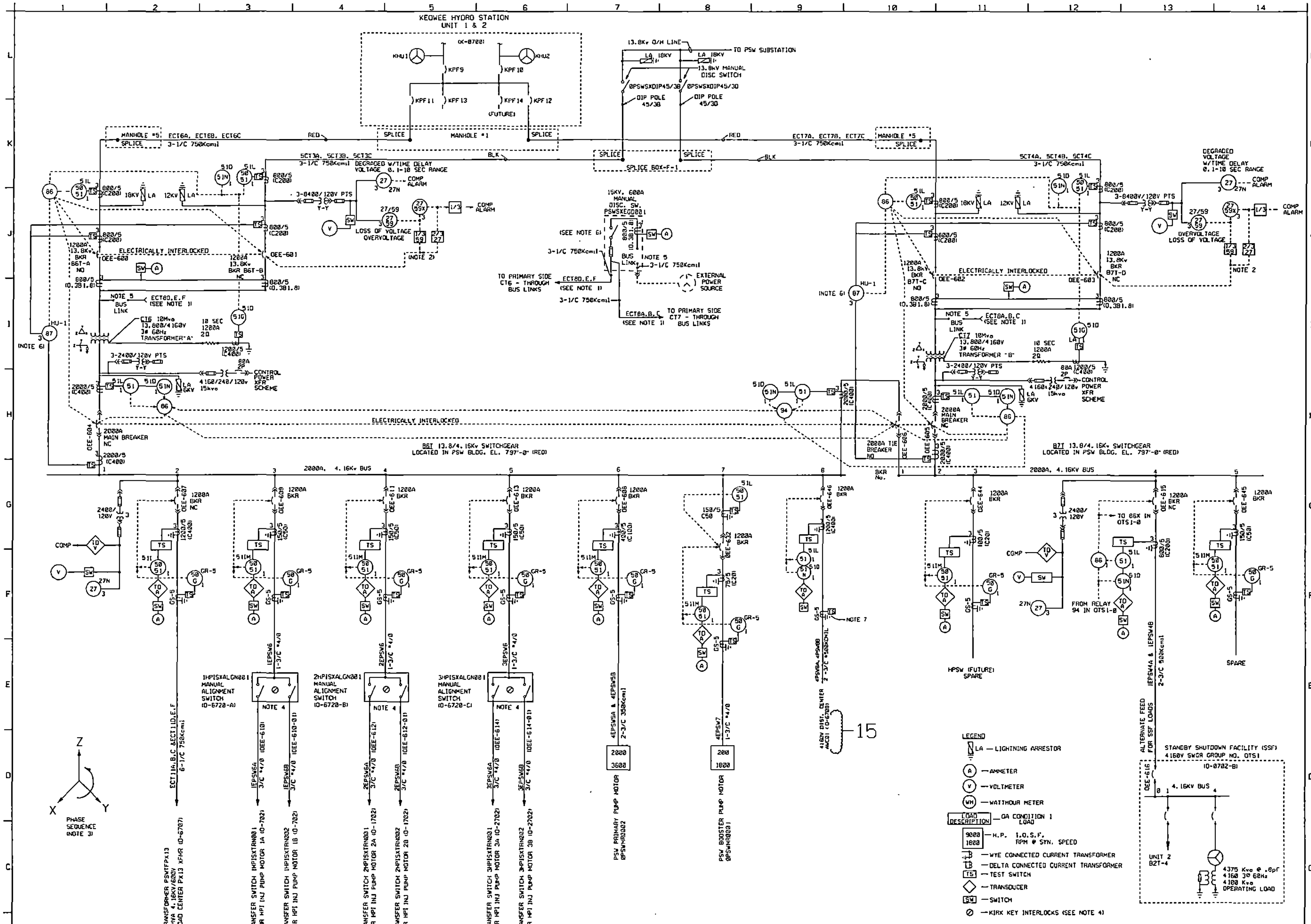
DUKE POWER COMPANY
OCONEE NUCLEAR STATION

ONE LINE DIAGRAM
AC ELEMENTARY DIAGRAM
3 LINE CONNECTION DIAGRAM
TRANSFORMER CT4

NO.	REVISIONS	DRN	DATE	CHKD	DATE	APPR	DATE	CIVIL	ELEC.	MECH.
14	PIP #12-12737, ED. EX. G.21	JHA	11-13-12	JRK	11-14-12	PB	11-14-12		-W-	
13	PIP #12-9736, ED. EX. G.21	FMW	8-22-12	JRK	8-22-12	PB	8-23-12		-W-	
12	EDITORIAL EXEMPTION #G.21, PIP 09-2250	RDR	9-15-09	JRK	9-16-09	PB	9-16-09		-W-	
11	EDITORIAL EXEMPTION #G.21, PIP 06-01295	TLF	4-25-06	MLM	4-25-06	TLB	4-26-06		EJW	
10	PIP #05-01421, ED. EX. G.21	FMW	3-29-05	SCA	3-30-05	TLB	3-30-05		EJW	
9	OE-12368	TLF	3-17-01	CWC	3-19-01	PB	3-20-01		EJW	
8	NSM ON-12962/00/AL1	MDF	10-22-97	CWC	10-22-97	JAK	10-14-97		WBE	
ORIG.	ORIGINAL DRAWING RETIRED									

INSPECTED

DESIGNER M.D. ROSEMAN DATE 1/20/78 INSP. W.H. OWEN/DSB DATE 6/2/78
DRAWN ROSEMAN DATE 1/26/78 INSP. L.C. DAIL DATE 6/2/78
CHECKED M. WALDROP JR DATE 6/2/78 APPR. C.J. WYLIE DATE 6/2/78
SCALE DWG. NO. 0-800-D REV. 14



REFERENCE DRAWINGS

- 0-702 — ONE LINE DIAGRAM (SWITCHGEAR 1TC & 1TE)
- 0-702-B — ONE LINE DIAGRAM (SSF 4160 AND 600V)
- 0-1702 — ONE LINE DIAGRAM (SWITCHGEAR 2TC & 2TE)
- 0-2702 — ONE LINE DIAGRAM (SWITCHGEAR 3TC & 3TE)
- 0-6892-G — PSW BLDG ELECTRICAL EQUIPT LAYOUT SUPPORT & CABLE TERMINATION
- OEE-600 — ELEMENTARY DIA 13.8Kv BREAKER A ALTERNATE FEED TO CT6 FOR SWGR B6T
- OEE-601 — ELEMENTARY DIA 13.8Kv BREAKER B NORMAL FEED TO CT6 FOR SWGR B6T
- OEE-602 — ELEMENTARY DIA 13.8Kv BREAKER C ALTERNATE FEED TO CT7 FOR SWGR B7T
- OEE-603 — ELEMENTARY DIA 13.8Kv BREAKER D NORMAL FEED TO CT7 FOR SWGR B7T
- OEE-604 — ELEMENTARY DIAGRAM 4160V MAIN SWGR B6T FEED FROM TRAN CT6
- OEE-605 — ELEMENTARY DIAGRAM 4160V MAIN SWGR B7T FEED FROM TRAN CT7
- OEE-606 — ELEMENTARY DIAGRAM 4160V BUS TIE BREAKER FOR SWGR B6T & B7T
- OEE-607 — ELEM DIA 4160V FEED TO XTFR PX13 & LC LCPSW1 SWGR B6T UNIT 2
- OEE-608 — ELEM DIA 4160V FEED TO PSW 2000HP PMP SWGR B6T UNIT 6
- OEE-609 — ELEM DIA 4160V FEED TO UNIT 1 XTFR SW, HPI UNIT 1 PMP SWGR B6T UNIT 3
- OEE-611 — ELEM DIA 4160V FEED TO UNIT 2 XTFR SW, HPI UNIT 2 PMP SWGR B6T UNIT 4
- OEE-613 — ELEM DIA 4160V FEED TO UNIT 3 XTFR SW, HPI UNIT 3 PMP SWGR B6T UNIT 5
- OEE-615 — ELEM DIA 4160V FEED TO OTS1-0, ALT FEED TO SSF SWGR B7T UNIT 4
- OEE-632 — ELEMENTARY DIA PSW BOOSTER PUMP 200HP SWGR B6T UNIT 7

NOTES:

1. CABLE WITH BUS LINK AND BOLTED CONNECTIONS.
2. FOR 27/59 RELAY, UNDERVOLTAGE TRIP LOGIC IS 2/3 AND OVERVOLTAGE TRIP IS 1/3.
3. FACING THE FRONT OF A BREAKER, A CUBICLE, OR AN ENCLOSURE, PHASE ORIENTATION IS Z-Y-X (A-B-C, 1-2-3) WITH CONDUCTOR COLOR CODE BK-WH-RD LEFT TO RIGHT, TOP TO BOTTOM, AND FRONT TO REAR. PHASE ROTATION IS COUNTER-CLOCKWISE.
4. EXTERNAL KIRK KEY INTERLOCKS PROVIDED TO PREVENT SIMULTANEOUS CLOSURE OF BOTH SWITCHES.
5. THE REMOVABLE BUS LINKS ARE NORMALLY REMOVED. ONLY INSTALL WHEN FEEDING TRANSFORMER CT6 OR CT7, NOT BOTH, FROM EXTERNAL POWER SOURCE.
6. TRANSFORMER DIFFERENTIAL PROTECTION (87) DOES NOT EXIST WHEN ENERGIZED THROUGH MANUAL DISCONNECT SWITCH.
7. GROUND SENSOR IN B6T-08 IS SHORTED AND SPARED. — 15

REFERENCE DRAWINGS

- OM 302.A--0052.001 — ONE LINE DIAGRAM (SWITCHGEAR B6T)
- OM 302.A--0052.002 — ONE LINE DIAGRAM (SWITCHGEAR B7T)
- OM 302.A--0091.001 — PSW 13.8KV DISCONNECT SWITCH 3-LINE DIAGRAM
- 2616P001 — OCONEE PSW - 100-13.8KV 3-LINE DIAGRAM (POWER DELIVERY SERVICES)

VTO

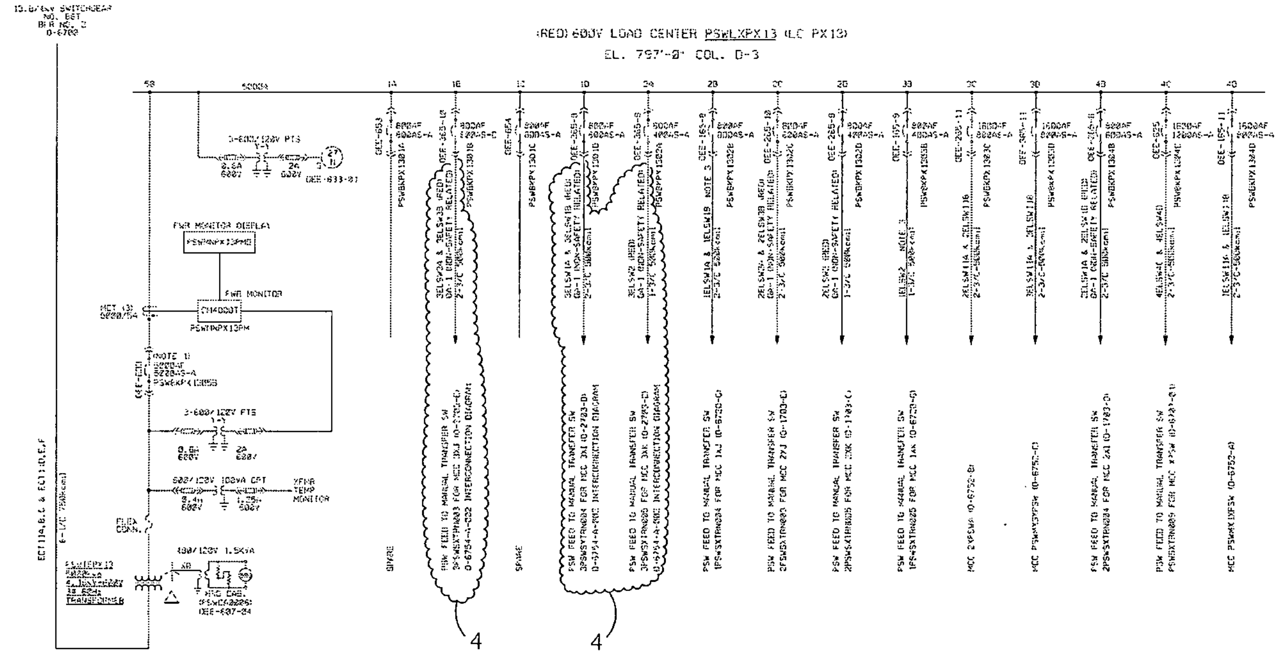
NO.	REVISIONS
15	REV PER EC409724
14	EC 0000400195
13	EC 0000113711
12	EC110408
11	EC110408
10	ISSUED AS-BUILT PER EC 91070
9	ISSUED AS-BUILT PER EC 91033
8	EQ.EX. G.B & PIP 0-14-08071

QA CONDITION 1

DUKE ENERGY
OCONEE NUCLEAR STATION UNITS 1, 2, & 3

ONE-LINE DIAGRAM
MAIN PSW SWITCHGEAR
13.8/4.16KV SYSTEM

SCALE NONE | DWG. NO. 0-6700 | REV. 15



NOTES:

1. MAIN BREAKER 5B IS DERATED TO 88% (4400A) PER QUALIFICATION REPORT SECTION 5.1.1.
2. FEEDER BREAKERS ARE DERATED TO 80% PER QUALIFICATION REPORT SECTION 5.1..
3. CABLE IS QA-1. HOWEVER, ITS DESIGN FUNCTION IS NON-SAFETY RELATED.

CIRCUIT BREAKER LEGEND

800AF — FRAME SIZE
600AS-C — SENSOR PLUG - RATING PLUG

REFERENCE DRAWINGS:

O-703-D & F — ONE LINE DIAGRAM (MCC 1XK & 1XT)
O-1703-C — ONE LINE DIAGRAM (L/C 2X4 & MCC 2XH, 2XK & 2XR)
O-1703-D — ONE LINE DIAGRAM (L/C 2X5 & MCC 2XI, 2XL & 2XO)
O-1703-E — ONE LINE DIAGRAM (L/C 2X6 & MCC 2XJ, 2XN & 2XP)
O-1752-A11, A13 & A32 — INTERCONNECTION DIAGRAM (MCC 2XI, 2XJ & 2XK)
4 O-2703-C — ONE LINE DIAGRAM (L/C 3X4 & MCC 3XH, 3XK, 3XR & 3XT)
O-2703-D — ONE LINE DIAGRAM (L/C 3X5 & MCC 3XI, 3XL & 3XO)
O-2703-E — ONE LINE DIAGRAM (L/C 3X6 & MCC 3XJ, 3XN & 3XP)
O-2752-A11 — INTERCONNECTION DIAGRAM MCC 3XJ
O-2752-A13 — INTERCONNECTION DIAGRAM MCC 3XI
O-2752-A32 — INTERCONNECTION DIAGRAM MCC 3XK
O-6720-K — C/D MANUAL TRANSFER SWITCHES 3PSWSXTRN003, 4, 5
O-6720-I — C/D MANUAL TRANSFER SWITCHES 2PSWSXTRN003, 4, 5
O-6754-A — INTERCONNECTION DIAGRAM 600VAC LOAD CENTER PSWLXPX13
O-6754-A-001 — INTERCONNECTION DIAGRAM 600VAC LOAD CENTER PSWLXPX13
O-6754-A-002 — INTERCONNECTION DIAGRAM LOAD CENTER PSWLXPX13
OM 303. --0185.001 — PSW SWITCHGEAR LAYOUT FOR 600 VAC SWITCHGEAR
OM 303. --0190.001 — GEN ARRANGEMENT FOR 600V SWITCHGEAR PSWLXPX13
OM 303. --0192.001 — NAMEPLATE DATA FOR 5kVA TRANSFORMER PSWTFPX13
OM 303. --0193.001 — TEMPERATURE MONITOR FOR TRANSFORMER PSWTFPX13
OM 303. --0194.001 — ONE LINE DIAGRAM FOR 600V SWITCHGEAR PSWLXPX13
OM 303. --0195.001 — THREE LINE DIAGRAM FOR 600V SWITCHGEAR PSWLXPX13
OM 303. --0217.001 — WIRING DIAGRAM FOR SWITCHGEAR PX13 SECTION 5
OM 303. --0218.001 — BILL OF MATERIALS FOR 600V SWITCHGEAR PSWLXPX13
OM 303. --0224.002 — QUALIFICATION REPORT

QA CONDITION 1
AS NOTED

DUKE ENERGY
OCONEE NUCLEAR STATION UNITS 1, 2, & 3

ONE-LINE DIAGRAM
PSW BUILDING ELEV. 797'-0"
600VAC LOAD CENTER PSWLXPX13

NO.	REVISIONS
4	ISSUED AS-BUILT PER EC 91659
3	ISSUED AS-BUILT PER EC 91849
2	ISSUED AS-BUILT PER EC 91825
1	ISSUED AS-BUILT PER EC 91873
0	ISSUED AS-BUILT PER EC 91833

SCALE NONE | DWG. NO. O-6707 | REV. 4

ATTACHMENT 3A

Associated with Response to RAI 3(a)

4.0 Calculation

4.1 Design Inputs for Calculation

Oconee, KHS and PSW specific analysis were used to provide the specific voltage, fault current and fault duration for this analysis. This includes Duke analysis and external vendor analysis/studies (MPR).

4.2 Method Used for Determination of Test Parameters Values

A 3% conservatism was added to account for test laboratory equipment uncertainty. This is based upon the instrument uncertainty for test equipment at KEMA which is less than or equal to 3%. See Attachment 7, page 2 for details.

Calculation KC-0094 (Keowee Generator Neutral Grounding) was utilized to determine the maximum available Keowee generator(s) ground fault current as well as the ground fault protection relaying operation timing. The original design of the Keowee generator neutral grounding system was performed in accordance with fundamental electrical circuit theory (i.e., basic Ohm's law, resistance/impedance reflection via transformer turns ratio and the application of an overvoltage relay parallel with the grounding resistor).

Calculation OSC-11013 (Short Circuit Currents on Keowee Underground Path) was utilized to determine the maximum available fault currents and voltage on the Keowee Underground Path to Oconee through transformer CT4.

Calculation OSC-11055 (Short Circuit Currents on Keowee from PSW Underground) was utilized to determine the maximum available fault currents and voltage on the Keowee Underground Path to PSW through transformers CT6 and CT7.

Calculation OSC-9832 (PSW ETAP Base File) was utilized to determine the maximum available fault currents (phase to phase and phase to ground) on the Fant feed to PSW through transformers CT6 and CT7.

Calculation OSC-11062 (Cable Electromagnetic Forces on Keowee and Protected Service Water Cables) was utilized to determine the breaker/protective relaying fault clearing times for the Keowee and PSW feeders.

Calculation OSC-2059 (Unit 1 AC Power System Voltage and Fault Duty Analysis) was utilized to determine the available fault current for the feeder to transformer CX (breaker 1TC-04) and maximum voltage.

Calculation OSC-9370 (U1,2,3 PSW AC Power System Voltages and Short Circuit Analysis) was utilized to determine the maximum PSW voltage for the testing.

EC 402424, Additional Short Circuit Currents from Fleet Electrical Analysis (FEA) was utilized to determine the maximum fault currents with the addition of load (mostly motor) fault contribution.

4.3 13.8kV Keowee Underground Path (Keowee to Transformer CT-4)

System Voltage: **14.49 kV** (phase-phase: pre-fault voltage 105% of 13.8 kV base per OSC-11013, Assumption 7.1)

Fault Currents: **19.5 kA** (three-phase symmetrical at ACB-3). ACB 3 fault current was used because the Keowee underground path (cable) begins on the load side of ACB 3 and 4 per K-700. Either ACB 3 or 4 fault currents could be used because both Keowee units are similar in design.

Revision 1 Comment: An additional 3.26kA of load fault contribution was added with this revision to support a postulated failure at any time (not time of demand). See page 6 of 11 of reference 2.3.8 (EC 402424) for additional details.

17.6 A (phase-ground - with neutral resistance grounding). Per KC-0094, page 3 of 9, section 1.4.

Fault Duration: **11 cycles (183 ms)** for phase-phase faults. Per section 5.4.1 of OSC-11062.

70.8 cycles (1.18 s) for phase-ground fault. See the calculation below for details.

Keowee Ground Fault Duration Calculation

The neutral grounding transformer has a ratio of 7620-240V (31.75) per section 2.9 of KC-0094, Rev 1.

The installed grounding resistor has a resistance of 0.45 Ohms per drawing K-700.

The installed ground fault overvoltage relay (59GN1/2) is an ABB CV-8 per drawing K-700.

Thus the maximum ground fault current at the generator is equal to the equivalent system resistance at the generator neutral terminal.

The equivalent resistance I_{maxG} = R * (neutral grounding transformer turns ratio)^2 = R * 31.75^2

Thus R_{eq} = 0.45 * 31.75^2 = 453.628 Ohms

The maximum ground fault at the generator is $I_{maxG} = (V_{L-L} / (SQRT(3)) / R_{eq}$. The line to line voltage is converted to the line to ground voltage by dividing by the square root of three because we are calculating a line to ground current.

This results in I_{maxG} = (13,800V/1.73)/453.628 Ohms = 17.585 A

This translates to a secondary current of I_{sec} = 17.585A*(31.75)= 558.312 A

Which results in a voltage across the grounding resistor: $V_{resistor} = I_{sec}$ * 0.45 Ohms

$V_{resistor}$ = 558.312 A * 0.45 Ohms = 251.240 V

Per EDB the 59GN1/2 relay (listed as ON-K1-GEN-RL-59GN1 and ON-K2-GEN-RL-59GN2) the setting is 5.4V pickup and the time dial is set at 3 based upon 1.6 sec at 27V (500%).

The percent pickup during a fault of 17.585A would be 251.240V/5.4V = 46.526 or 4653%

Based upon a review of figure 10a in the instruction leaflet for the ABB CV-8 relay (see Attachment 1 to this analysis), this trip set-point corresponds to a trip time around 1 second. This relay then trips the 86E-1/2 (LOR) relay.

Per section 5.4.3 of OSC-11062, Rev. 0, the 86E-1/2 (LOR) relay has an operating time of 8ms. The LOR then trips the breaker (Keowee ACBs-1/2/3/4) for the faulted unit. Also, per section 5.4.3 of OSC-11062, Rev. 0, the ACBs (air circuit breakers) have a clearing time of 8 cycles (133ms).

This results in a total ground fault clearing time of: 1 sec + 0.008 sec + 0.133 sec = 1.141 sec.

The ground fault clearing time of 70.8 cycles (1.18 s) will be used for conservatism.

Test Parameters: These parameters were used as the testing criteria for the cable testing described in Appendix C.

Applying a conservative 3% uncertainty results in the following values that should be used in the test setup. Also, an additional 3% maximum was applied to bound any measurement uncertainty.

Revision 1 Comment: It was determined that the revision 0 upper tolerance of 10% was overly conservative and was removed as part of revision 1.

System Voltage: **14.9247 kV (phase-phase: pre-fault voltage)**

Fault Currents: **20.085 kA to 20.688 kA (three-phase symmetrical at ACB-3)**
18.128 A to 18.672 A (phase-ground - with neutral resistance grounding)

Fault Duration: **11 cycles (183 ms) for phase-phase faults**
70.8 cycles (1.18 s) for phase-ground fault of 18.128 A to 19.941 A

References:
2.3.5, AR 1905669, PIP O-13-8748 PDO Section
2.2.5, OSC-11062 Rev. 0 Section 5.4.1
2.2.3, OSC-11013 Rev. 0 Section 4.0 Table 1 (Fault Duty at ACB-3) and Assumption 7.1
2.2.1, KC-0094 Rev. 1, Page 3 of 9, section 1.4
2.3.8, EC 402424, Rev. 0, Additional Short Circuit Currents from Fleet Electrical Analysis (FEA)

4.4 4.16kV Keowee Underground Path (Breaker 1TC-04 to Keowee Transformer CX)

System Voltage: 4.402 kV (phase-phase: pre-fault voltage 105.8% of 4.16 kV base). Per Table C-06 of OSC-2059.

Fault Currents: 8.76 kA (three-phase symmetrical fault located 3700 feet from breaker 1TC-4 per reference 2.3.8, pages 8 and 9). This is validated by Appendix B determined that the Trench 3 distance is approximately 3700 feet. Furthermore there is additional CX feeder cable from the entrance to Trench 3 in the CT4 blockhouse to breaker 1TC-04.

6.03 kA (L-G symmetrical) (Reference 2.3.8, page 10)

Revision 1 Comment: The above fault currents for the CX feeder were reduced in revision 1 when compared to revision 0 due to excessive conservatisms used for the analysis. For instance, Attachment 2 of Rev. 0 of this calculation, page 75 of 373 states that a conservative pre-fault voltage of 107.69% of 4.16kV was utilized but 105.8% is the actual pre-fault voltage that should be used per Table C-06 of OSC-2059. This would result in a reduction of the fault current.

Fault Duration: 11 cycles (183 ms) for L-G fault. See the below calculation for details.

7 cycles (117mS) for a phase-phase fault per OSC-11062, Section 5.4.2

Transformer CX Feeder (Breaker 1TC-04) Ground Fault Duration Calculation

The CX Transformer feeder is protected from ground faults by the use of an ABB GR-5 relay and an ABB HK breaker (see drawing O-702). Per page 18 of OSC-7729, Rev. 0, and EDB (ON-1-EL-RL-50GTC4) this relay has an operating time of 6 cycles. This relay then directly operates the breaker trip coil per OEE-117-42. Per OSC-11062, Rev. 0, section 5.4.2, the HK breaker has a fault clearing time of 5 cycles. Thus this results in a total ground fault clearing time of 11 cycles.

Test Parameters: These parameters were used as the testing criteria for the cable testing described in Appendix C.

Applying a conservative 3% uncertainty results in the following values that should be used in the test setup. Also, an additional 3% maximum was applied to bound any measurement uncertainty.

Revision 1 Comment: It was determined that the revision 0 upper tolerance of 10% was overly conservative and was removed as part of revision 1.

System Voltage:	**4.535 kV (phase-phase: pre-fault voltage)**
Fault Currents:	**9.0228 kA to 9.293 kA (three-phase symmetrical fault located 3,700 feet from 1TC-04)** **6.211 kA to 6.397 kA (L-G symmetrical)**
Fault Duration:	**11 cycles (183 ms) for L-G fault** **7 cycles (117mS) for a phase-phase fault**
References:	2.2.6, OSC-2059, Rev. 25, Table C-06 2.2.5, OSC-11062 Rev. 0 Section 5.4.1 2.3.8, EC 402424, Rev. 0, Additional Short Circuit Currents from Fleet Electrical Analysis (FEA)

4.5 <u>13.8kV PSW Underground Path (KHS to PSW Switchgear)</u>

System Voltage: **14.49 kV** (phase-phase: pre-fault voltage 105% of 13.8 kV base). Per Assumption 7.1, OSC-11055.

Fault Currents: **17.60 kA** (three-phase symmetrical at KPF-2 bus per Reference 2.3.8, page 3).

Revision 1 Comment: An additional 1.34kA of load fault contribution was added with this revision to support a postulated failure at any time (not time of demand). See page 3 of 11 of reference 2.3.8 (EC 402424) for additional details.

17.6 A (phase-ground - with neutral resistance grounding). Per KC-0094, page 3 of 9, section 1.4.

Fault Duration: **11 cycles (183 ms)** for phase-phase faults. Per section 5.4.3, OSC-11062. This is the fault clearing time for breakers KPF-9/10 (breakers that are downstream of the Keowee Unit 2 Terminal Bus).

70.8 cycles (1.18 s) for phase-ground fault of 17.6 A per section 4.4 of this analysis.

Applying a conservative 3% uncertainty results in the following values that should be used in the test setup. Also, an additional 3% maximum was applied to bound any measurement uncertainty.

Revision 1 Comment: It was determined that the revision 0 upper tolerance of 10% was overly conservative and was removed as part of revision 1.

Test Parameters: These parameters were used as the testing criteria for the cable testing described in Appendix C.

System Voltage: **14.935 kV (phase-phase: pre-fault voltage 105% of 13.8 kV base)**

Fault Currents: **18.128 kA to 18.672 kA (three-phase symmetrical at KPF2 Bus)**
18.128 A to 18.672 A (phase-ground - with neutral resistance grounding)

Fault Duration: **11 cycles (183 ms) for phase-phase faults**
70.8 cycles (1.18 s) for 18.128 A to 19.941 A phase-ground fault

References: 2.2.3, OSC-11055 Rev. 0 Section 4.0 Table 1
2.2.5, OSC-11062
2.2.1, KC-0094
2.1.2, O-6700

2.1.1, K-700
2.3.8, EC 402424, Rev. 0, Additional Short Circuit Currents from Fleet Electrical Analysis (FEA)

4.6 **13.8kV Fant Path (PSW Substation to PSW Switchgear)**

System Voltage: **14.5kV** (105.084% of 13.8kV per OSC-9370 Appendix D page D2)

Fault Currents:

5.66 kA (three-phase symmetrical per Reference 2.3.8, page 4. Fault Duty at dip-poles which is upstream of Manhole 6). Since the dip (overhead to underground transition) poles are upstream of the underground cable (see drawing O-6700), this is a conservative value.

4.435 kA (phase-ground symmetrical: solidly grounded system) OSC-9832 Rev. 3 Attachment 13 Page 1 (Fault Duty at dip-poles which is upstream of Manhole 6). There is greater than 200 feet of underground cable between the dip poles and manhole 6 (MH6). Since the dip (overhead to underground transition) poles are upstream of the underground cable (see drawing O-6700), this is a conservative value.

Revision 1 Comment: No additional load fault current contribution is expected because the transformers in question (CT6 and CT7) are delta (13.8kV primary) to wye (4.16kV) connected. Per reference 2.3.9, the zero sequence impedance on the delta primary side (13.8kV) is an open circuit due to the delta connection (per cases 4 and 5 of figure 11.17 on pages 450 as well as pages 454-456). Per figure 12.8, page 484 of reference 2.3.9, if there is an open circuit of the zero sequence impedance, then no current will flow in the single line to ground equivalent circuit for the CT6 and CT7 transformers. Therefore no load fault contribution from the secondary side (wye) of the wye delta transformer should be considered when a single line to ground fault occurs.

Fault Duration: **4.302 cycles (71.7 ms)** for both phase-phase and phase-ground faults. Per Attachment 5 (breaker clearing time of 3 cycles (50 ms) plus 5 ms SEL relay instantaneous relay operating time plus 1 cycle (16.7 ms) This is due to the instantaneous overcurrent pickup setting being greater than 4 (0.5 cycle) (see Figure 3.5, Attachment 5 and Reference 2.3.5) and assuming the instantaneous cycle is an additional 0.5 cycle. So this would result in a 71.7 ms (50 ms + 5 ms + 16.7 ms).

Applying a conservative 3% uncertainty results in the following values that should be used in the test setup. Also, an additional 3% maximum was applied to bound any measurement uncertainty.

Revision 1 Comment: It was determined that the revision 0 upper tolerance of 10% was overly conservative and was removed as part of revision 1.

Test Parameters: These parameters were used as the testing criteria for the cable testing described in Appendix C.

System Voltage:	**14.935kV**
Fault Currents:	**5.830 kA to 6.005 kA (three-phase symmetrical)** **4.568 kA to 4.706 kA (phase-ground symmetrical: solidly grounded system)**
Fault Duration:	**4.302 cycles (71.7 ms) for both phase-phase and phase-ground faults.**
References:	Attachment 5 2.2.5, SEL-351S Protection System Instruction Manual 2.2.4, OSC-9832 2.2.7, OSC-9370 2.1.2, O-6700 2.3.8, EC 402424, Rev. 0, Additional Short Circuit Currents from Fleet Electrical Analysis (FEA)

4.7 Transient Overvoltage Phenomena

Attachment 3 as well as references 2.3.1, 2.3.2 and 2.3.3 discuss the potential for very high (290-300% of nominal line to ground per figure 47 of Attachment 3) transient voltage lasting for a short period of time (1/4 of a cycle per figure 45 of Attachment 3) during a line to ground fault (arc fault restrike) or during breaker opening (breaker restrike).

Even though this is a high transient voltage, it is relatively short in duration and therefore would not have an adverse impact on the cable insulation system. For instance, the 13.8kV feeder cables are 15kV rated cables that are tested to 52kV for a duration of 5 minutes per page B40 of KC-0094 (reference 2.2.1). This is approximately 347% of the cable rating (52kV/15kV) for a much longer duration.

Also, per Attachment 4, the 5kV (250MCM power cable) utilized in the CX feeder was tested at 28kV for 5 minutes without any damage. This is 560% (28kV/5kV) of the cable rating for a long period of time.

Since it is believed that the (both 5kV and 15kV) cables will not be exposed to transient voltages with a magnitude and duration exceeding manufacturing tests, there is no reason to believe the cables will be damaged during the potential transient overvoltage phenomena described in Attachment 3.

4.8 **Control Cable Induced Voltage During Short Circuit Event**

A third party FEA (finite element analysis) was performed by MPR to determine any potentially adverse impacts of an induced voltage during postulated short circuit events. This study is included in Attachment 6 to this analysis. The two voltages of interest included the maximum differential voltage (the voltage developed across two control cable conductors) and the maximum common mode voltage (the voltage developed on any control cable conductor relative to ground). The maximum differential voltage was studied to determine the potential for spurious actuation or drop of control circuits for the Keowee emergency power system. The maximum differential voltage was studied to determine the potential for insulation system breakdown/failures relative to station ground (control cable armor, terminal blocks and other system components).

This analysis includes several known conservatisms, including use of the most limiting cable separation (set to minimum allowable by the duct geometry) and intra-cable bundle low voltage conductor separation (set to the maximum allowable by the cable bundle diameter), neglecting control conductor helical twist along the length of the cable (has the effect of canceling magnetic coupling), and a conservatively high line-ground fault current (16,000 Amps-peak). See page 1 of Attachment 6 for additional details.

This analysis specifically studied the future configuration of the 13.8kV Fant to PSW feeder parallel to the control cables from Manhole 6 to the PSW building. The assumption of a 16kA peak line to ground fault current well bounds the actual available fault current of 5.66kA (see section 4.6 of this calculation) for this configuration.

The analysis determined that the differential voltage induced on a galvanized steel interlocked armor (GSIA) control cable conductor pair is less than one volt. Since this differential voltage is so minute, there is no concern for mal-operation of the control circuits for the Keowee emergency power system. This is described further in Section 2.0 of the MPR analysis. This study is included in Attachment 6 to this analysis.

The analysis further determined that the common mode voltage is approximately 14 volts for the armored control cable case. A common mode voltage of 14 volts is well within the insulation system of the Keowee emergency power system components (cables, relays, etc). This study is included in Attachment 6 to this analysis.

Small voltage changes (less than 1 volt across conductors (differential) and 14 volts relative to ground (common mode)) would have an insignificant impact on an ungrounded 125VDC control system such as the Keowee Emergency Start circuit(s). These are relatively small changes relative to the system limits. For instance, 1 volt differential is less than 1 percent of the rating (125VDC) of the connected emergency start relays and would not interfere with the emergency start or operation of a Keowee unit.

The common mode voltage is an insulation (relative to ground) rating. A common mode voltage of 14 volts is only 11 percent more than the rating of the most limiting device relative to ground (14/125VDC for emergency start relays). Typically cable systems, terminal blocks, etc are rated for at least 150 percent of their nominal rating (i.e., 1000Vac cable in a 600Vac application) relative to ground per Assumption 3.4.

4.9 Results

The results presented at the end (after the instrument uncertainties have been applied) of their respective sections (Sections 4.3 – 4.6) were utilized for cable testing based upon the respective configuration to be tested.

4.10 Comparison of Test Results

Attachment C to this analysis (Engineering Report on Medium Voltage Cable Testing at KEMA Labs) will discuss the test results and compare them to the calculated fault current and duration values.

ATTACHMENT 3B

Associated with Response to RAI 3(a)

Appendix C

Engineering Report on Medium Voltage Cable Testing at KEMA Labs

1.0 Background:

The 2014 Oconee NRC Component Design Basis Inspection (CDBI) resulted in an Unresolved Item with respect to the adequacy of the cable separation between the 13.8 kV and 4.16 kV single conductor medium voltage circuits and the low voltage instrumentation and control (I&C) circuits routed together from Keowee to the plant, from Keowee to the Protected Service Water (PSW) Building and from the PSW substation to the PSW building.

Both the medium voltage and I&C cables were routed and installed in accordance with existing Oconee (ONS) Cable and Wiring Separation Criteria OSS-0218-00-00-0019 by Nuclear Station Modification ON53065 and Engineering Changes 91880 and 91874.

The single conductor medium voltage cables have bronze metallic tape armor. Bronze armor is referenced in the UFSAR Section 8.3.1.4.6.2 (Cable Separation) as type of cable armor. However, upon further review during the CDBI it was determined that there is not sufficient testing to support the separation distance for bronze armored cable. This condition was determined to be Operable But Degraded/Nonconforming (OBDN) as documented in PIPs O-14-3190 (now Action Request 019059999) and O-14-5125 (now Action Request 01906088).

The CDBI Inspection Team hypothesized that an initial phase-to-ground fault on these medium voltage cables would propagate to a multi-phase (i.e. two-phase or three-phase) fault with resultant high energy arc flash, electromagnetically induced cable movement and the induction of 13.8 kV and 4.16 kV voltage on the low voltage instrumentation and control cables with potentially significant consequential effects on the Keowee and plant electrical systems. Duke's analysis of these scenarios during the CDBI (which included Initial and Prompt Determinations of Operability) concluded that a phase-to-ground fault would not result in a multi-phase fault.

The pertinent section from the NRC CDBI Inspection Report dated June 27, 2014 documenting the URI is provided below:

> *<u>(Opened) Potential Unanalyzed Condition Associated with Emergency Power System</u>*
>
> *<u>Introduction:</u> The team identified a URI to determine whether a performance deficiency exists related to the configuration of electrical cabling in the underground concrete raceway. Specifically, the team was concerned that short circuits and/or ground faults in the cabling could potentially impact the functionality of the emergency power system which is required to mitigate certain design basis events.*
>
> *<u>Description:</u> During a review of Oconee's engineered safeguards protection system (ESPS) emergency power start control for the KHUs, the team noted that the 125Vdc control cables for train A of the ESPS and cables for supervisory control of both KHUs were recently modified. The team also noted that these 125Vdc control cables were installed in the same underground concrete raceway systems as the 4160Vac auxiliary power cables, 13.8kVac power cables for both emergency power and protected service water (PSW), and were in close proximity to these power cables. The team was concerned that a short circuit (which the licensee considered outside their design basis) in the 13.8kVac cables could induce voltage and currents in the dc control system which*

could potentially impact the functionality of the emergency power system which is required to mitigate certain design basis events. A similar issue exists in Manhole 6 of the PSW underground raceway where the new power supply to the PSW (adjacent to the 125Vdc control emergency power system) could short circuit or fault to ground. The licensee had not performed an analysis to determine the effects of such failures on the ability of the emergency power system to perform its safety function, thus the team questioned whether the plant was in an unanalyzed condition. Although the licensee did not agree that these failures were part of their licensing basis, they reported this as an unanalyzed condition to the NRC in accordance with 10 CFR 50.73(a)(2)(ii)(B) in Licensee Event Report 269/2014-01. In response to the team's concerns, the licensee entered this issue into their corrective action program, and performed immediate and prompt determinations of operability in which they concluded a reasonable expectation of operability exists.

The team has requested assistance from subject matter experts in the Office of Nuclear Reactor Regulation via a Task Interface Agreement to review the emergency power system licensing basis to determine the acceptability of the licensee's design. If the design is found to be noncompliant with the licensing basis, the licensee will be required to implement corrective actions to restore compliance.

This issue is being tracked as URI 05000269/2014007-05, 05000270/2014007-05, 05000287/2014007-05, Potential Unanalyzed Condition Associated with Emergency Power System.

2.0 Purpose of Testing:

To supplement the Duke analysis and resolution of the OBDN, a testing program was conducted by Oconee Design Engineering at KEMA Laboratories in Chalfont, PA during November 2015 and witnessed by the NRC. The testing was designed to support or refute the hypothesis that a single phase-to-ground fault would propagate to a multi-phase fault. The test program consisted of energizing the bronze armor single conductor medium voltage cables with a purposely created phase-to-ground fault and determining if a multi-phase fault occurred.

While not required to address the primary concern, low voltage I&C cables were installed along with the medium voltage cables and monitored for voltage during testing.

3.0 Scope of Testing:

The testing scope was designed to support or refute the hypothesis that an initial phase-to-ground fault on the Duke design bronze armor single conductor medium voltage power cables would propagate to a multi-phase fault as documented in the NRC URI.

The testing scope was not a qualification type test (e.g. IEEE-323, IEEE-383) of the cables, the cable restraint fixtures (i.e. cable cleats), other components of the cable test articles or attempt to replicate the full scale cable trench configuration. The testing scope was purposely limited to facilitate resolution of the OBDN.

The testing scope does not specifically include the consequential effects of electromagnetically induced cable movement (i.e. "cable whip"). For cable whip to occur, at least two of the three phases must carry fault current; therefore, the consequential effects of cable whip is not a test consideration if the initial fault is confined to phase-to-ground.

4.0 Test Acceptance Criteria:

1. For each test, the voltage, fault current and duration meet the minimum required test parameters.
2. A phase-to-ground fault on the medium voltage single conductor cables does not result in a multi-phase fault.

5.0 Selection of Testing Lab:

For this type of testing, a lab with a power source that can simultaneously provide high voltage and high current is required. After contacting various labs to determine if they had both the capability and availability, KEMA Laboratories was selected as a candidate to perform the testing.

KEMA is a division of DNV GL Energy and is located in Chalfont PA. Oconee Design Engineering (Bert Spear/Lead Nuclear Engineer and Ray Price/Manager Design Basis Engineering) met at KEMA Oct. 15-16, 2015 to assess the capability of KEMA to perform the testing.

Based on inspection of the facility and discussion with KEMA staff, it was determined that KEMA had previous experience with similar testing, power sources that met the required voltage and current parameters and the necessary data acquisition systems to monitor and record the test results. Test cell availability also coincided with Duke's anticipated testing schedule. While at KEMA, Duke witnessed high energy arcing fault testing being conducted by the NRC, and the Staff provided positive feedback on KEMA's capabilities. This feedback confirmed Duke's initial impression that KEMA was suitable for the cable testing program.

6.0 Description of Tested Medium Voltage Cables:

Cable type 1BA750G15 is used in the 13.8 kV power paths from Keowee to the plant and the PSW substation to the PSW building and cable type 1BA250G5 is used in the 4.16 kV power path from the plant to Keowee.

Duke single conductor medium voltage cable type 1BA750G15 was procured per Duke specification OSS-0139.00-00-0010. Cable Description: Okonite medium voltage single-conductor voltage shielded power cable, 750 kcmil copper compact round conductor, extruded semiconducting strand and insulation screens, 15 kV EPR at 173% insulation level (260 mils EPR), two helically applied 10 mil layers of bronze tape shield armor, jacket.

Duke single conductor medium voltage type 1BA250G5 was procured per Duke specification OSS-0139.00-00-0010. Cable Description: Okonite medium voltage single conductor shielded cable, 250 kcmil copper compact round conductor, extruded semiconducting strand and insulation screens with 5 kV EPR at 173% insulation level (140 mils EPR), two 10 mil layers of helically applied bronze tape shield armor, jacket.

Both cable types 1BA250G5 and 1BA750G15 were tested.

7.0 Description of Low Voltage Instrumentation and Control Cables:
Low voltage instrumentation and control (I&C) cable types 8SXJ9G1, 19SXJ12G1 and 8SPXJ16G.3 were used in the Trench 3 underground path from Keowee to the plant (Ref. K-904-A).

Duke cable type 8SXJ9G1 was procured per Duke specification CNS-1354.02-00-0002 . Cable Description: Eight (8) #9 AWG conductors, 1kV XLPE insulation, polyester and copper tapes over cable core, galvanized steel interlocked armor, jacket.

Duke cable type 19SXJ12G1 was procured per Duke specification CNS-1354.02-00-0002. Cable Description: Nineteen (19) #12 AWG conductors, 1kV XLPE insulation, polyester and copper tapes over cable core, galvanized steel interlocked armor, jacket.

Duke cable type 8SPXJ16G.3 was procured per Duke specification CNS-1354.03-00-0001. Cable Description: Sixteen (16) shielded #16 AWG pairs with drain wire, 300 V XLPE insulation aluminum and polyester tapes, galvanized steel interlocked armor, jacket.

The differences between types 8XSJ9G1 and 19SXJ12G1 are eight #9 AWG conductors vs. nineteen #12 AWG conductors. Control cable type 8SXJ9G1 and signal cable type 8SPXJ16G.3 were selected as representative for testing purposes.

8.0 Failure Modes of Single Conductor Medium Voltage Cables:
As part of development of the test article design, it was necessary to determine the configuration and spacing of the single conductor medium voltage cables. For a single phase-to-ground fault to propagate to a multi-phase fault, the following sequence of events would have to occur:

1. An insulation failure occurs on a medium voltage single conductor cable. The cable insulation failure allows current to flow from the conductor to the grounded metallic shield installed over the insulation which results in a phase-to-ground fault. The power cables were terminated per IP/0/A/3009/018 which grounded both ends of the cable metallic shields.
2. The arcing energy of the faulted cable would have to be of sufficient magnitude and duration to penetrate the faulted cable jacket, the cable jacket on the adjacent cable(s), the bronze metallic tape shield on the adjacent cable(s) and the insulation on the adjacent cable(s). An additional path to ground has now been created though the adjacent cable(s) resulting in a multi-phase fault.
3. The preceding events would occur before the cable protective relaying and breaker could detect and clear the fault. An additional failure of the protective relaying and breaker is not postulated since this scenario is beyond the ONS single failure criteria as described in Section of 3.2.3.2 of OSS-0254.00-00-4013 and the UFSAR Section 8.3.1.2.

Based on the above discussion, the most conservative test configuration is to install the phase conductors in a triangular bundle with the faulted cable held in direct contact with the adjacent phase conductor cables. The faulted cable will be oriented such that the fault area is perpendicular (i.e. pointed at) an adjacent cable. This configuration ensures that any arcing that penetrates the faulted cable will impinge on the non-faulted cables held in close proximity thus providing the greatest opportunity for additional fault(s) to occur.

9.0 Power Cable Fault Preparation:
For each three-phase medium voltage circuit configuration, one of the phase conductors is prepared such that when energized, a single phase-to-ground fault immediately occurs. The preferred method is to create a cable insulation failure at a specific location without compromising the integrity of the cable jacket or bronze metallic tape.

Duke Design Engineering (Bert Spear) met with Okonite Oct. 13-14, 2015 at their Cable Evaluation and Development Laboratory in Patterson NJ. The purpose of the meeting was to determine if a cable insulation failure could be induced at a specific location without have to resort to drilling through the cable jacket and bronze tape metallic shield. It was desired to avoid, if possible, compromising the bronze tape and cable jacket integrity since these cable system components were barriers that would assist in containing the arc produced by the phase-to-ground fault. The Supporting Documents section of this Appendix includes data and photographs from this meeting.

A length of Duke 750 kcmil cable was connected to Okonite's high voltage impulse equipment. Prior to energizing the cable, the cable was inserted through a short length of steel pipe connected to a current source. A cable jacket temperature of approximately 130°C was achieved by I^2R heating of the pipe. The intent was to decrease the insulation dielectric strength in the heated cable section to make the heated section more susceptible to insulation failure at a specific location compared to the rest of the cable at ambient temperature.

Two series of high voltage impulse tests were conducted. The first test began at 140 kV and continued to 530 kV when an insulation failure occurred. However, the insulation failure location was not externally visible. A DC hi-pot tester was next used to locate the fault by the application of repetitive sustained voltage which had the effect of causing the bronze tape and jacket to form a small convex area. The convex area identified the fault location as approximately six feet from a cable end which was outside the heated area. A second impulse test was performed on another cable beginning at 300 kV and ending at 420 kV with insulation breakdown. In the same manner as before, the fault was located at approximately five feet from a cable end which was also outside the heated area.

Okonite surmised that while the heated cable section did have decreased dielectric strength, the insulation failure near cable ends was attributed to the relatively short cable causing end reflection and doubling effects from the steep wave front of the voltage impulse. Okonite test equipment failure prevented additional impulse testing.

In order to ensure a reliable cable insulation failure at a specific location, an alternate method was developed and tested. This method consisted of cutting a triangular flap in the cable jacket and drilling a small hole through the cable bronze metallic shield, insulation semicon, insulation and conductor semicon to the conductor. The jacket flap was then positioned back in place and secured to the cable jacket with tape while avoiding covering the jacket at the hole location.

Using AC hipot test equipment, the cable insulation failed at 3.7 kV. This test was repeated several times at the same voltage with insulation failure occurring each time. Inspection of the faulted area beneath the cable jacket revealed a small soot deposit around the drilled hole. As a contingency in case the drill hole method fails to produce the required fault, the same test was performed at Okonite with a #18 AWG copper wire inserted in the hole thus forming a solid conductive path between the conductor and metallic shield. For the KEMA testing with a resistance-grounded power source with limited phase-to-ground fault currents, a #18 AWG copper wire will be used. For solidly-grounded systems with significant phase-to-ground fault currents, a #12 AWG copper wire will be used.

When voltage is applied to the cable prepared with inserting a wire, an immediate phase-to-ground cable fault will occur. This method, while conservative, compromises both the cable jacket and bronze metallic shield before the test - two of the barriers that would protect the adjacent cables from the effects of the cable fault.

10.0 Test Article Configurations:

The power systems referenced in the URI and OBDN issues resulted in the need to test four configurations as described below. The Supporting Documents section of this Appendix includes sketches for each test article type.

Test Type CT4:

This the 13.8 kV power path from Keowee to plant transformer CT4 which consists of two 750 kcmil conductors (cable type 1BA750G15) per phase installed in a 36 inch wide cable tray for testing purposes. The Keowee power source is resistance grounded which limits the phase-to-ground fault current. Each triangular bundle contains the A, B and C phases connected in parallel to the KEMA power source (line side) and unconnected on the load side. I&C cable types 8SXJ9G1 and 8SPXJ16G.3 are attached to the cable tray on either side of the power cable bundles.

Test Type KPF:

This is the 13.8 kV power path from Keowee to the PSW building which consists of one 750 kcmil conductor (cable type 1BA750G15) per phase installed in a 24 inch wide cable tray for testing purposes. The Keowee power source is resistance grounded which limits the phase-to-ground fault current. The triangular bundle containing the A, B and C phases is connected to the KEMA power source (line side) and unconnected on the load side. I&C cable types 8SXJ9G1 and 8SPXJ16G.3 are attached to the cable tray on either side of the power cable bundle.

Test Type Fant:

This is the 13.8 kV power path fed from the PSW substation to the PSW building. The section of the power path under consideration begins at PSW Manhole 6, through a ductbank where the circuit terminates at the PSW building switchgear. This test consists of one 750 kcmil conductor (cable type 1BA750G15) per phase installed in a 24 inch wide cable tray for testing purposes. The PSW substation power source is solidly grounded which results in large magnitude phase-to-ground fault currents. The triangular bundle containing the A, B and C phases is connected to the KEMA power source (line side) and unconnected on the load side. I&C cable types 8SXJ9G1 and 8SPXJ16G.3 are attached to the cable tray on either side of the power cable bundle.

Test Type CX:

This is the 4.16 kV power path from plant switchgear 1TC to Keowee Station Service Transformer CX which consists of one 250 kcmil conductor per phase installed in a 24 inch wide cable tray for testing purposes. The switchgear 1TC power source is solidly grounded which results in large magnitude phase-to-ground fault currents. The triangular bundle containing the A, B and C phases is connected to the

KEMA power source (line side) and unconnected on the load side. I&C cable types 8SXJ9G1 and 8SPXJ16G.3 are attached to the cable tray on either side of the power cable bundle.

11.0 Test Article Cable Positioning and Installation:
The test cable bundles (A/B/C phases) were installed in a 12 foot long galvanized steel open ladder-type cable tray. The purpose of the cable tray was to provide a means of holding the cable bundle(s). The cable tray was clamped to prevent movement and supported with wood blocks or other suitable material to ensure the tray is electrically insulated from the ground or mounting surface. The purpose of electrically isolating the cable tray is to ensure that all fault currents flow through the cable metallic shield to ground. If the cable tray was grounded and the faulted cable jacket is punctured where it was in contact with a tray rung, an additional ground path would be created through the conductor to the metallic shield and then the grounded tray.

The power cables were arranged in triangular bundles and secured to the cable tray rungs by Cooper B-Line stainless steel cable cleats to hold the faulted cable in close proximity to the adjacent cables and to prevent potential cable movement during fault conditions. The I&C cables were secured to the cable tray rungs with stainless steel ty-wraps to maintain their position during transport into the KEMA test cell.

As previously stated, the faulted power cable conductor was positioned and orientated such that the effects of the fault would directly impinge on the adjacent cables and create an environment conducive for a multi-phase fault to occur. For consistency, the C-phase conductor will always be the pre-faulted cable.

The I&C cables were initially spaced from the power cables in accordance with OSS-0218.00-00-0019 Section 5.3. The I&C cable interlocked steel armor and underlying shielding were grounded at both ends. The I&C cable conductors were not energized during the test but monitored for induced voltage. During the course of the tests, the I&C cables were repositioned closer to the power cables and changes to both the I&C termination and voltage measurements methods were made to develop additional data.

12.0 Cable Testing Conditions:
The feasibility of testing the power cables with the conductors at the nominal 90°C operating temperature was investigated during the KEMA pre-test visit.

Pre-heating the cables could be accomplished by two methods. The first method by connecting a load to the energized cables and achieving operating temperature through conductor ohmic heating. The second method would raise the cable temperature in a thermal chamber. Both methods would also raise the temperature of the cable bronze metallic tape shield to operating temperature. The shield metallic temperature would be less than 90°C due to the temperature gradient created by the insulation system between the conductor and the metallic shield.

For Method 1, KEMA did not have an onsite load bank with sufficient capacity to raise the cables to the required temperatures due to the large conductor sizes (250 and 750 kcmil). If a load bank was used, there would be a period of time when the cable were disconnected from the load bank and then connected to the testing power source. During this interval, the cables would undergo cooling.

For Method 2, KEMA would have to construct a thermal chamber outside of the test cell that could accommodate the cables and cable tray. After the cables were sufficiently heated, the cables and tray would have to be transported to the test cell and connected to the power source. It was estimated that this evolution would take approximately two to three hours during which time the cables would cool. This method was not selected.

Since Methods 1 and 2 were logistically unfeasible, the acceptability of testing the cables at ambient temperature with no preheating was investigated by reviewing industry guidance and applicable standards.

The applicable industry guidance for metallic shield ratings is found in Insulated Conductor Engineers Association (ICEA) Publication P-45-482-2013 which provides a methodology for determining the short circuit capacity of the metallic shield on insulated cable. Per P-45-482, the thermal capacity of the metallic shield on a medium voltage cable is based on the shield material and the transient temperature limit of the adjacent cable component materials. The heat contained in the metallic shield is a function of the fault current and the shield temperature rise during fault conditions. The temperature rise magnitude is the difference between the upper temperature limit of the cable material in contact with the shield and the pre-fault shield temperature. Therefore, the thermal withstand capability of the metallic shield will be marginally increased at a lower pre-fault ambient temperature.

However, the methodology in P-45-482-2013 is conservative for the following reasons:

- To simplify the calculations, the shield heating process is assumed to be entirely adiabatic, .i.e. all heat developed by the fault is contained within the shield and there is no heat dissipation into the surrounding materials or environment.
- The allowable fault magnitude or fault duration parameters are calculated based on not causing any significant material change so that a cable undergoing a through-type fault could be potentially returned to service. For the purposes of the cable testing, the cable materials are allowed to be damaged provided the initial phase-to-ground fault does not propagate to a multi-phase fault.

An IEEE standards review was performed to gain additional insight into the need to preheat the cable conductors. IEEE Standard C37.20.2 provides information on designing and testing of metal-clad switchgear. Section 6.2.2.2 (Ambient Temperature Limits) states that the testing can be performed with the ambient air temperature between 10°C (50°F) and 40°C (104°F). The calorimeter data from the KEMA Test Report indicates that the ambient temperature during testing was between 10°C and 40°C. Sections 6.2.3 and Section 6.2.4 demonstrates the switchgear components ability to withstand the rated momentary and short-time currents. For these tests, preheating is not required. If preheating were required, the switchgear bus bar and other heated components would be expected to have reduced bus bracing capability - similar to preheating the cable metallic shields would reduce the thermal margin.

Based on the above discussion, preheating the cable conductors from ambient to operating temperature was not expected to have significant influence on the test results and the tests proceeded without preheating.

13.0 KEMA Laboratory Power Sources:
The testing laboratory replicated the pertinent elements of the Oconee power systems including generator/power source neutral grounding arrangement (resistance or solidly grounded), voltages and phase-to-ground and three-phase fault currents, and fault durations that include relay response and breaker opening times as provided by OSC-11504 Rev. 0.

14.0 Test Electrical Parameters:
At the time testing was conducted, the acceptance criteria for minimum voltage, fault currents and duration were based on calculation OSC-11504 Rev. 0 as summarized in the table below.

Cable Test Parameters Data Source: OSC-11504 Rev. 0					
Test Type	Minimum Pre-Fault Voltage (P-P)	Minimum Fault Current (Three-Phase)	Minimum Fault Current (P-G)	Minimum Fault Duration (Three-Phase)	Minimum Fault Duration (P-G)
CT4	14.9 kV	16.8 kA	18.1 A	11 cycles (183 ms)	70.8 cycles (1.18 s)
KPF	14.9 kV	18.0 kA	18.1 A	11 cycles (183 ms)	70.8 cycles (1.18 s)
Fant	14.9 kV	4.9 kA	4.6 kA	4.3 cycles (71.7 ms)	4.3 cycles (71.7 ms)
CX	4.5 kV	9.6 kA	6.5 kA	7 cycles (117 ms)	11 cycles (183 ms)

After the KEMA cable testing was completed, OSC-11504 was revised to include additional information including updated electrical software models. Resolving the fault current differences between Rev. 0 and Rev. 1 is discussed in Section 17 of this Appendix.

15.0 Conduct of Testing:
The testing was performed by KEMA personnel using an approved KEMA test procedure. Duke Engineering provided continuous oversight and maintained a test log separate from KEMA. The entire testing program was witnessed by the NRC staff. Okonite engineers attended one day of testing.

For each of the four cable configurations, a minimum of five tests were performed. In addition to pre and post-test activities by KEMA personnel, the following items were inspected by Duke Engineering:

1. The pre-test calibration test shot satisfies the required test voltage, current and duration.
2. A pre-test inspection to ensure the test article is properly connected to the power source and test instrumentation and photograph and video equipment are correctly orientated and operating.
3. Post-test verification that the required test parameters for voltage, current and duration were met by review of the test data.
4. Post-test data verification review that the single phase-to-ground fault did not result in a multi-phase fault.
5. Post-test review of measured voltage on the I&C cables.
6. Post-test visual inspection and photographs of the power and control cables.
7. Post-test review to determine if adjustment of power or I&C cable configurations and electrical parameters for subsequent tests were desired to provide additional testing conservatism or test data.

16.0 Summary of Test Results:

Cable testing was conducted Nov. 2 - 6, 2015 at KEMA Laboratories and the results are documented in KEMA Report 15208-B. Additionally, Duke engineering maintained a test logbook and took photographs.

Section 17.0 addresses the testing with respect to the medium voltage power cables. The data collected for the control and signal cables is addressed separately in Section 18 of this Appendix.

For Tests 1 - 21, a comparison is made between the tested electrical parameters and the required minimum electrical parameters from OSC-11504 Rev. 0 to determine if the test acceptance criteria was met. A summary and analysis of the post-test condition of the power cables is performed based on the KEMA report, inspection by Duke engineering and photographs. A determination is made if the initial phase-to-ground fault stayed confined to a single phase-to-ground fault or propagated to a multi-phase fault.

Test 1 Test Type CT4 (Resistance Grounded System)
Test Data Compared to Test Requirements: System Test Voltage (L-L)= 15.0 kV > 14.9 kV #1 C-Phase Neutral Current = 9.6 A #2 C-Phase Neutral Current = 15.1 A Sum of #1 and #2 C-Phase Neutral Currents = 24.7 A > 18.1 A Fault Current Duration: 0.200 s < 1.18 s
Discussion of Test Results and Post-Test Inspection: Test voltage and L-G fault current requirements were met. The test L-G fault current duration requirement was <u>not</u> met. Test 1 was performed with no copper wire inserted in the hole between bronze tape and conductor. Review of the Neutral 1 and 2 current oscillographs indicates that the waveforms were intermittent and irregular and lasted for 0.200 seconds though voltage was present for the required 1.18 seconds. Post-test inspection of the fault location on the C-phase cable found the jacket undamaged. There were no soot deposits, heat damage or any other visible affects to adjacent power and control cables. The tape securing the jacket flap was fully intact. The tape was removed and jacket flap was folded back revealing small soot deposits around the drill hole and the area of the jacket exposed to the fault. Inspection of the entire test article did not reveal any damage or anomalies. See Supporting Documentation Section 21.3 for post-test photographs of the C-phase cable with the jacket flap removed to expose the fault area and, if any damage occurred, post-test photographs of the A-Phase and B-phase cables. The intermittent and short duration fault current is attributed to the combination of low magnitude fault current, high voltage and distance between the conductor and shield causing the deposition of arc-induced insulation byproducts. These byproducts provided sufficient insulation between the conductor and bronze tape to prematurely extinguish the fault-induced arc.
Comments: • This test is invalid since the fault current duration requirement was not met. • The initial single phase-to-ground fault did not propagate to a multi-phase fault. • To ensure the fault current last for the required duration, a copper wire will be inserted in the hole between the bronze tape and conductor for all subsequent tests.

Test 2 Test Type CT4 (Resistance Grounded System)
Test Data Compared to Test Requirements: System Test Voltage (L-L)= 15.0 kV > 14.9 kV #1 C-Phase Neutral Current = 7.4 A #2 C-Phase Neutral Current = 11.9 A Sum of #1 and #2 C-Phase Neutral Currents = 19.3 A > 18.1 A Fault Current Duration: 1.31 s > 1.18 s
Discussion of Test Results and Post-Test Inspection: Test voltage, L-G fault current and L-G fault current duration requirements were met. Test 2 was performed with a #18 AWG copper wire inserted in the hole between bronze tape and conductor. Review of the Neutral 1 and 2 current oscillographs indicates that the waveforms are now regular and lasted for the required duration. Post-test inspection of the fault location on the C-phase cable found the jacket undamaged. There were no soot deposits, heat damage or any other visible affects to adjacent power and control cables. The tape securing the jacket flap was fully intact. The tape was removed and jacket flap was folded back revealing no soot deposits or arcing damage around the drill hole or the area of the jacket exposed to the fault. The #18 AWG wire showed no indications of overheating. Inspection of the entire test article did not reveal any damage or anomalies. See Supporting Documentation Section 21.3 for post-test photographs of the C-phase cable with the jacket flap removed to expose the fault area and, if any damage occurred, post-test photographs of the A-Phase and B-phase cables.
Comments: • All test parameter requirements were met. • The initial single phase-to-ground fault did not propagate to a multi-phase fault. • Addition of copper wire between the bronze tape and conductor creates a bolted phase-ground fault that lasts for required test duration. This method will be used for all subsequent tests.

Test 3 Test Type CT4 (Resistance Grounded System)
Test Data Compared to Test Requirements: System Test Voltage (L-L)= 15.0 kV > 14.9 kV #1 C-Phase Neutral Current = 7.3 A #2 C-Phase Neutral Current = 11.9 A Sum of #1 and #2 C-Phase Neutral Currents = 19.2 A > 18.1 A Fault Current Duration: 2.13 s > 1.18 s
Discussion of Test Results and Post-Test Inspection: Test voltage, L-G fault current and L-G fault current duration requirements were met. The fault duration was increased to 2.13 s by Duke engineering. Test 3 was performed with a #18 AWG copper wire inserted in the hole between bronze tape and conductor. Post-test inspection of the fault location on the C-phase cable found the jacket undamaged. There were no soot deposits, heat damage or any other visible affects to adjacent power and control cables. The tape securing the jacket flap was fully intact. The tape was removed and jacket flap was folded back revealing no soot deposits or arcing damage around the drill hole or the area of the jacket exposed to the fault. The #18 AWG wire showed no indications of overheating. Inspection of the entire test article did not reveal any damage or anomalies. See Supporting Documentation Section 21.3 for post-test photographs of the C-phase cable with the jacket flap removed to expose the fault area and, if any damage occurred, post-test photographs of the A-Phase and B-phase cables.
Comments: • All test parameter requirements were met. • The initial single phase-to-ground fault did not propagate to a multi-phase fault.

Test 4 Test Type CT4 (Resistance Grounded System)
Test Data Compared to Test Requirements: System Test Voltage (L-L)= 15.0 kV > 14.9 kV #1 C-Phase Neutral Current = 7.2 A #2 C-Phase Neutral Current = 12.0 A Sum of #1 and #2 C-Phase Neutral Currents = 19.2 A > 18.1 A Fault Current Duration: 2.13 s > 1.18 s
Discussion of Test Results and Post-Test Inspection: Test voltage, L-G fault current and L-G fault current duration requirements were met. Test 4 was performed with a #18 AWG copper wire inserted in the hole between bronze tape and conductor. Post-test inspection of the fault location on the C-phase cable found the jacket undamaged. There were no soot deposits, heat damage or any other visible affects to adjacent power and control cables. The tape securing the jacket flap was fully intact. The tape was removed and jacket flap was folded back revealing no soot deposits or arcing damage around the drill hole or the area of the jacket exposed to the fault. The #18 AWG wire showed no indications of overheating. Inspection of the entire test article did not reveal any damage or anomalies. See Supporting Documentation Section 21.3 for post-test photographs of the C-phase cable with the jacket flap removed to expose the fault area and, if any damage occurred, post-test photographs of the A-Phase and B-phase cables.
Comments: • All test parameter requirements were met. • The initial single phase-to-ground fault did not propagate to a multi-phase fault

Test 5 Test Type CT4 (Resistance Grounded System)
Test Data Compared to Test Requirements: System Test Voltage (L-L)= 15.0 kV > 14.9 kV #1 C-Phase Neutral Current = 7.3 A #2 C-Phase Neutral Current = 12.0 A Sum of #1 and #2 C-Phase Neutral Currents = 19.3 A > 18.1 A Fault Current Duration: 2.13 s > 1.18 s
Discussion of Test Results and Post-Test Inspection: Test voltage, L-G fault current and L-G fault current duration requirements were met. Test 5 was performed with a #18 AWG copper wire inserted in the hole between bronze tape and conductor. Post-test inspection of the fault location on the C-phase cable found the jacket undamaged. There were no soot deposits, heat damage or any other visible affects to adjacent power and control cables. The tape securing the jacket flap was fully intact. The tape was removed and jacket flap was folded back revealing no soot deposits or arcing damage around the drill hole or the area of the jacket exposed to the fault. The #18 AWG wire showed no indications of overheating. Inspection of the entire test article did not reveal any damage or anomalies. See Supporting Documentation Section 21.3 for post-test photographs of the C-phase cable with the jacket flap removed to expose the fault area and, if any damage occurred, post-test photographs of the A-Phase and B-phase cables.
Comments: • All test parameter requirements were met. • The initial phase-to-ground fault did not propagate to a multi-phase fault

Test 6 Test Type KPF (Resistance Grounded System)
Test Data Compared to Test Requirements: System Test Voltage (L-L)= 15.9 kV > 14.9 kV #1 C-Phase Neutral Current = 4.4 A #2 C-Phase Neutral Current = 7.0 A Sum of #1 and #2 C-Phase Neutral Currents = 11.4 A < 18.1 A Fault Current Duration: 2.13 s > 1.18 s
Discussion of Test Results and Post-Test Inspection: Test voltage and L-G fault current duration requirements were met. L-G fault current requirement was not met due an incorrectly configured load bank. The system voltage was increased to 15.9 kV and fault current to 24.2 A by Duke engineering for this and subsequent KPF tests. Test 6 was performed with a #18 AWG copper wire inserted in the hole between bronze tape and conductor. Post-test inspection of the fault location on the C-phase cable found the jacket undamaged. There were no soot deposits, heat damage or any other visible affects to adjacent power and control cables. The tape securing the jacket flap was fully intact. The tape was removed and jacket flap was folded back revealing no soot deposits or arcing damage around the drill hole or the area of the jacket exposed to the fault. The #18 AWG wire showed no indications of overheating. Inspection of the entire test article did not reveal any damage or anomalies. See Supporting Documentation Section 21.3 for post-test photographs of the C-phase cable with the jacket flap removed to expose the fault area and, if any damage occurred, post-test photographs of the A-Phase and B-phase cables.
Comments: • All test parameter requirements were not met therefore this was an invalid test. Test will be repeated using same cable. • The initial phase-to-ground fault did not propagate to a multi-phase fault

Test 7 Test Type KPF (Resistance Grounded System)
Test Data Compared to Test Requirements: System Test Voltage (L-L)= 15.9 kV > 14.9 kV #1 C-Phase Neutral Current = 9.3 A #2 C-Phase Neutral Current = 14.9 A Sum of #1 and #2 C-Phase Neutral Currents = 24.2 A > 18.1 A Fault Current Duration: 2.13 s > 1.18 s
Discussion of Test Results and Post-Test Inspection: Test voltage, L-G fault current and L-G fault current duration requirements were met. Test 7 was performed with a #18 AWG copper wire inserted in the hole between bronze tape and conductor. Post-test inspection of the fault location on the C-phase cable found the jacket undamaged. There were no soot deposits, heat damage or any other visible affects to adjacent power and control cables. The tape securing the jacket flap was fully intact. The tape was removed and jacket flap was folded back revealing no soot deposits or arcing damage around the drill hole or the area of the jacket exposed to the fault. The #18 AWG wire showed no indications of overheating. Inspection of the entire test article did not reveal any damage or anomalies. See Supporting Documentation Section 21.3 for post-test photographs of the C-phase cable with the jacket flap removed to expose the fault area and, if any damage occurred, post-test photographs of the A-Phase and B-phase cables.
Comments: • All test parameter requirements were met. • The initial phase-to-ground fault did not propagate to a multi-phase fault.

Test 8 Test Type KPF (Resistance Grounded System)
Test Data Compared to Test Requirements: System Test Voltage (L-L)= 15.9 kV > 14.9 kV #1 C-Phase Neutral Current = 8.7 A #2 C-Phase Neutral Current = 15.5 A Sum of #1 and #2 C-Phase Neutral Currents = 24.2 A > 18.1 A Fault Current Duration: 2.13 s > 1.18 s
Discussion of Test Results and Post-Test Inspection: Test voltage, L-G fault current and L-G fault current duration requirements were met. Test 8 was performed with a #18 AWG copper wire inserted in the hole between bronze tape and conductor. Post-test inspection of the fault location on the C-phase cable found the jacket undamaged. There were no soot deposits, heat damage or any other visible affects to adjacent power and control cables. The tape securing the jacket flap was fully intact. The tape was removed and jacket flap was folded back revealing no soot deposits or arcing damage around the drill hole or the area of the jacket exposed to the fault. The #18 AWG wire showed no indications of overheating. Inspection of the entire test article did not reveal any damage or anomalies. See Supporting Documentation Section 21.3 for post-test photographs of the C-phase cable with the jacket flap removed to expose the fault area and, if any damage occurred, post-test photographs of the A-Phase and B-phase cables.
Comments: • All test parameter requirements were met. • The initial phase-to-ground fault did not propagate to a multi-phase fault.

Test 9 Test Type KPF (Resistance Grounded System)
Test Data Compared to Test Requirements: System Test Voltage (L-L)= 15.9 kV > 14.9 kV #1 C-Phase Neutral Current = 9.3 A #2 C-Phase Neutral Current = * Sum of #1 and #2 C-Phase Neutral Currents = * Fault Current Duration: 2.13 s > 1.18 s * #2 C-Phase Neutral Current was not recorded due to an open Current Transformer (CT) connection. The Total Neutral Current CT recorded 23.4 A which is greater than 18.1 A. #2 C-Phase Neutral Current is then 23.4 - 9.3 = 14.1 A which is similar to KPF tests 7, 8, 10 and 11.
Discussion of Test Results and Post-Test Inspection: Test voltage, L-G fault current and L-G fault current duration requirements were met. Test 9 was performed with a #18 AWG copper wire inserted in the hole between bronze tape and conductor. Post-test inspection of the fault location on the C-phase cable found the jacket undamaged. There were no soot deposits, heat damage or any other visible affects to adjacent power and control cables. The tape securing the jacket flap was fully intact. The tape was removed and jacket flap was folded back revealing no soot deposits or arcing damage around the drill hole or the area of the jacket exposed to the fault. The #18 AWG wire showed no indications of overheating. Inspection of the entire test article did not reveal any damage or anomalies. See Supporting Documentation Section 21.3 for post-test photographs of the C-phase cable with the jacket flap removed to expose the fault area and, if any damage occurred, post-test photographs of the A-Phase and B-phase cables.
Comments: • All test parameter requirements were met. • The initial phase-to-ground fault did not propagate to a multi-phase fault.

Test 10 Test Type KPF (Resistance Grounded System)
Test Data Compared to Test Requirements: System Test Voltage (L-L)= 15.9 kV > 14.9 kV #1 C-Phase Neutral Current = 9.3 A #2 C-Phase Neutral Current = 14.9 A Sum of #1 and #2 C-Phase Neutral Currents = 24.2 A > 18.1 A Fault Current Duration: 2.13 s > 1.18 s
Discussion of Test Results and Post-Test Inspection: Test voltage, L-G fault current and L-G fault current duration requirements were met. Test 10 was performed with a #18 AWG copper wire inserted in the hole between bronze tape and conductor. Post-test inspection of the fault location on the C-phase cable found the jacket undamaged. There were no soot deposits, heat damage or any other visible affects to adjacent power and control cables. The tape securing the jacket flap was fully intact. The tape was removed and jacket flap was folded back revealing no soot deposits or arcing damage around the drill hole or the area of the jacket exposed to the fault. The #18 AWG wire showed no indications of overheating. Inspection of the entire test article did not reveal any damage or anomalies. See Supporting Documentation Section 21.3 for post-test photographs of the C-phase cable with the jacket flap removed to expose the fault area and, if any damage occurred, post-test photographs of the A-Phase and B-phase cables.
Comments: • All test parameter requirements were met. • The initial phase-to-ground fault did not propagate to a multi-phase fault.

Test 11 Test Type KPF (Resistance Grounded System)
Test Data Compared to Test Requirements: System Test Voltage (L-L)= 15.9 kV > 14.9 kV #1 C-Phase Neutral Current = 9.4 A #2 C-Phase Neutral Current = 14.7 A Sum of #1 and #2 C-Phase Neutral Currents = 24.1 A > 18.1 A Fault Current Duration: 2.13 s > 1.18 s
Discussion of Test Results and Post-Test Inspection: Test voltage, L-G fault current and L-G fault current duration requirements were met. Test 11 was performed with a #18 AWG copper wire inserted in the hole between bronze tape and conductor. Post-test inspection of the fault location on the C-phase cable found the jacket undamaged. There were no soot deposits, heat damage or any other visible affects to adjacent power and control cables. The tape securing the jacket flap was fully intact. The tape was removed and jacket flap was folded back revealing no soot deposits or arcing damage around the drill hole or the area of the jacket exposed to the fault. The #18 AWG wire showed no indications of overheating. Inspection of the entire test article did not reveal any damage or anomalies. See Supporting Documentation Section 21.3 for post-test photographs of the C-phase cable with the jacket flap removed to expose the fault area and, if any damage occurred, post-test photographs of the A-Phase and B-phase cables.
Comments: • All test parameter requirements were met. • The initial single phase-to-ground fault did not propagate to a multi-phase fault.

Test 12 Test Type Fant (Solidly Grounded System)
Test Data Compared to Test Requirements: System Test Voltage (L-L)= 15.0 kV > 14.9 kV #1 C-Phase Neutral Current = 3.7 kA #2 C-Phase Neutral Current = 1.1 kA Sum of #1 and #2 C-Phase Neutral Currents = 4.8 kA > 4.6 kA Fault Current Duration: 78.6 ms > 71.7 ms
Discussion of Test Results and Post-Test Inspection: Test voltage, L-G fault current and L-G fault current duration requirements were met. Test 12 was performed with a #12 AWG copper wire inserted in the hole between bronze tape and conductor. For the solidly grounded tests, the copper wire sized was increased since the L-G fault current is significant higher than the resistance grounded tests. Post-test inspection of the fault location on the C-phase cable found the jacket flap completely opened. This is attributed to the formation of gases generated by arc-induced insulation byproducts.. Since the jacket flap was the weakest point directly over the fault area, the sudden pressure increase beneath the cable jacket ruptured the tape sealing the flap. See Supporting Documentation Section 21.3 for post-test photographs of the C-phase cable with the jacket flap removed to expose the fault area and, if any damage occurred, post-test photographs of the A-Phase and B-phase cables. The faulted C-phase cable underside of the jacket flap had soot deposits but was not damaged. An approximately 0.5 inch "fish mouth" hole was burned completely through the cable insulation. A large portion of the copper conductor was melted or vaporized. Roughly centered over the hole, both layers of bronze tape were vaporized in an elliptical area measuring approximately 3 by 2 inches. Both A-phase and B-phase cables had soot deposits and jacket indentations. The indentations are attributed to being forcefully struck by the C-phase cable jacket flap and/or expulsion of arc-induced gasses.
Comments: • All test parameter requirements were met. • The initial phase-to-ground fault did not propagate to a multi-phase fault.

Test 13 Test Type Fant (Solidly Grounded System)
Test Data Compared to Test Requirements: System Test Voltage (L-L)= 15.0 kV > 14.9 kV #1 C-Phase Neutral Current = 3.8 kA #2 C-Phase Neutral Current = 0.99 kA Sum of #1 and #2 C-Phase Neutral Currents = 4.8 kA > 4.6 kA Fault Current Duration: 78.6 ms > 71.7 ms
Discussion of Test Results and Post-Test Inspection: Test voltage, L-G fault current and L-G fault current duration requirements were met. Test 13 was performed with a #12 AWG copper wire inserted in the hole between bronze tape and conductor. Post-test inspection of the fault location on the C-phase cable found the jacket flap partially opened. This is attributed to the formation of gases generated by arc-induced insulation byproducts. Since the jacket flap was the weakest point directly over the fault area, the sudden pressure increase beneath the cable jacket ruptured the tape sealing the flap. See Supporting Documentation Section 21.3 for post-test photographs of the C-phase cable with the jacket flap removed to expose the fault area and, if any damage occurred, post-test photographs of the A-Phase and B-phase cables. The C-phase cable underside of the jacket flap had soot deposits and a circular area of jacket thinning over the fault location. An approximately 0.5 inch "fish mouth" hole was burned completely through the cable insulation. A large portion of the copper conductor was melted or vaporized. Roughly centered over the hole, both layers of bronze tape were vaporized in an elliptical area measuring approximately 1.75 by 2 inches. Both A-phase and B-phase cables had soot deposits only. There was no damage to the cable jackets.
Comments: • All test parameter requirements were met. • The initial phase-to-ground fault did not propagate to a multi-phase fault.

Test 14 Test Type Fant (Solidly Grounded System)
Test Data Compared to Test Requirements: System Test Voltage (L-L)= 15.0 kV > 14.9 kV #1 C-Phase Neutral Current = 3.7 kA #2 C-Phase Neutral Current = 0.98 kA Sum of #1 and #2 C-Phase Neutral Currents = 4.7 kA > 4.6 kA Fault Current Duration: 78.6 ms > 71.7 ms
Discussion of Test Results and Post-Test Inspection: Test voltage, L-G fault current and L-G fault current duration requirements were met. Test 14 was performed with a #12 AWG copper wire inserted in the hole between bronze tape and conductor. Post-test inspection of the fault location on the C-phase cable found the jacket flap partially opened. This is attributed to the formation of gases generated by arc-induced insulation byproducts. Since the jacket flap was the weakest point directly over the fault area, the sudden pressure increase beneath the cable jacket ruptured the tape sealing the flap. See Supporting Documentation Section 21.3 for post-test photographs of the C-phase cable with the jacket flap removed to expose the fault area and, if any damage occurred, post-test photographs of the A-Phase and B-phase cables. The faulted C-phase cable underside of the jacket flap had soot deposits and a circular area of jacket thinning and a 0.25 inch through wall split over the fault location. An approximately 0.375 inch circular hole was burned completely through the cable insulation. A large portion of the copper conductor was melted or vaporized. Roughly centered over the hole, both layers of bronze tape were vaporized in an elliptical area measuring approximately 2.25 by 2 inches in diameter. Both A-phase and B-phase cables had soot deposits only. There was no damage to the cable jackets.
Comments: • All test parameter requirements were met. • The initial phase-to-ground fault did not propagate to a multi-phase fault.

Test 15 Test Type Fant (Solidly Grounded System)
Test Data Compared to Test Requirements: System Test Voltage (L-L)= 15.0 kV > 14.9 kV #1 C-Phase Neutral Current = 3.7 kA #2 C-Phase Neutral Current = 1.0 kA Sum of #1 and #2 C-Phase Neutral Currents = 4.7 kA > 4.6 kA Fault Current Duration: 78.6 ms > 71.7 ms
Discussion of Test Results and Post-Test Inspection: Test voltage, L-G fault current and L-G fault current duration requirements were met. Test 15 was performed with a #12 AWG copper wire inserted in the hole between bronze tape and conductor. Post-test inspection of the fault location on the C-phase cable found the jacket flap completely opened. This is attributed to the formation of gases generated by arc-induced insulation byproducts. Since the jacket flap was the weakest point directly over the fault area, the sudden pressure increase beneath the cable jacket ruptured the tape sealing the flap. See Supporting Documentation Section 21.3 for post-test photographs of the C-phase cable with the jacket flap removed to expose the fault area and, if any damage occurred, post-test photographs of the A-Phase and B-phase cables. The faulted C-phase cable underside of the jacket had soot deposits only. There is an approximately 0.5 inch "fish mouth" hole burned completely through the insulation. A large portion of the copper conductor appears to have been melted or vaporized. Roughly centered over the hole, both layers of bronze tape were vaporized in a circular area measuring approximately 2 inches in diameter. Both A-phase and B-phase cables had soot deposits. The B-phase cable jacket had an indentation. The indentation is attributed to being forcefully struck by the C-phase cable jacket flap and/or expulsion of arc-induced gasses. The C-phase and B-phase cables were replaced for Test 16.
Comments: • All test parameter requirements were met. • The initial phase-to-ground fault did not propagate to a multi-phase fault

Test 16 Test Type Fant (Solidly Grounded System)
Test Data Compared to Test Requirements: System Test Voltage (L-L)= 15.0 kV > 14.9 kV #1 C-Phase Neutral Current = 3.7 kA #2 C-Phase Neutral Current = 1.1 kA Sum of #1 and #2 C-Phase Neutral Currents = 4.8 > 4.6 kA Fault Current Duration: 78.6 ms > 71.7 ms
Discussion of Test Results and Post-Test Inspection: Test voltage, L-G fault current and L-G fault current duration requirements were met. Test 16 was performed with a #12 AWG copper wire inserted in the hole between bronze tape and conductor. Post-test inspection of the fault location on the C-phase cable found the jacket flap completely opened. This is attributed to the formation of gases generated by arc-induced insulation byproducts. Since the jacket flap was the weakest point directly over the fault area, the sudden pressure increase beneath the cable jacket ruptured the tape sealing the flap. See Supporting Documentation Section 21.3 for post-test photographs of the C-phase cable with the jacket flap removed to expose the fault area and, if any damage occurred, post-test photographs of the A-Phase and B-phase cables. The faulted C-phase cable underside of the jacket flap had soot deposits and a circular area of jacket thinning over the fault location. There is an approximately 0.375 inch circular hole burned completely through the insulation. A large portion of the copper conductor appears to have been melted or vaporized. Roughly centered over the hole, both layers of bronze tape were vaporized in a circular area measuring approximately 2 inches in diameter.
Comments: • All test parameter requirements were met. • The initial phase-to-ground fault did not propagate to a multi-phase fault.

Test 17 Test Type CX (Solidly Grounded System)
Test Data Compared to Test Requirements: System Test Voltage (L-L)= 4.6 kV > 4.5 kV Load Side C-Phase Neutral Current = 2.3 kA Line Side C-Phase Neutral Current = 4.7 kA Sum of Load and Line Sides C-Phase Neutral Currents = 7.0 kA > 6.5 kA Fault Current Duration: 187 ms > 183 ms
Discussion of Test Results and Post-Test Inspection: Test voltage, L-G fault current and L-G fault current duration requirements were met. Test 17 was performed with a #12 AWG copper wire inserted in the hole between bronze tape and conductor. Post-test inspection of the fault location on the C-phase cable found the jacket flap completely opened. This is attributed to the formation of gases generated by arc-induced insulation byproducts. Since the jacket flap was the weakest point directly over the fault area, the sudden pressure increase beneath the cable jacket ruptured the tape sealing the flap. See Supporting Documentation Section 21.3 for post-test photographs of the C-phase cable with the jacket flap removed to expose the fault area and, if any damage occurred, post-test photographs of the A-Phase and B-phase cables. The C-phase load-side termination ground strap was severed. The area where the ground strap broke showed indications of bending and overheating. It is surmised that the bending caused embrittlement of ground strap metal due to cold-working. As the ground strap rapidly heated while carrying the fault current, the weakened area failed due to the stresses imposed by residual tension between the ground strap attachment points. The faulted C-phase cable underside of the jacket flap had soot deposits and an approximately 1 inch circular hole in the jacket over the fault location. There is an approximately 1 inch "fish mouth" hole burned completely through the insulation. The copper conductor is completely melted through. Centered over the fault area for approximately 2 inches in length, both layers of bronze tape were completely vaporized around the entire cable circumference. Both A-phase and B-phase cables had soot deposits and indentations. The indentations are attributed to being forcefully struck by the C-phase cable jacket flap and/or expulsion of arc-induced gasses.
Comments: • All test parameter requirements were met. • The initial phase-to-ground fault did not propagate to a multi-phase fault

Test 18 Test Type CX (Solidly Grounded System)
Test Data Compared to Test Requirements: System Test Voltage (L-L)= 4.6 kV > 4.5 kV Load Side C-Phase Neutral Current = 2.3 kA Line Side C-Phase Neutral Current = 4.7 kA Sum of Load and Line Sides C-Phase Neutral Currents = 7.0 kA > 6.5 kA Fault Current Duration: 187 ms > 183 ms
Discussion of Test Results and Post-Test Inspection: Test voltage, L-G fault current and L-G fault current duration requirements were met. Test 18 was performed with a #12 AWG copper wire inserted in the hole between bronze tape and conductor. Post-test inspection of the fault location on the C-phase cable found the jacket flap completely opened. This is attributed to the formation of gases generated by arc-induced insulation byproducts. Since the jacket flap was the weakest point directly over the fault area, the sudden pressure increase beneath the cable jacket ruptured the tape sealing the flap. See Supporting Documentation Section 21.3 for post-test photographs of the C-phase cable with the jacket flap removed to expose the fault area and, if any damage occurred, post-test photographs of the A-Phase and B-phase cables. The faulted C-phase cable underside of the jacket flap had soot deposits and an approximately 1 inch circular hole in the jacket over the fault location. There is an approximately 1 inch "fish mouth" hole burned completely through the insulation. The copper conductor is partially melted. Centered over the fault area for approximately 2 inches in length, both layers of bronze tape were vaporized around the entire cable circumference expect for a small portion located on the opposite side of the fault. The A-phase cable had soot deposits and an indentation. The indentation is attributed to being forcefully struck by the C-phase cable jacket flap and/or expulsion of arc-induced gasses. The B-phase cable had soot deposits and an approximately 0.375 circular hole through both the cable jacket and both layers of bronze tape.
Comments: • All test parameter requirements were met. • The initial phase-to-ground fault did not propagate to a multi-phase fault

Test 19 Test Type CX (Solidly Grounded System)
Test Data Compared to Test Requirements: System Test Voltage (L-L)= 4.6 kV > 4.5 kV Load Side C-Phase Neutral Current = 2.4 kA Line Side C-Phase Neutral Current = 4.6 kA Sum of Load and Line Sides C-Phase Neutral Currents = 7.0 kA > 6.5 kA Fault Current Duration: 187 ms > 183 ms
Discussion of Test Results and Post-Test Inspection: Test voltage, L-G fault current and L-G fault current duration requirements were met. Test 19 was performed with a #12 AWG copper wire inserted in the hole between bronze tape and conductor. Post-test inspection of the fault location on the C-phase cable found the jacket flap completely opened. This is attributed to the formation of gases generated by arc-induced insulation byproducts. Since the jacket flap was the weakest point directly over the fault area, the sudden pressure increase beneath the cable jacket ruptured the tape sealing the flap. See Supporting Documentation Section 21.3 for post-test photographs of the C-phase cable with the jacket flap removed to expose the fault area and, if any damage occurred, post-test photographs of the A-Phase and B-phase cables. The faulted C-phase cable underside of the jacket flap had soot deposits and a small 0.25 inch oval hole near the apex of the triangular cable flap. There is an approximately 1 inch "fish mouth" hole burned completely through the insulation. The copper conductor is partially melted. Centered over the fault area for approximately 2 inches in length, both layers of bronze tape were vaporized around the entire cable circumference. The A-phase and B-phase cables had soot deposits with an indentation on the A-phase cable and a very minor indentation on the B-phase cable. The indentations are attributed to being forcefully struck by the C-phase cable jacket flap and/or expulsion of arc-induced gasses.
Comments: • All test parameter requirements were met. • The initial phase-to-ground fault did not propagate to a multi-phase fault.

Test 20 Test Type CX (Solidly Grounded System)
Test Data Compared to Test Requirements: System Test Voltage (L-L)= 4.6 kV > 4.5 kV Load Side C-Phase Neutral Current = 2.1 kA Line Side C-Phase Neutral Current = 4.9 kA Sum of Load and Line Sides C-Phase Neutral Currents = 7.0 kA > 6.5 kA Fault Current Duration: 187 ms > 183 ms
Discussion of Test Results and Post-Test Inspection: Test voltage, L-G fault current and L-G fault current duration requirements were met. Test 20 was performed with a #12 AWG copper wire inserted in the hole between bronze tape and conductor. Post-test inspection of the fault location on the C-phase cable found the jacket flap completely opened. This is attributed to the formation of gases generated by arc-induced insulation byproducts. Since the jacket flap was the weakest point directly over the fault area, the sudden pressure increase beneath the cable jacket ruptured the tape sealing the flap. See Supporting Documentation Section 21.3 for post-test photographs of the C-phase cable with the jacket flap removed to expose the fault area and, if any damage occurred, post-test photographs of the A-Phase and B-phase cables. The faulted C-phase cable underside of the jacket flap had soot deposits only. There is an approximately 1 inch "fish mouth" hole burned completely through the insulation. The copper conductor is partially melted. Centered over the fault area for approximately 2 inches in length, both layers of bronze tape were vaporized around the entire cable circumference expect for small area opposite the cable fault location. The A-phase and B-phase cables had soot deposits and indentations. The indentations are attributed to being forcefully struck by the C-phase cable jacket flap and/or expulsion of arc-induced gasses.
Comments: • All test parameter requirements were met. • The initial phase-to-ground fault did not propagate to a multi-phase fault.

Test 21 Test Type CX (Solidly Grounded System)
Test Data Compared to Test Requirements: System Test Voltage (L-L)= 4.6 kV > 4.5 kV Load Side C-Phase Neutral Current = 2.3 kA Line Side C-Phase Neutral Current = 4.7 kA Sum of Load and Line Sides C-Phase Neutral Currents = 7.0 kA > 6.5 kA Fault Current Duration: 187 ms > 183 ms
Discussion of Test Results and Post-Test Inspection: Test voltage, L-G fault current and L-G fault current duration requirements were met. Test 21 was performed with a #12 AWG copper wire inserted in the hole between bronze tape and conductor. Post-test inspection of the fault location on the C-phase cable found the jacket flap completely opened. This is attributed to the formation of gases generated by arc-induced insulation byproducts. Since the jacket flap was the weakest point directly over the fault area, the sudden pressure increase beneath the cable jacket ruptured the tape sealing the flap. See Supporting Documentation Section 21.3 for post-test photographs of the C-phase cable with the jacket flap removed to expose the fault area and, if any damage occurred, post-test photographs of the A-Phase and B-phase cables. The faulted C-phase cable underside of the jacket flap had soot deposits and an approximately 0.75 "fish mouth" hole in the jacket over the fault location. There is an approximately 1 inch "fish mouth" hole burned completely through the insulation. The copper conductor is partially melted. Centered over the fault area for approximately 3 inches in length, both layers of bronze tape were vaporized around the entire cable circumference. The A-phase and B-phase cables had soot deposits and indentations. The indentations are attributed to being forcefully struck by the C-phase cable jacket flap and/or expulsion of arc-induced gasses.
Comments: • All test parameter requirements were met. • The initial phase-to-ground fault did not propagate to a multi-phase fault.

17.0 Evaluation of Power Cable Test Results:

Each Test Type will be evaluated separately. Additional evaluations will be performed on conductor preheating and the revisions of OSC-11504 that resulted in changes to some of the test electrical parameters.

Test Type CT4 (Tests 1-5):

These tests simulated Keowee as the power source which is a resistance grounded system. Resistance grounded power systems are designed to limit phase-to-ground fault currents and are typically selected to lessen equipment damage from faults of this type (Ref. IEEE-142 Section 1.4.3).

Test 1 was performed with only a drilled hole through the shield to the conductor. While the test voltage and phase-to-ground fault current parameters were met, the fault current was intermittent and not sustainable for the required duration of 1.18 seconds. The alternate method of inserting a #18 AWG copper wire into the drill hole was used on all subsequent tests for resistance grounded systems.

Tests 2, 3, 4 and 5 met all required voltage, phase-to-ground fault current and duration parameters.

For all five CT4 tests, there was no indication of the overheating of the copper wire or damage to the underneath of the jacket flap on the C-phase cable which completely contained the phase-to-ground faults. There was no damage to the adjacent A-phase and B-phase cables.

For CT4 tests 2, 3, 4 and 5, all acceptance criteria were met. Test voltages, fault currents and durations exceeded the minimum values and phase-to-ground faults did not result in multi-phase faults. It was determined that there was not need to repeat Test 1 due to the low magnitude phase-to-ground fault current not causing any visible damage for the CT4 and KPF test series.

Test Type KPF (Tests 6-11):

As in the CT4 tests, the KPF tests simulated Keowee as the power source which is a resistance grounded system. Resistance grounded power systems are designed to limit phase-to-ground fault currents and are typically selected to lessen equipment damage from faults of this type.

The Test 6 phase-to-ground fault current was below the minimum value of 18.1 A due to improper load cell configuration. An additional test was added to the KPF tests series and the faulted Test 6 cable was reused for Test 7.

Tests 7, 8, 9, 10 and 11, met all required voltage, phase-to-ground fault current and duration parameters.

For all five KPF tests, there was no indication of the overheating of the copper wire or damage to the underneath of the jacket flap on the C-phase cable which completely contained the phase-to-ground faults. There was no damage on the adjacent A-phase and B-phase cables which were reused for Tests 7-11.

For KPF tests 7, 8, 9, 10 and 11, all acceptance criteria were met. Test voltages, fault currents and durations exceeded the minimum values and phase-to-ground faults did not result in multi-phase faults.

Test Type Fant (Tests 12-16):
These tests simulated the PSW substation as the power source which is a solidly grounded system with high-magnitude phase-to-ground fault current available. Comparing phase-to-ground faults to resistance grounded power sources, it was expected that solidly grounded systems will experience greater fault damage.

To accommodate the significantly larger phase-to-ground fault currents for both the Fant and CX tests, the copper wire size inserted in the drill hole was increased from #18 AWG to #12 AWG.

The entire Fant series of tests resulted in significant damage to the C-Phase faulted cables and some fault-related interactions to the A-phase and B-phase cables which were characterized by:

- The tape securing the C-phase cable jacket flap was not sufficient to contain the arc and gas formation and either fully or partially opened. In some cases, portions of the cable jacket flap over the area of the cable fault was thinned and/or experienced a minor split.
- Both layers of the C-phase cable bronze tape were vaporized in the area around the fault location due to the extreme temperature generated by the arcing fault.
- The arcing fault eroded holes in the C-phase insulation down to the conductor.
- Portions of the C-phase conductor were melted or vaporized.
- In some cases, the jackets of the adjacent A-phase and B-phase cables were dented by being forcefully struck by the cable jacket and/or gasses generated by the arcing fault. However, the cable insulation system was still electrical functional for the entire fault duration.

While the Fant tests resulted in significant damage to the C-phase faulted cables and some external damage to A-phase and B-phase cables, the acceptance criteria were met. Test voltages, fault currents and durations exceeded the minimum values and phase-to-ground faults did not result in multi-phase faults.

Test Type CX (Tests 17-21):
These tests simulated plant switchgear 1TC as the power source which is a solidly grounded system with high-magnitude phase-to-ground fault current available. Comparing phase-to-ground faults to resistance grounded power sources, it is expected that solidly grounded systems will experience greater fault damage. The magnitude of the CX phase-to-ground fault current was higher than the Fant tests.

To accommodate the significantly larger phase-to-ground fault current for the CX tests, the copper wire size inserted in the drilled hole was #12 AWG.

The entire CX series of tests resulted in the greatest damage compared to the CT4, KPF and Fant tests with significant damage to the C-Phase faulted cables and some fault-related interactions to the A-phase and B-phase cables which were characterized by:

- The tape securing the C-phase cable jacket flap was not sufficient to contain the arc and gas formation and fully or partially opened. In some cases, portions of the cable jacket flap over the area of the cable fault was thinned or developed holes.
- Both layers of the C-phase cable bronze tape were vaporized in the area around the fault location due to the extreme temperature generated by the arcing fault. In some case, both

layers of bronze tape were vaporized around the entire cable circumference at the fault location.

- The arcing fault eroded holes in the C-phase insulation down to the conductor.
- At the fault locations, portions of the C-phase conductor were melted or vaporized and in in some cases, a section of the conductor was completely vaporized.
- In some cases, the jackets of the adjacent A-phase and B-phase cable were dented by being forcefully struck by the cable jacket and/or gasses generated by the arcing fault. However, the cable insulation system was still electrical functional for the entire fault duration.
- For the Test 18 B-phase cable, an approximately 3/8 (0.375) inch hole through the cable jacket and both layers of bronze tape was located directly over the faulted area of the C-phase cable. This was the most significant damage for all non-faulted cables include the CT4, KPF and Fant test and is further discussed below.

To further assess the extent of damage to the Test 18 B-phase cable, VLF/Tan Delta electrical testing was performed to test the cable insulation integrity per IEEE 400.2 and Oconee procedure IP/0/A/2000/001. As documented in Work Order 20021958-03, a 30 minute maintenance level VLF/Tan Delta test was performed with step voltages at 1.8 kV, 3.5 kV, and 5.3 kV for 3 minutes each and then held at 7.0 kV for 30 minutes. The Test 18 B-phase cable passed the VLF/Tan Delta test. For the CX power source, the phase-to-ground voltage is 4.16 kV/√3 = 2.4 kV. The cable was electrically undamaged as demonstrated by the withstand test at three time the operating voltage for 30 minutes. The VLF/Tan Delta test report is included in the Supporting Documentation Section of this Appendix.

While the CX tests resulted in significant damage to the C-phase faulted cables, some external damage to A-phase and B-phase cables including a hole through the Test 18 B-phase jacket and both layers of bronze tape, the acceptance criteria were met. Test voltages, fault currents and durations exceeded the minimum values and phase-to-ground faults did not result in multi-phase faults.

<u>Conductor Preheating:</u>
As discussed in Section 12.0, testing with the conductors at nominal 90°C operating temperature was considered but found to be not feasible and testing at ambient temperature was found to be acceptable. For the CT4 and KPF resistance grounded power sources, the very low magnitude phase-to-ground fault currents present no challenge to the thermal capacity of the bronze tape metallic shield. For the solidly grounded Fant and CX test with high magnitude phase-to-ground fault currents, the extreme temperature generated by the arcing fault resulted in vaporization of the bronze tape. For the Fant and CX tests, elevating the pre-fault conductor temperature to 90°C would have had inconsequential effects on the degree of bronze tape damage.

<u>Electrical Test Parameter Changes from Rev. 0 to Rev. 1 of OSC-11504.</u>
Section 15.0 referenced a revision of OSC-11504 that resulted in changes to some of the electrical parameters used during the KEMA cable tests. For each test type, the tables below provide a comparison between the test minimum electrical parameters between OSC-11504 Rev. 0 and Rev. 1.

CT4 Electrical Parameters			
Parameter	OSC-11504 Rev. 0	OSC-11504 Rev. 1	Comments
Minimum Pre-Fault Voltage (P-P)	14.9 kV	14.9 kV	Unchanged
Minimum Fault Current (Three-Phase)	16.8 kA	20.1 kA	CT4 test results were all phase-to-ground therefore this change did not affect the test results.
Minimum Fault Current (P-G)	18.1 A	18.1 A	Unchanged
Minimum Fault Current Duration (Three-Phase) (P-G)	 11 cycles/183 ms 70.8 cycles/1.18 s	 11 cycles/183 ms 70.8 cycles/1.18 s	 Unchanged Unchanged

KPF Electrical Parameters			
Parameter	OSC-11504 Rev. 0	OSC-11504 Rev. 1	Comments
Minimum Pre-Fault Voltage (P-P)	14.9 kV	14.9 kV	Unchanged
Minimum Fault Current (Three-Phase)	18.0 kA	18.1 KA	KPF test results were all phase-to-ground therefore this change did not affect the test results.
Minimum Fault Current (P-G)	18.1 A	18.1 A	Unchanged
Minimum Fault Current Duration (Three-Phase) (P-G)	 11 cycles/183 ms 70.8 cycles/1.18 s	 11 cycles/183 ms 70.8 cycles/1.18 s	 Unchanged Unchanged

Fant Electrical Parameters			
Parameter	OSC-11504 Rev. 0	OSC-11504 Rev. 1	Comments
Minimum Pre-Fault Voltage (P-P)	14.9 kV	14.9 kV	Unchanged
Minimum Fault Current (Three-Phase)	4.9 kA	5.8 kA	FANT test results were all phase-to-ground therefore this change did not affect the test results.
Minimum Fault Current (P-G)	4.6 kA	4.6 kA	Unchanged.
Minimum Fault Current Duration (Three-Phase)	 4.3 cycles/71.7 ms	 4.3 cycles/71.7 ms	 Unchanged

Fant Electrical Parameters			
Parameter	OSC-11504 Rev. 0	OSC-11504 Rev. 1	Comments
(P-G)	4.3 cycles/71.7 ms	4.3 cycles/71.7 ms	Unchanged

CX Electrical Parameters			
Parameter	OSC-11504 Rev. 0	OSC-11504 Rev. 1	Comments
Minimum Pre-Fault Voltage (P-P)	4.5 kV	4.5 kV	Unchanged
Minimum Fault Current (Three-Phase)	9.6 kA	9.0 KA	CX test results were all phase-to-ground therefore this change did not affect the test results.
Minimum Fault Current (P-G)	6.5 kA	6.2 KA	Higher Rev. 0 value was tested.
Minimum Fault Current Duration (Three-Phase) (P-G)	7 cycles/117 ms 11 cycles/183 ms	7 cycles/117 ms 11 cycles/183 ms	Unchanged Unchanged

18.0 Evaluation of Control and Signal Cable Test Data:

The table below provides the measured peak voltages on the control and signal (I&C) cables for each of the four test types as documented in the KEMA test report. The I&C cables were not connected to a power supply and all voltages were induced.

Control and Signal Cable Induced Voltages							
Test Number/ Type	System Voltage (kV)	Fault Current	#1 Control Cable (V_{peak})	#2 Control Cable (V_{peak})	#3 & 4 Control Cables (V_{peak})	Cable Spacing (inches)	Remarks
1 CT4	15.0	24.7 A	23.6	18.7	20.6 V	5	
2 CT4	15.0	19.3 A	13.7	8.2	6.2 V	5	
3 CT4	15.0	19.2 A	14.4	8.6	6.8 V	5	
4 CT4	15.0	19.2 A	14.4	8.1	5.9 V	5	
5 CT4	15.0	19.3 A	13.5	7.5	5.4 V	5	
				Signal Cable (V_{peak})			
6 KPF	15.9	11.4 A	4.0	6.9	N/A	5	
7 KPF	15.9	24.2 A	22.5	56.4	N/A	5	Control and signal cables were disconnected to evaluate the effects on the measured voltages.
8 KPF	15.9	24.2 A	1.8	45.8	N/A	5	Control cable was monitored by

Control and Signal Cable Induced Voltages							
							optically isolated voltage transmitter and signal cable voltage monitored as in Test 7.
9 KPF	15.9	23.4 A	0.966	0.578	N/A	2	Both control and signal cables now monitored by optically isolated voltage transmitter. Cable spacing decreased to 2 inches.
10 KPF	15.9	24.2 A	0.957	2.9	N/A	0	Control spacing decreased to -0- inches.
11 KPF	15.9	24.1 A	.0949	2.8	N/A	0	
12 Fant	15.0	4.8 kA	0.587	0.168	N/A	5	Load side of control and signal cables connected relay coils. Spacing returned to 5 inches.
13 Fant	15.0	4.8 kA	0.585	0.165	N/A	5	
14 Fant	15.0	4.7 kA	0.618	0.169	N/A	5	
15 Fant	15.0	4.7 kA	0.595	0.216	N/A	2	Cable spacing reduced to 2 inches.
16 Fant	15.0	4.8 kA	0.624	0.177	N/A	2	
17 CX	4.6	7.0 kA	0.370	0.759	N/A	5	Cable spacing restored to 5 inches.
18 CX	4.6	7.0 kA	0.417	0.674	N/A	5	
19 CX	4.6	7.0 kA	0.414	0.672	N/A	5	
20 CX	4.6	7.0 kA	0.421	0.650	N/A	5	
21 CX	4.6	7.0 kA	0.838	0.715	N/A	0	Cable spacing decreased to 0 inches.

For the CT4, KPF, Fant and CX test types, various adjustments to cable shield grounding configurations, conductor termination methods and cable spacing were made. The purpose of the adjustments was to correlate the control and signal cable induced voltage data with the system test voltage, fault current and cable spacing. After the addition of the optically isolated voltage transmitters and relays, the measured voltage significantly decreased.

It was surmised that the data was influenced to some degree by the ambient electrical fields present in the KEMA test cell environment. To quantify the expected induced voltages, an analytical approach was developed by MPR Associates and is included in Attachment 6 of this calculation. MPR modeled the 13.8 kV Fant path from Manhole 6 to the PSW building and estimated the induced voltages on the I&C cables for cable faults.

As summarized in Section 4.8 of the calculation body, the MPR analysis concluded that the I&C cables would have induced voltages of approximately 14 volts common mode and less than one volt differential mode which would have not adversely affect the operation of the equipment associated with the I&C cables. See Section 4.8 and Attachment 6 of this calculation for additional information.

19.0 Conclusions:

The program conducted at KEMA labs to support resolution of the 2014 Component Design Basis Inspection Unresolved Items was successfully completed.

For all four configurations and the program of 21 tests, the initial single phase-to-ground fault did not result in a multi-phase fault. These results support the previous analysis done by Duke during the 2014 CDBI and related Initial and Prompt Determinations of Operability.

Notwithstanding the induced voltages on the I&C cables from the KEMA testing, the MPR analysis and Section 4.8 of the calculation body determined that the magnitude of the induced voltages on the I&C cables would not adversely affect equipment operation.

20.0 References:

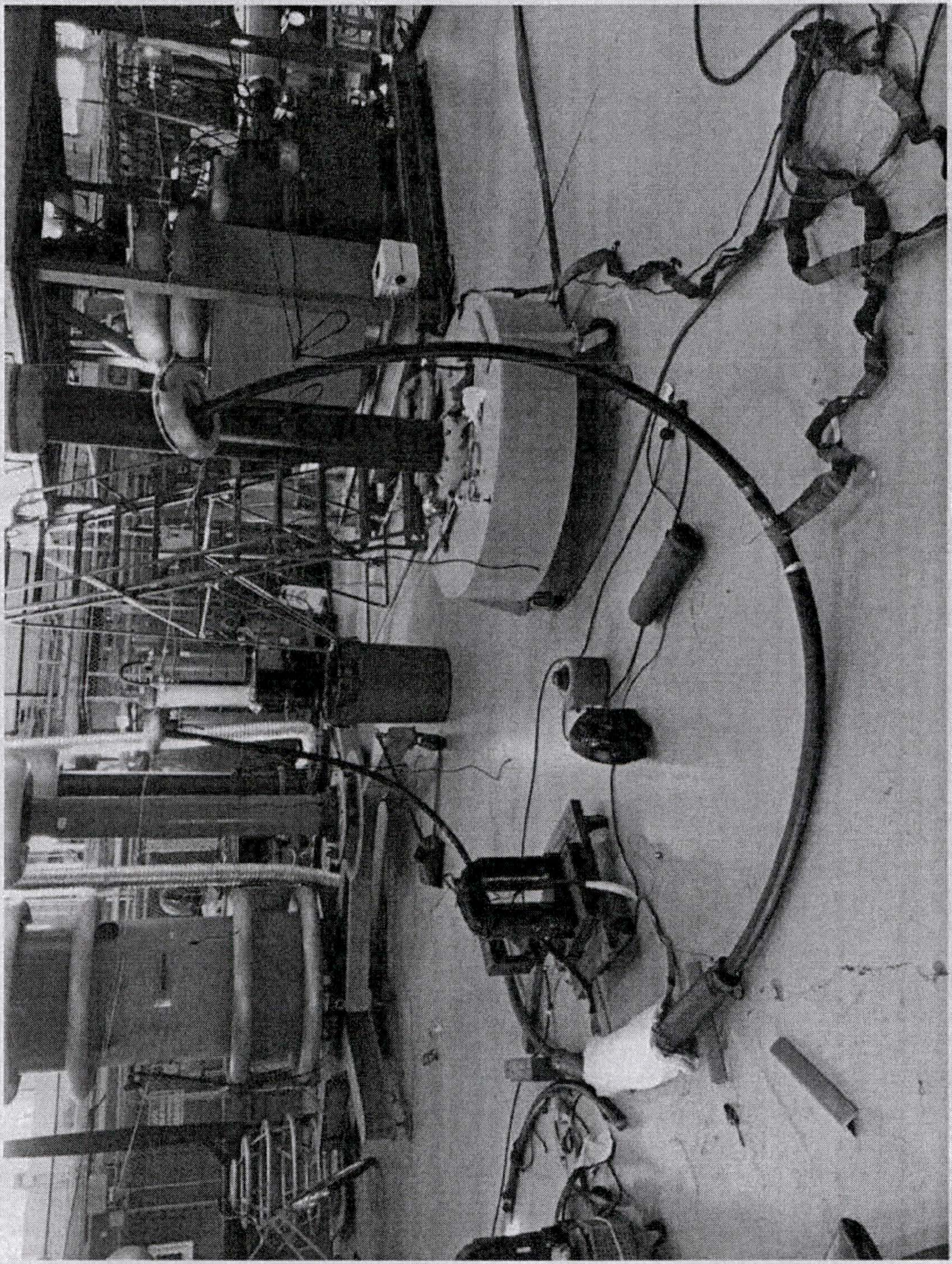
1. NRC letter to Scott Batson dated June 27, 2014, Oconee Nuclear Station - NRC Component Design Bases Inspection Report 05000269/2014007, 05000270/2014007, and 05000287/2014007
2. K-904-A Rev. 1, Sections and Details Pre-Fab Concrete Trench #3
3. OSC-7729 Rev. 3, Oconee-Keowee Underground Power Cable Replacement Calculations (for NSM ON-53065)
4. OSC-9508 Rev. 3, Electrical Design Input Calculation (DIC) for EC 91874 (ID500923)
5. OSC-11504 Rev. 0, Medium Voltage Cable Testing Analysis
6. CNS-1354.02-00-0002 Rev. 5, Procurement Specification for Multiconductor Switching Station Control Cable
7. CNS-1354-.03-00-0001 Rev. 8, Procurement Specification for Shielded Pair Instrumentation Cable
8. OSS-0139.00-00-0010 Rev. 1, Keowee Underground Replacement Medium Voltage Single Conductor Power Cable
9. OSS-0218.00-00-0019 Rev. 17, Cable and Wiring Separation Criteria
10. OSS-0254.00-00-4013 Rev. 5, Design Basis Specification for the Oconee Single Failure Criterion
11. PIP Documenting Initial and Prompt Determinations of Operability: O-13-8748, O-14-2965, O-14-3190, O-14-5125
12. NSM ON-53065, Replace Underground Power, Aux Power & Control Cables from Keowee Hydro to Oconee Nuclear Station.
13. EC 91880, Keowee Emergency Start Cable Re-Routes
14. EC 91874, 13.8 kV Feed to PSW System From 100 kV APS
15. IP/0/A/2000/001 Rev. 13, Power and Control Cable Inspection and Testing
16. Updated Final Safety Analysis Report Rev. 23
17. Work Order 20021958-03 (Test 18 B-Phase Cable VLF/Tan Delta Test)
18. KEMA Laboratories Test Report 15208-B dated Jan. 15, 2016
19. ICEA Publication P-45-482-2013, Short Circuit Performance of Metallic Shields and Sheaths on Insulated Cable
20. IEEE Std. 142-1991, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems
21. IEEE Std. 323-1974, IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations

22. IEEE Std. 383-1974, IEEE Standard for Qualifying Class 1E Electric Cables, Field Splices and Connections for Nuclear Power Generating Stations
23. IEEE Std. C37.20.2-2015, IEEE Standard for Metal-Clad Switchgear
24. IP/0/A/3009/018 Rev. 25, Terminating and Splicing of Cable Rated > 600 V to 15 kV
25. IEEE Std. 400.2-2013, IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF) (less than 1 Hz)

21.0 Supporting Documentation:

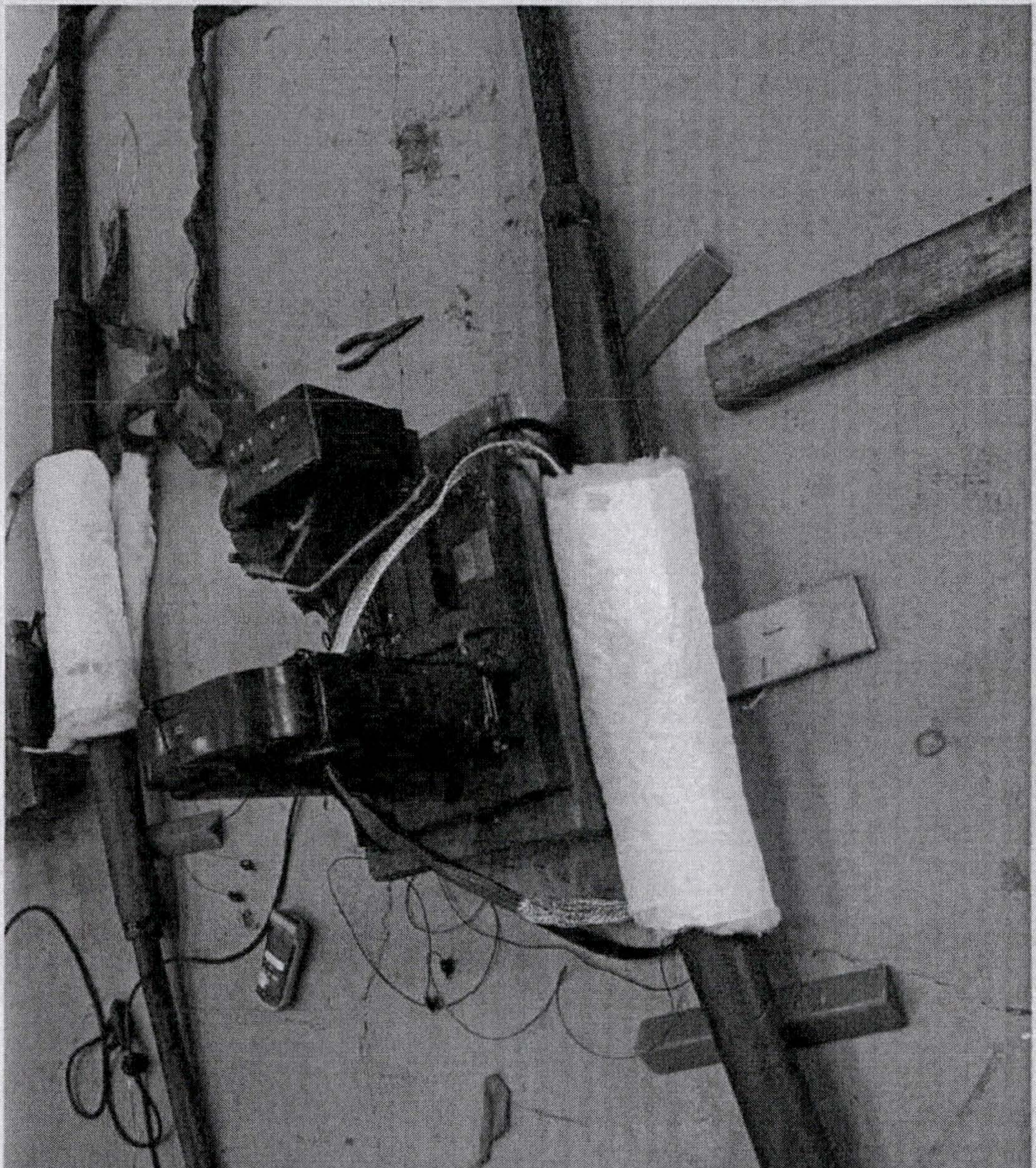
21.1. Okonite Cable Preparation and Testing
21.2. Test Article Photographs and Sketches
21.3. KEMA Post-Test Cable Photographs.
21.4. Trial 18 B-Phase VLF/Tan Delta Test Report

21.1 Okonite Cable Preparation and Testing:



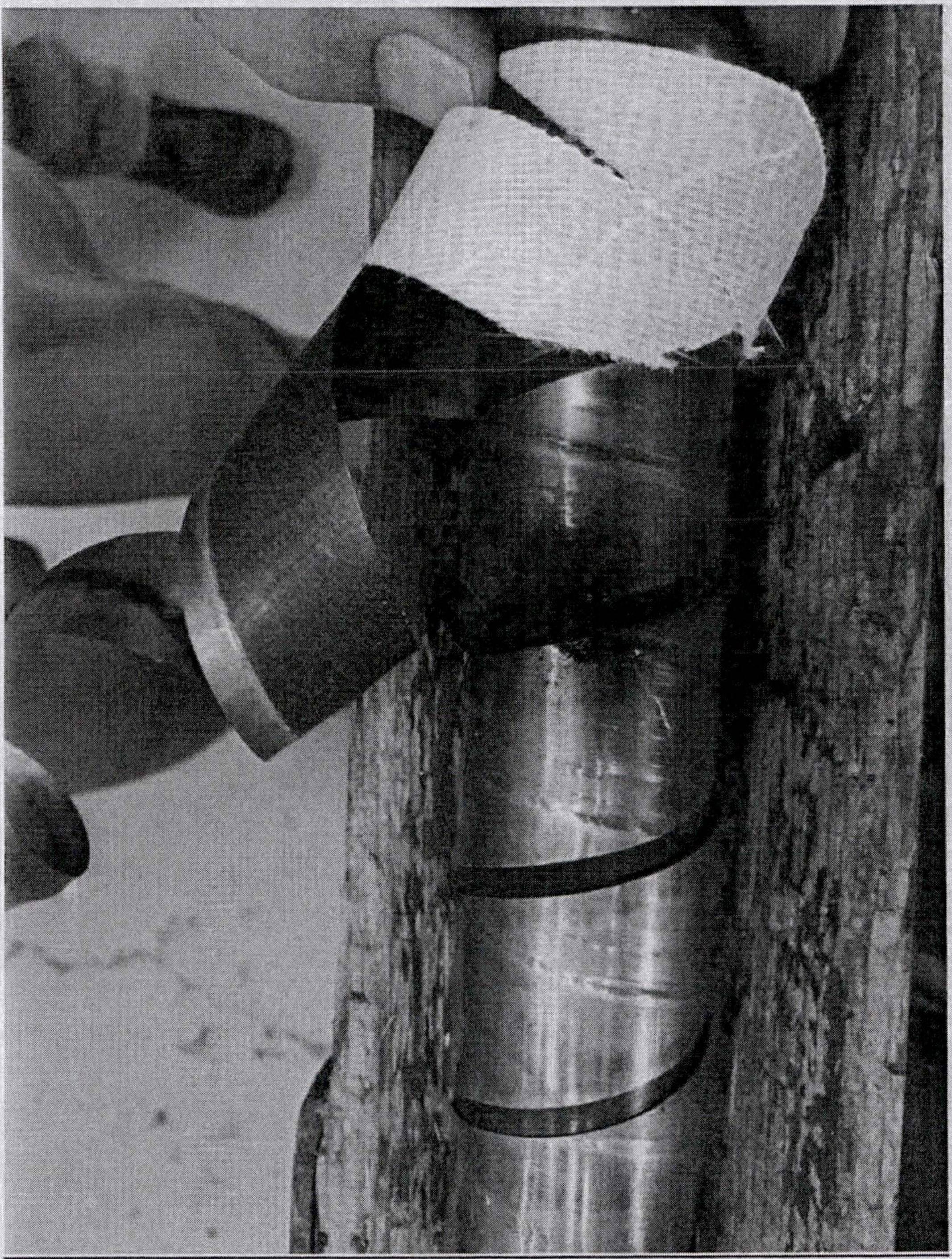
Okonite High Impulse Voltage Test Equipment with Cable Heating Device

21.1 Okonite Cable Preparation and Testing:



Okonite Cable Heating Device

21.1 Okonite Cable Preparation and Testing:

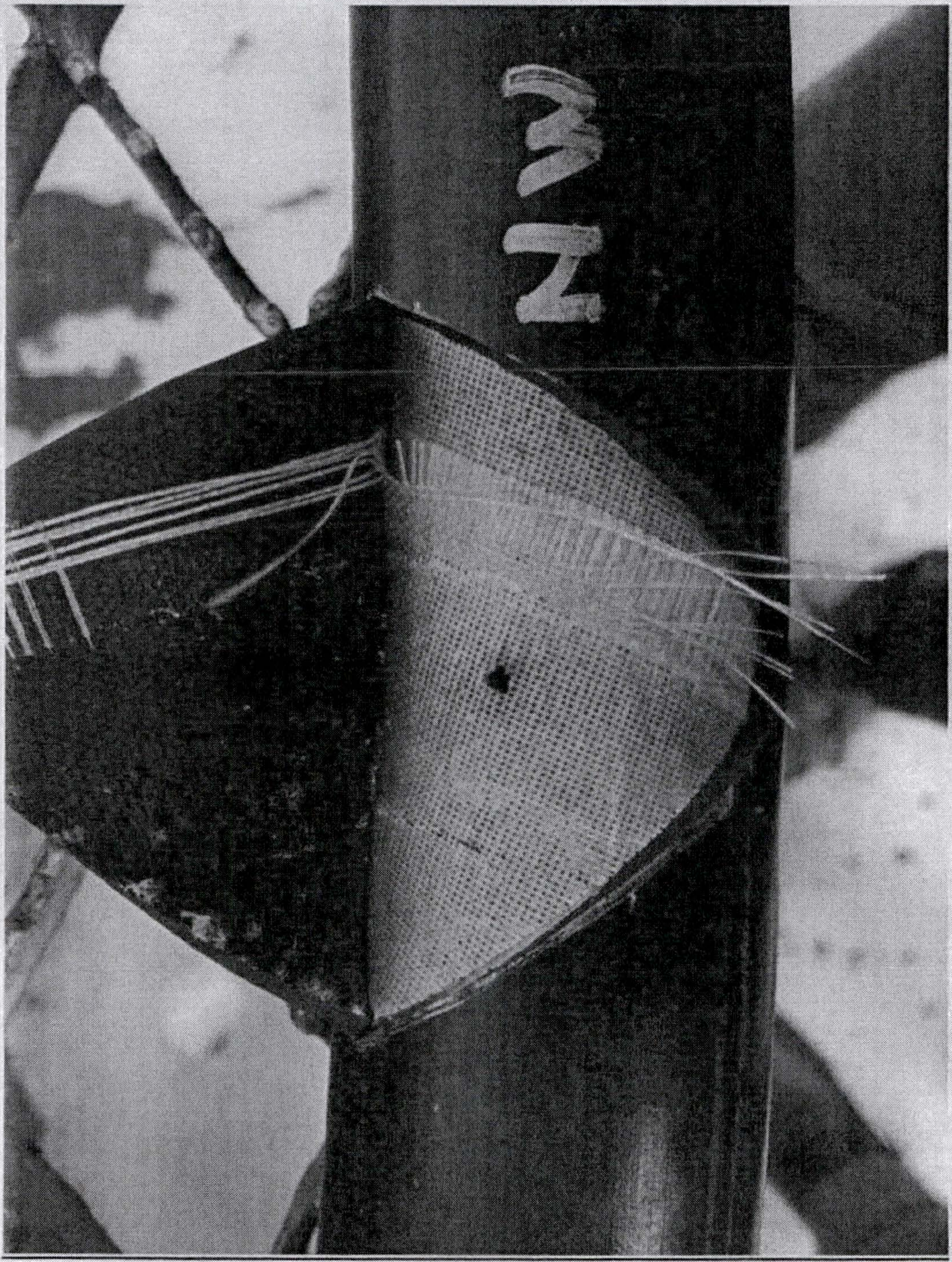


High Voltage Impulse Fault

21.1 Okonite Cable Preparation and Testing:

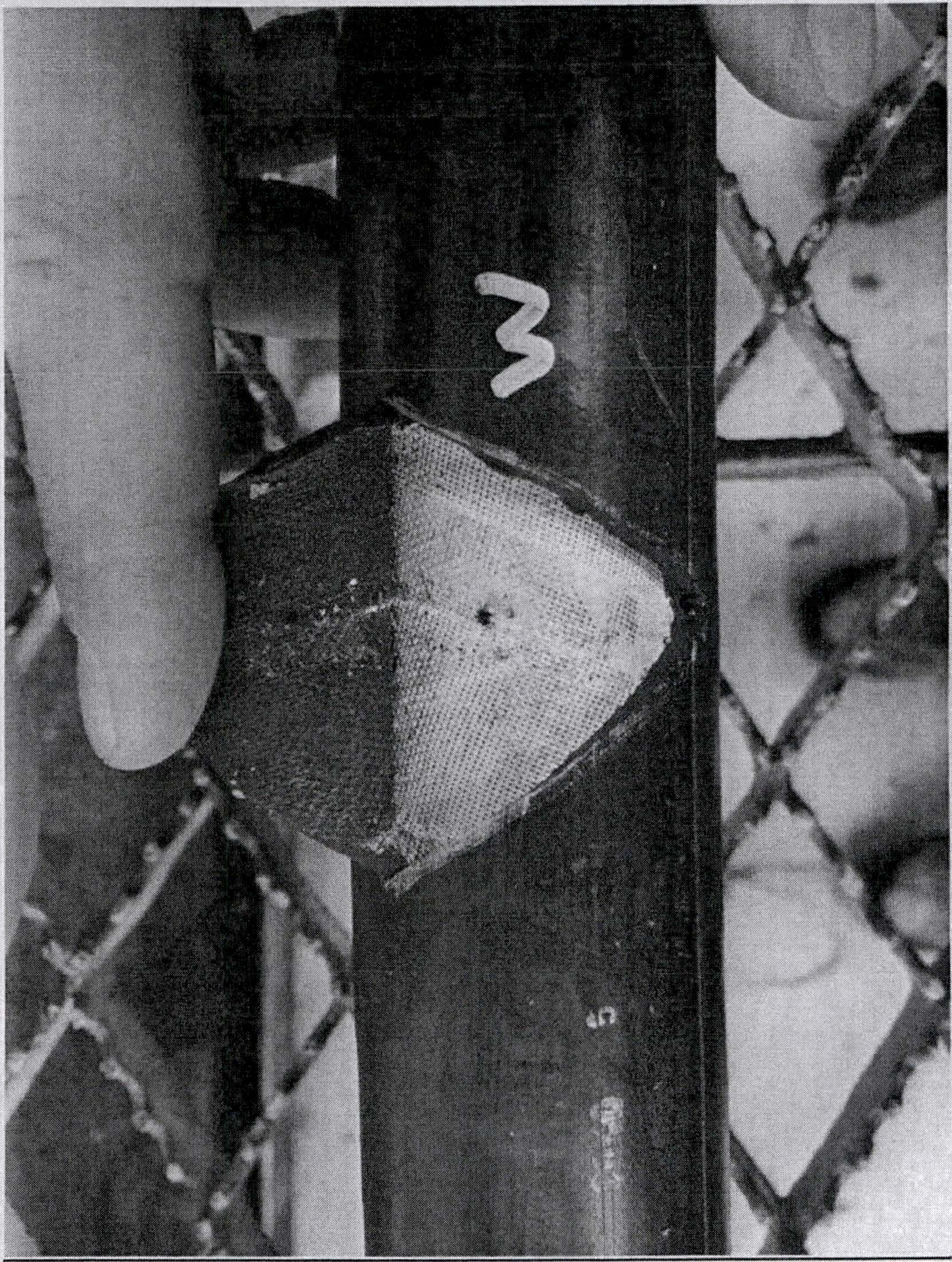
High Voltage Impulse Fault
Insulatation Semiconductor Layer Exposed

21.1 Okonite Cable Preparation and Testing:



Fault Induced by Drilled Hole Only

21.1 Okonite Cable Preparation and Testing:



Fault Induced by Wire Inserted in Drilled Hole

21.1 Okonite Cable Preparation and Testing:

Impulse Test Sheet

Project 4347 Date: 10/13/15 Tested by: MP

Test Condition CENTER JACKET @ 102C 2x8a TEST #1
750 KCM CU, 260G, SC EPR, TAPE, JKT

Total Load Capacitance (pF)		Test Setup	
Cable		Number of Stages	4
Divider		Wave Front Number	3
Dummy		Wave-Tail (In/Out)	IN
Potheads		Divider Plug-in Cap (uF)	0.45 uF
Total		Divider Ratio	414.72

Waveshape (+) ______ µS X ______ µS
Waveshape (-) ______ µS X ______ µS

Tekronix 420A Okonite ID# 2-05-4 Tek 420A Attentuator Box (1000-1) 2-14-1

KV/Stage = (Desired kV) / (Number of stages x efficiency)

kV	kV/Stage	Vpeak (mv)	%Eff	Number of Shots	Comments
140	38.9				
170	47.2 kV	360	90/79.1	✓	
200	63.2	480	"	✓	
230	72.7	552	"	✓	
260	82.2	626	"	✓	
290	91.7	704	"	✓	
320	101.2	776	"	✓	
350	110.6	848	"	✓	
380	120.1	920	"	✓	
410	129.6	992	"	✓	
440	139.1	1.064	"	✓	
470	148.6	1.144/1.136	"	FO ✓	
500	158	1.216		✓	
530	167.5	1.004		(-) FAILURE	

HVL-054 Rev 3.0

Okonite High Votage Impulse Datasheet

21.1 Okonite Cable Preparation and Testing:

Impulse Test Sheet

Project 4347 Date: 10/13/15 Tested by: MP

Test Condition CENTER JACKET @ 126°C TEST # 2
750 KCM CU, 260 g, SC EPR, ~~FR~~ 2x BZ TP - JKT

Total Load Capacitance (pF)		Test Setup	
Cable		Number of Stages	4
Divider		Wave Front Number	3
Dummy		Wave-Tail (In/Out)	IN
Potheads		Divider Plug-in Cap (uF)	0.45 uF
Total		Divider Ratio	414.72

Waveshape (+) ______ μS X ______ μS
Waveshape (-) ______ μS X ______ μS

Tekronix 420A Okonite ID# 2-05-4 Tek 420A Attentuator Box (1000-1) 2-44-1

KV/Stage = (Desired kV) / (Number of stages x efficiency)

kV	kV/Stage	Vpeak (mv)	%Eff	Number of Shots	Comments
300 kV	94.8	732	80	✓	11.29
330	104.3	804	"	✓	
360	113.8	~~880~~ 876	"	✓	
390	123.3	948	"	✓	
420	132.7	1.016	"	A FAILURE	11.33

HVL-054 Rev 3.0

Okonite High Votage Impulse Datasheet

21.1 Okonite Cable Preparation and Testing:

Impulse Test Sheet

Project 4347 Date: 10/13/15 Tested by: MP

Test Condition CENTRAL JNT @130C TEST #3
BOTH CABLE ENDS TIED TOGETHER

Total Load Capacitance (pF)		Test Setup	
Cable		Number of Stages	4
Divider		Wave Front Number	3
Dummy		Wave-Tail (In/Out)	IN
Potheads		Divider Plug-in Cap (uF)	0.45 uF
Total		Divider Ratio	414.72

Waveshape (+) ______ μS X ______ μS
Waveshape (-) ______ μS X ______ μS

Tekronix 420A Okonite ID# 2054 Tek 420A Attentuator Box (1000-1) 2141

KV/Stage = (Desired kV) / (Number of stages x efficiency)

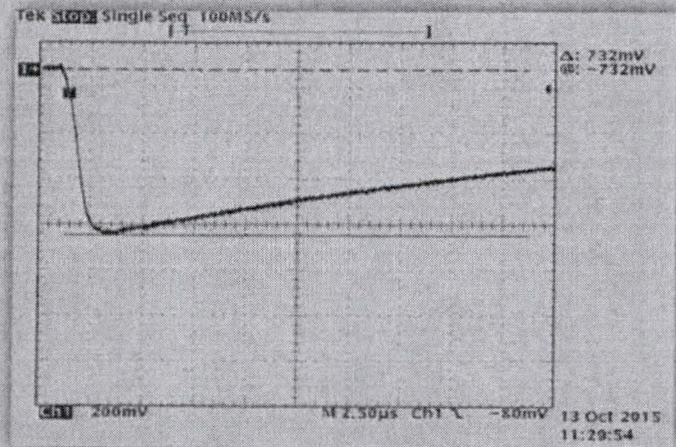
kV	kV/Stage	Vpeak (mv)	%Eff	Number of Shots	Comments
300	94.8	736	79.1	✓	
330	102.5	792	80	✓	
360	111.8	872	"	✓	
390	121.1	940.		✓	
420	130.4	1.016	"	✓ SMALL FLASHOVER	ON TAIL
				DISCONTINUE	TEST DUE
				TO EQUIPMENT	ISSUE

HVL-054 Rev 3.0

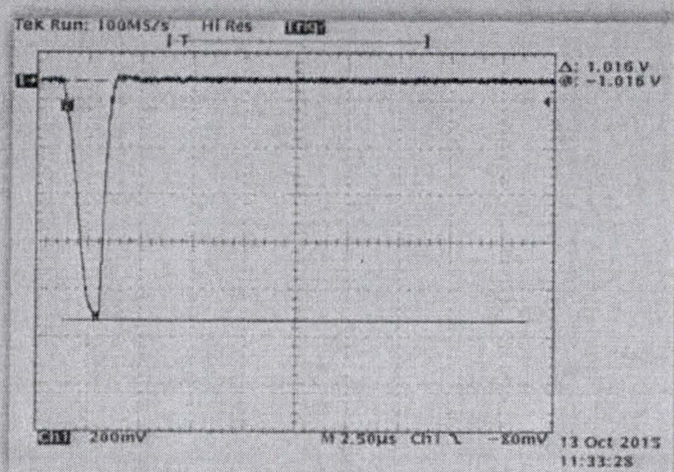
Okonite High Votage Impulse Datasheet

21.1 Okonite Cable Preparation and Testing:

Project 4347 Duke Energy



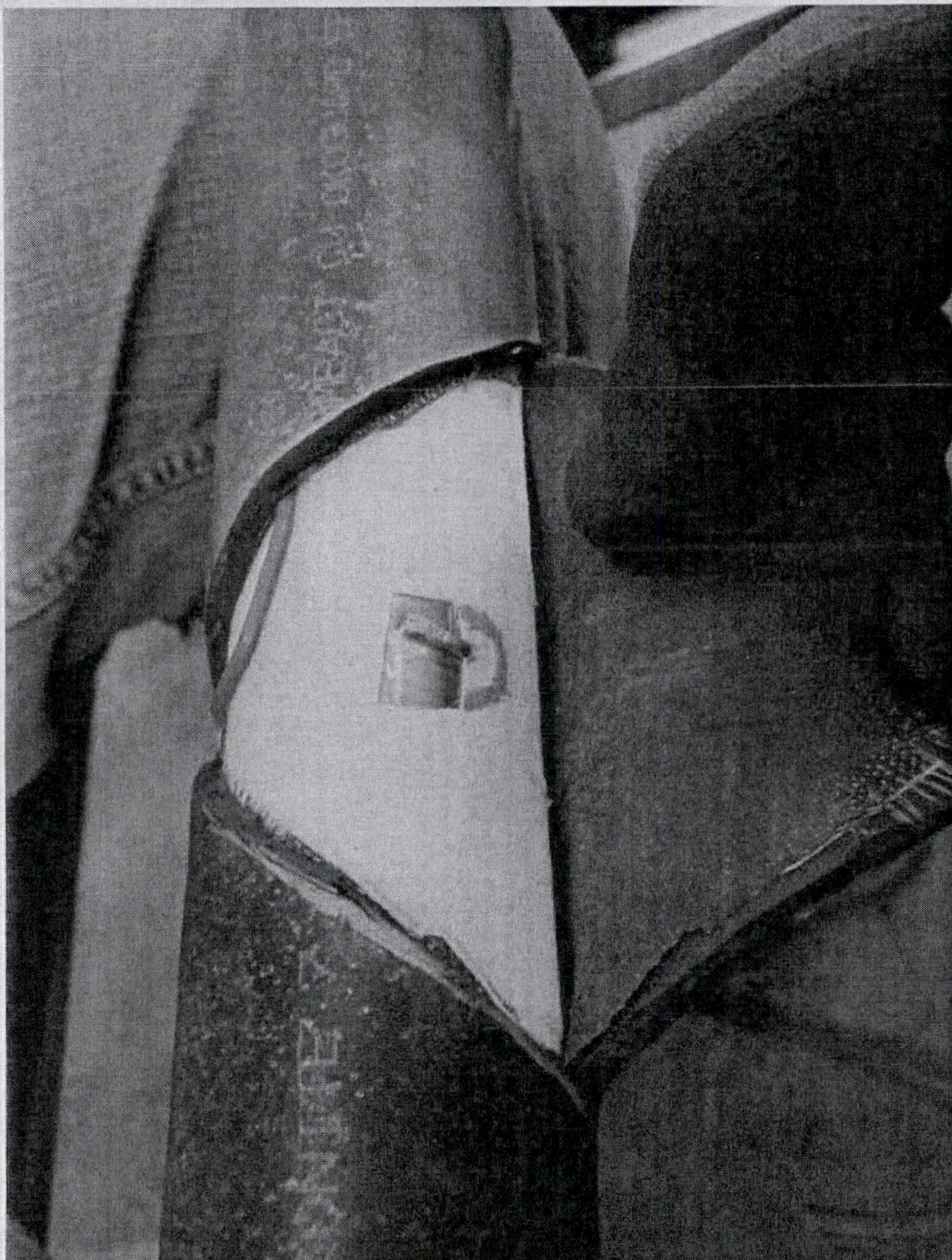
Test #2 Impulse at -300kV



Test #2 Impulse failure at -420kV

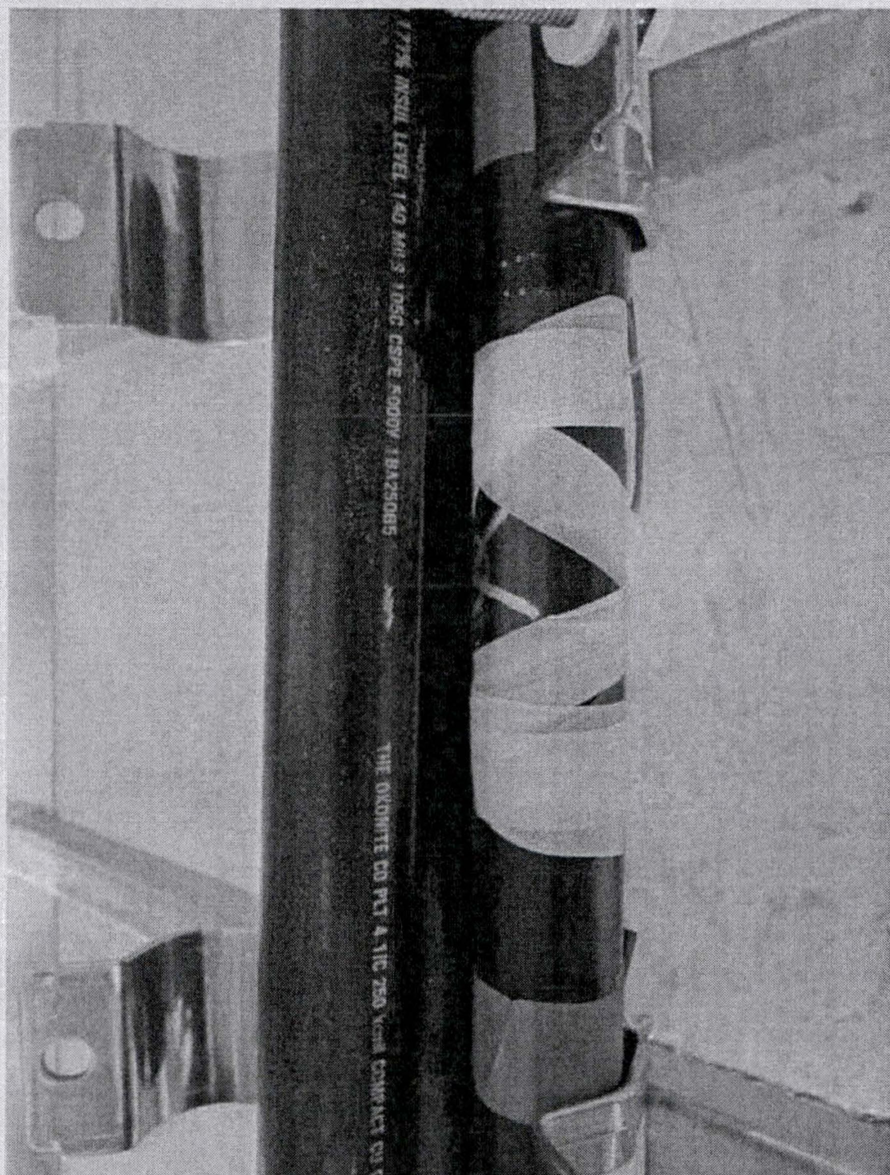
Okonite High Votage Impulse Waveforms

21.2 Test Article Photographs and Sketches:



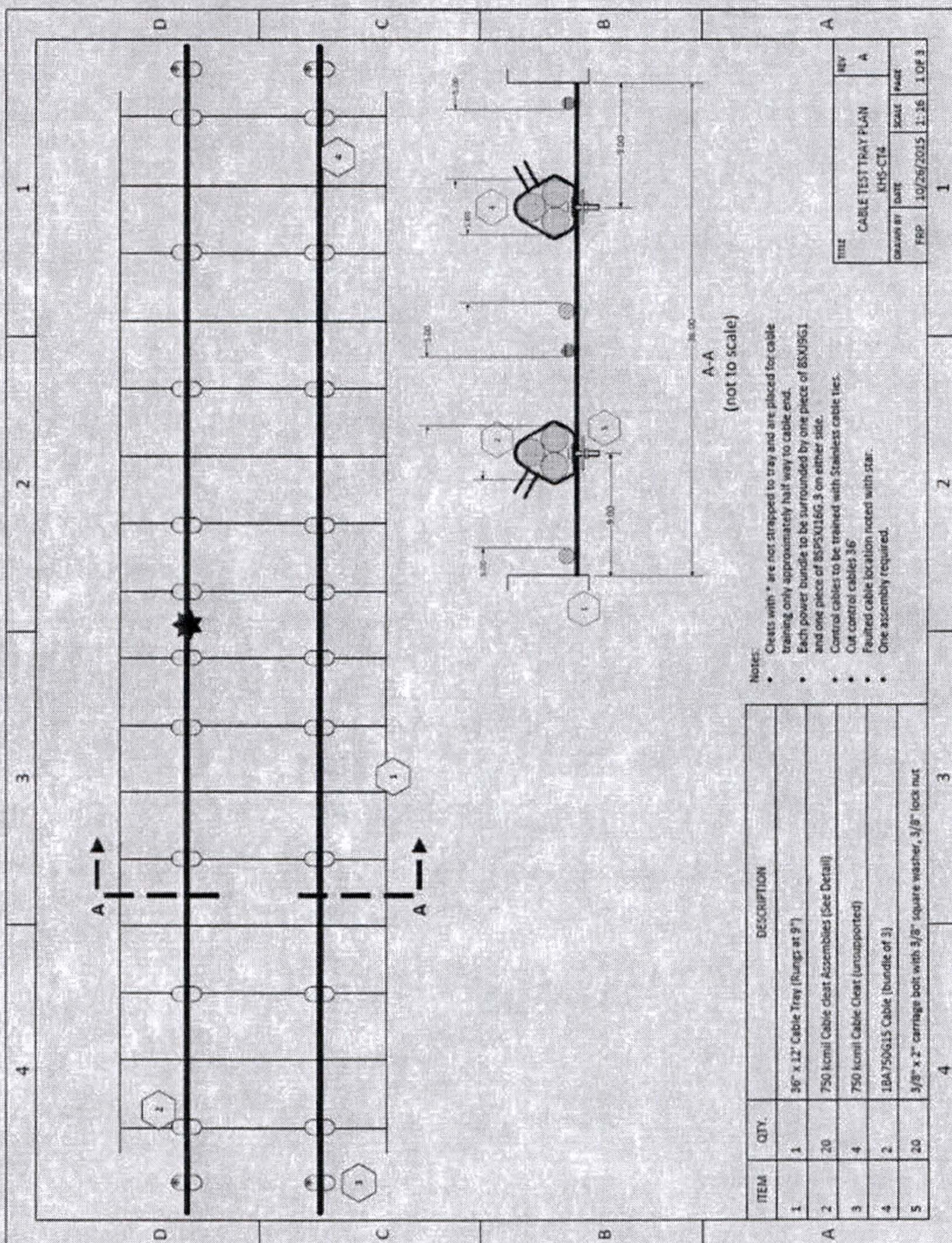
Copper Wire Inserted Beneath C-Phase Jacket Flap

21.2 Test Article Photographs and Sketches:



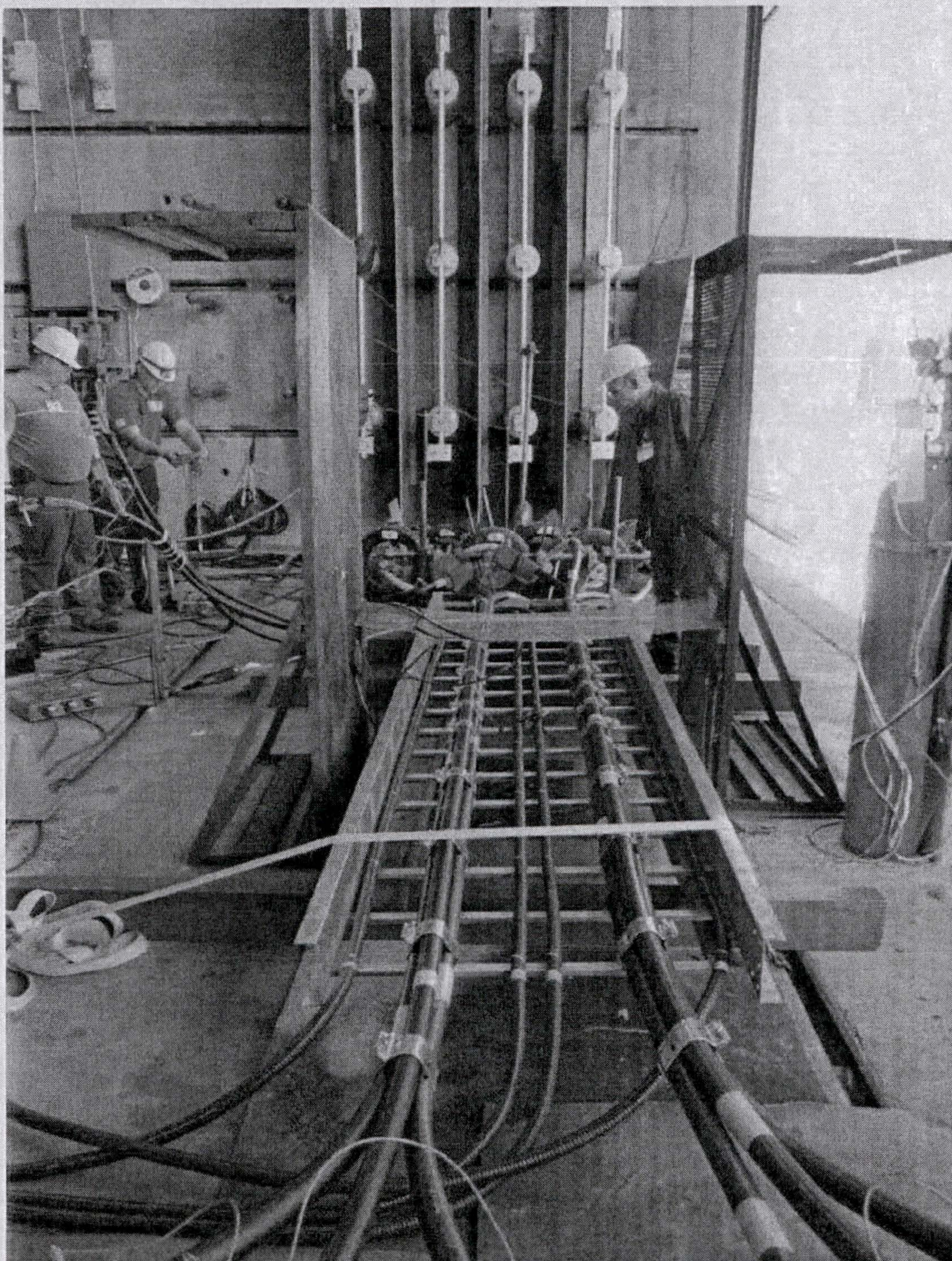
C-Phase Cable Jacket Flap Taped Back in Place and Installed in Triangular Bundle
Fault Location Oriented Towards Adjacent B-Phase Cable

21.2 Test Article Photographs and Sketches:



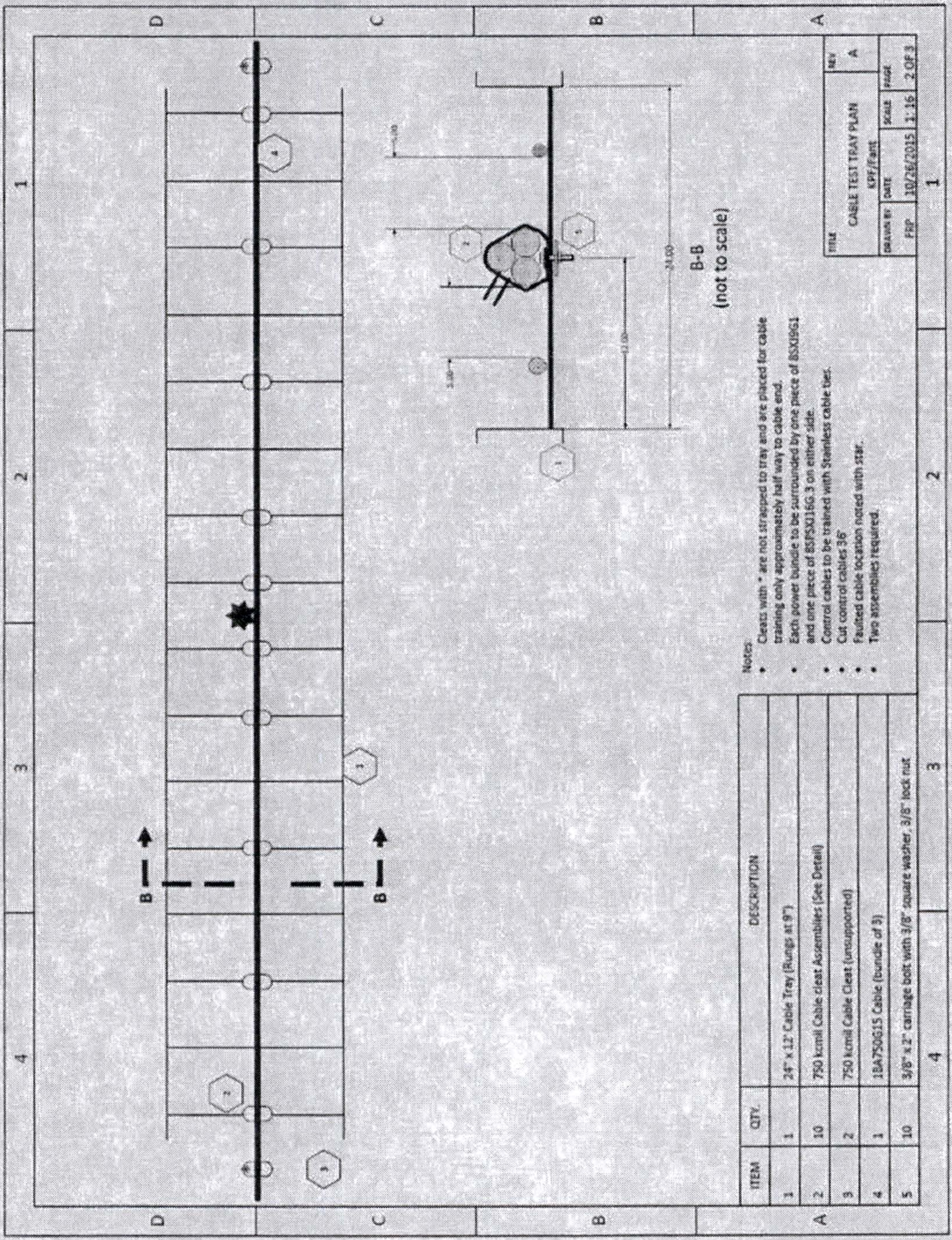
CT4 Test Article Sketch

21.2 Test Article Photographs and Sketches:



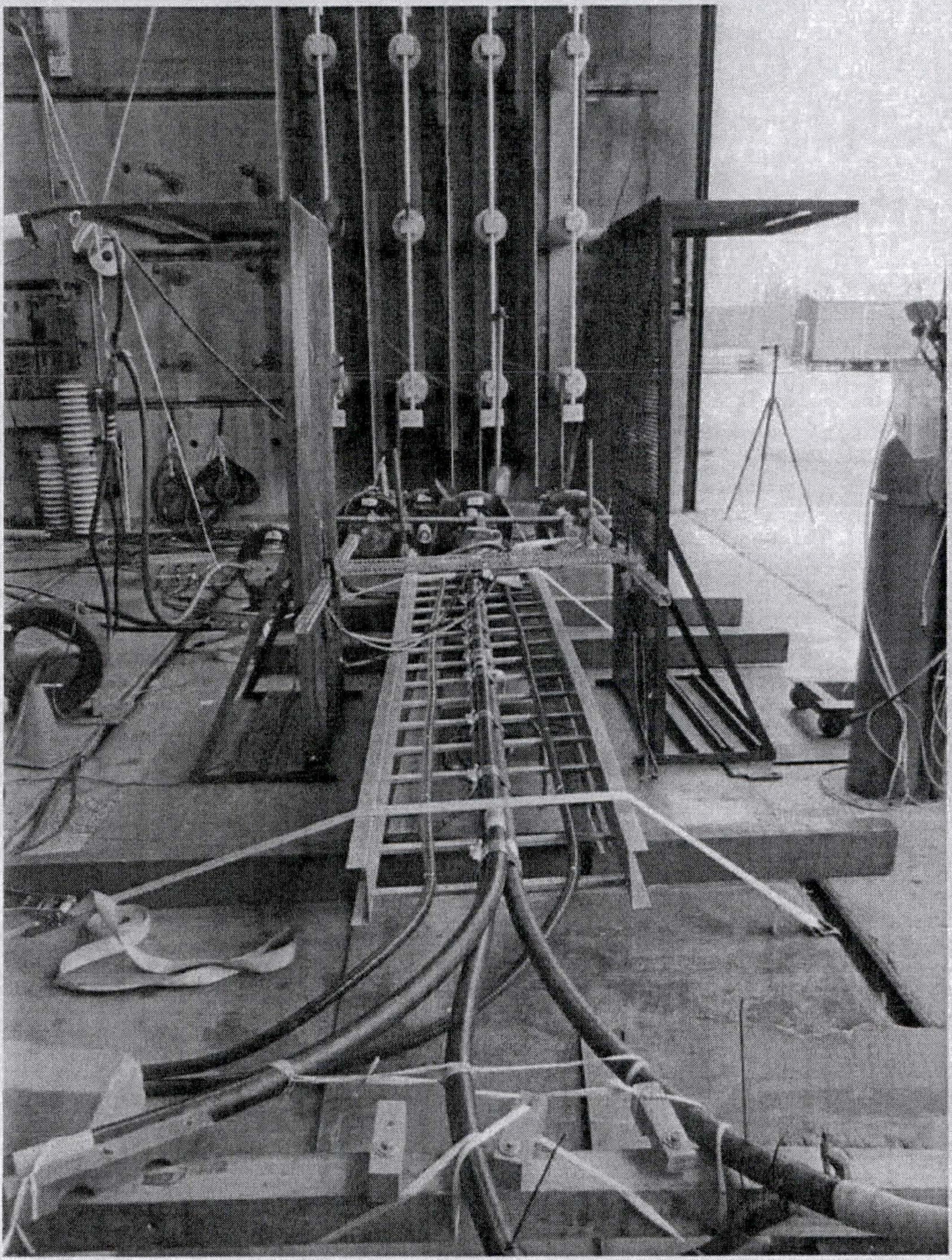
CT4 Test Article in KEMA Test Cell

21.2 Test Article Photographs and Sketches:



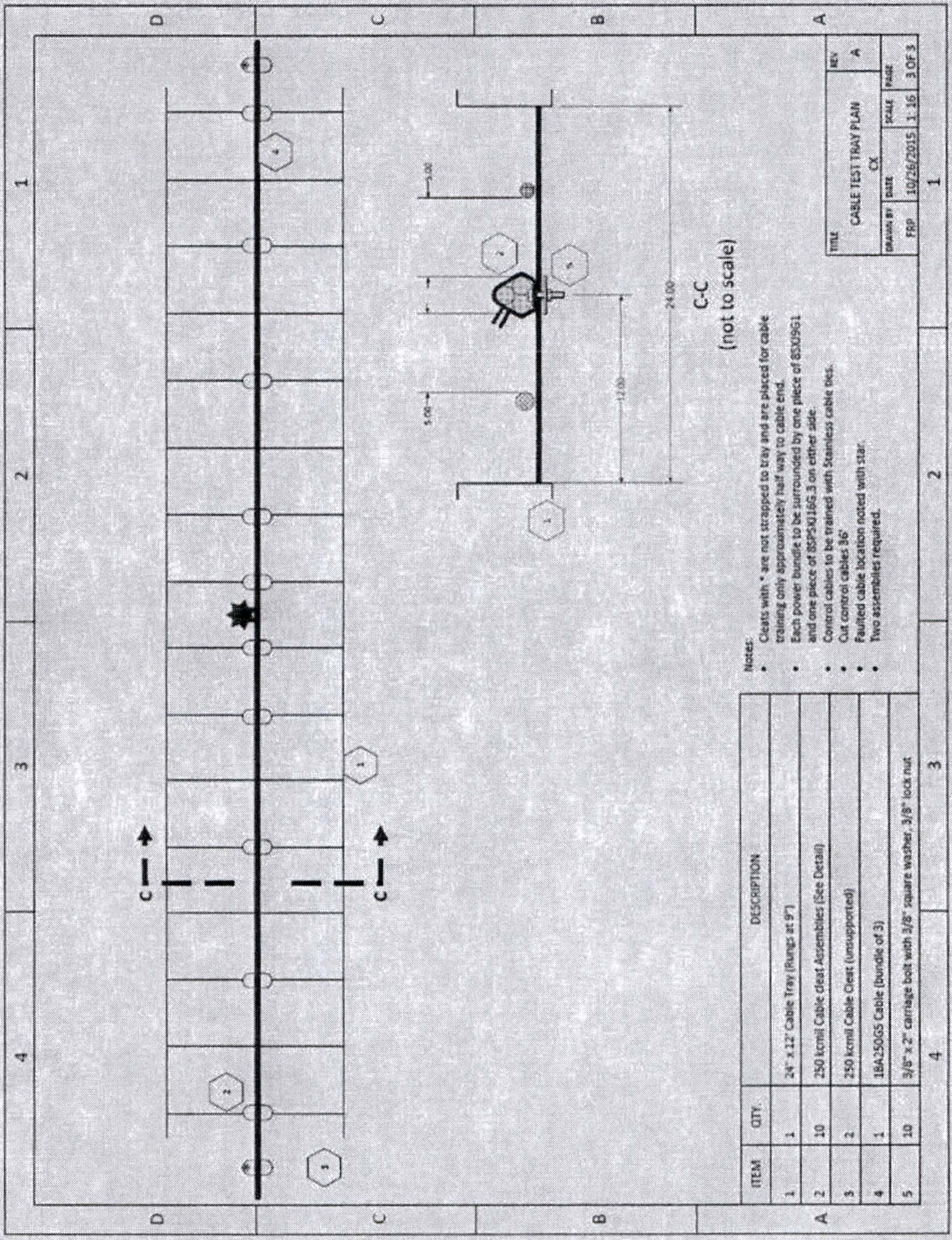
KPF and Fant Test Article Sketch

21.2 Test Article Photographs and Sketches:



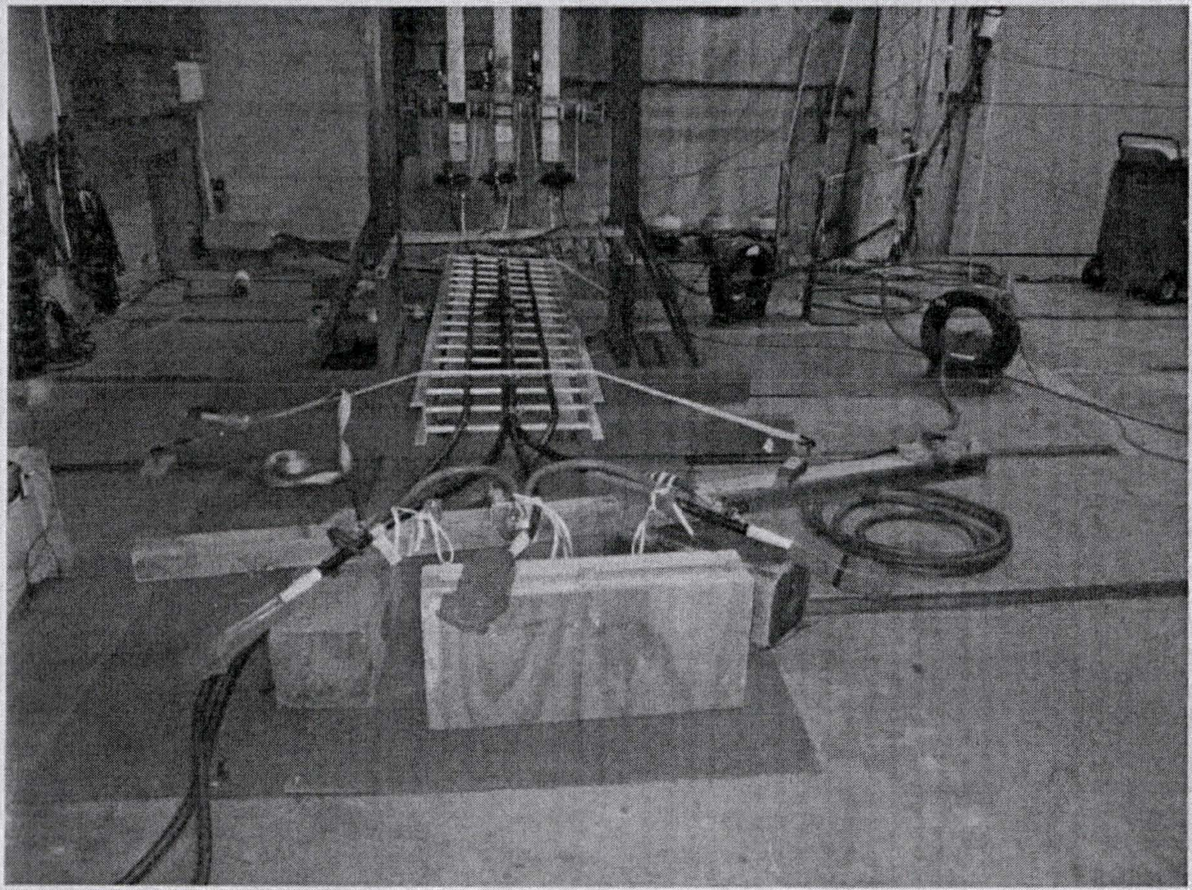
KPF and Fant Test Article in KEMA Test Cell

21.2 Test Article Photographs and Sketches:



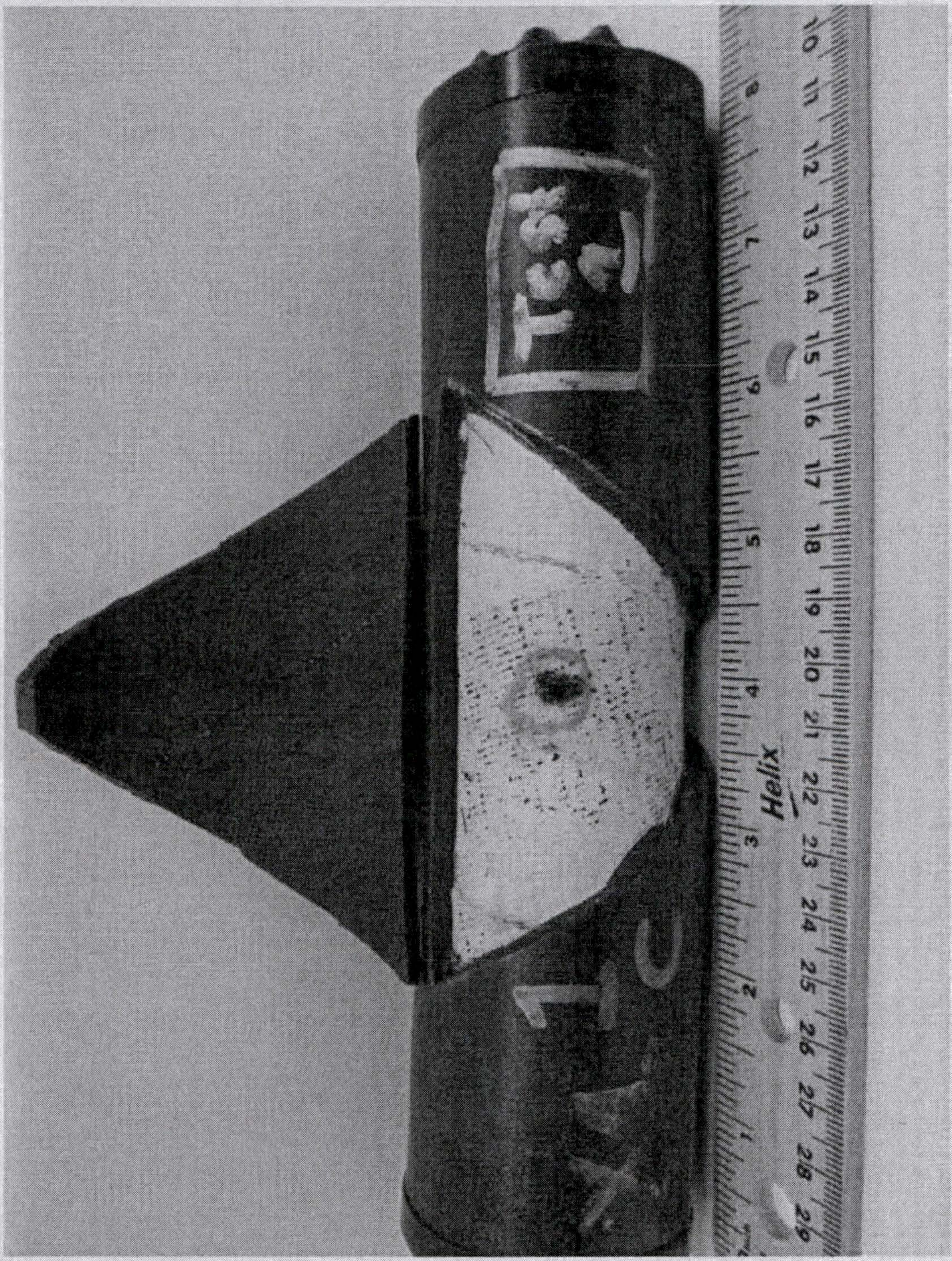
CX Test Article Sketch

21.2 Test Article Photographs and Sketches:



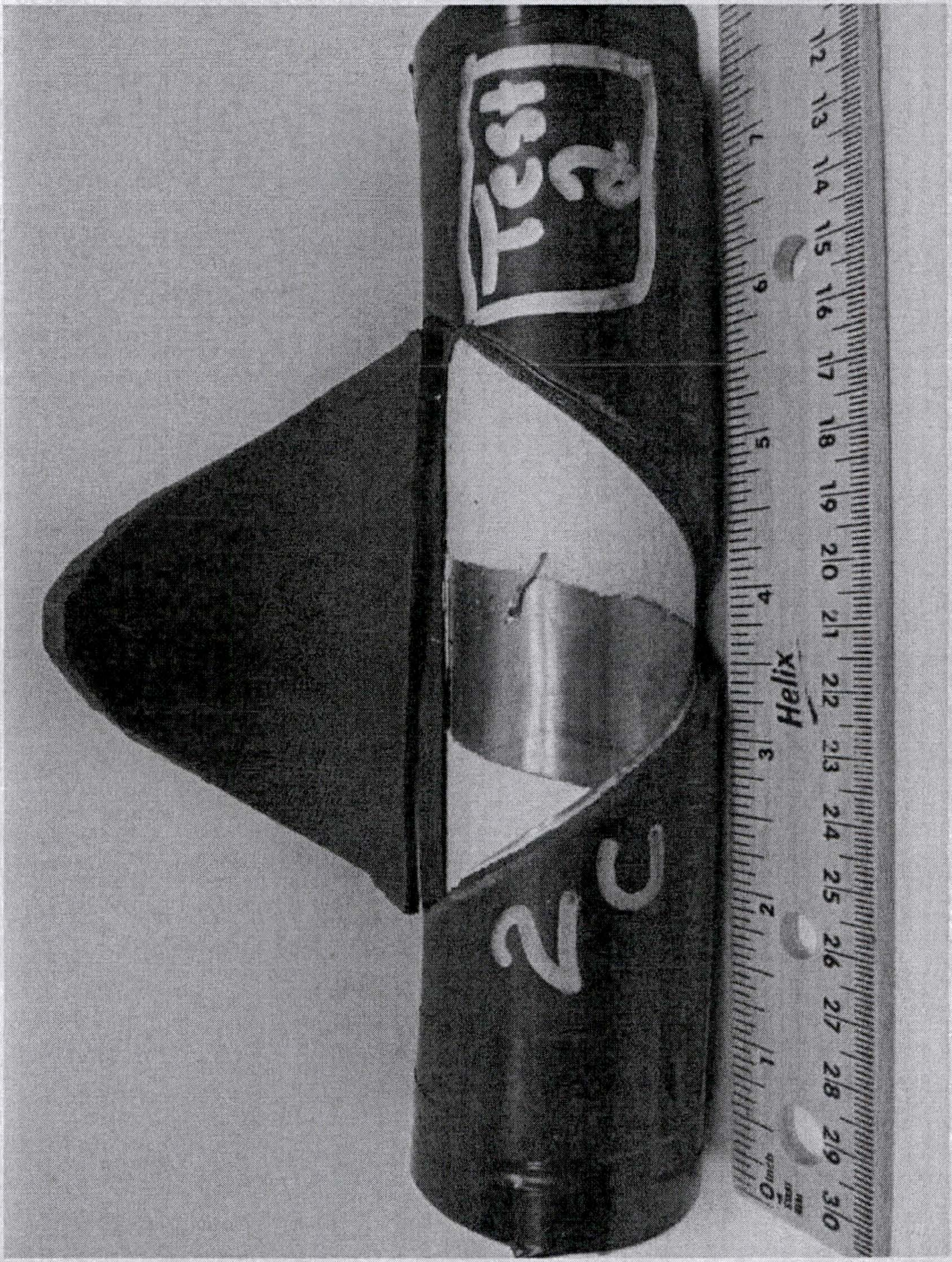
CX Test Article in KEMA Test Cell

21.3. KEMA Post-Test Cable Photographs:



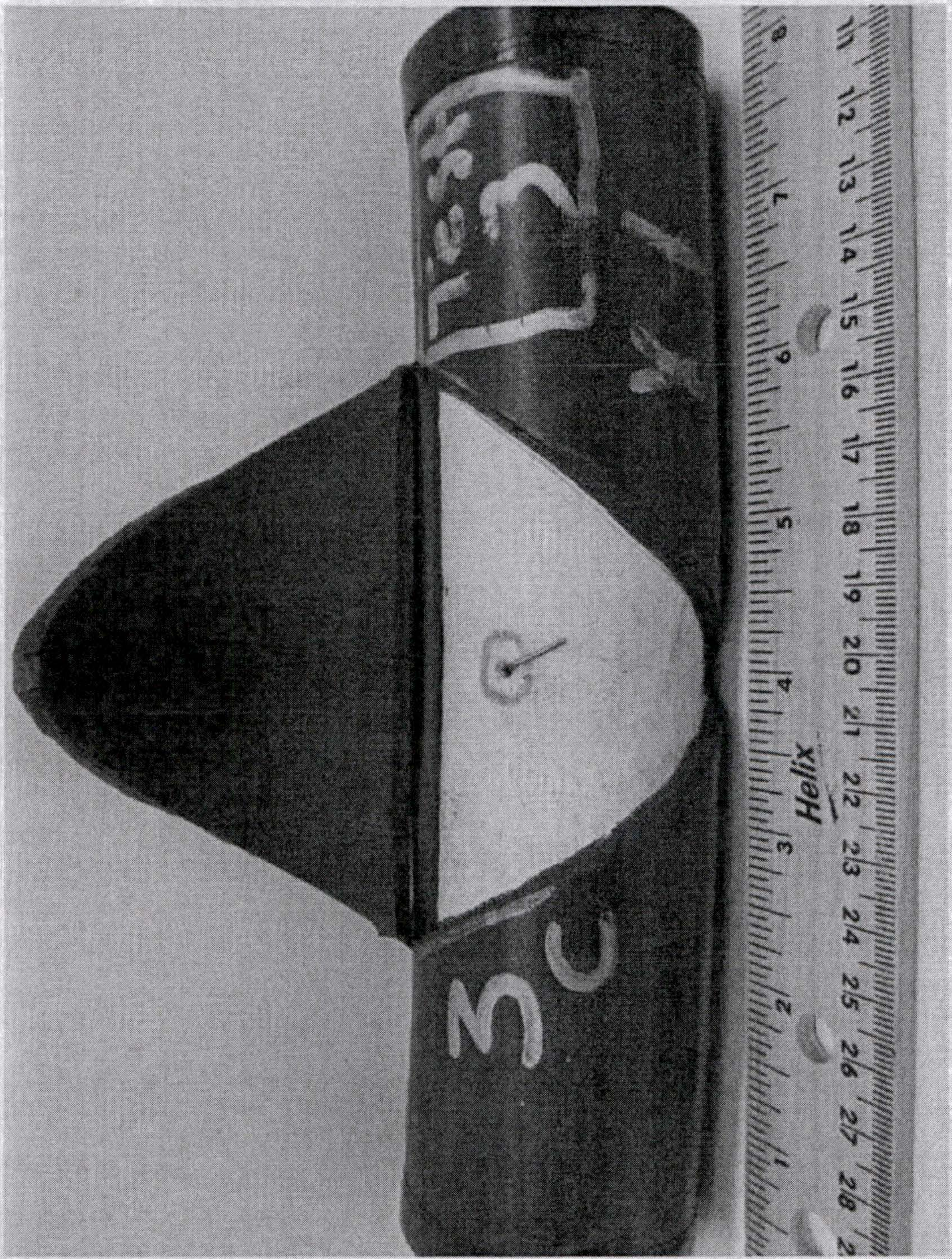
Test 1 C-Phase Cable
CT4 Configuration With Resistance Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:



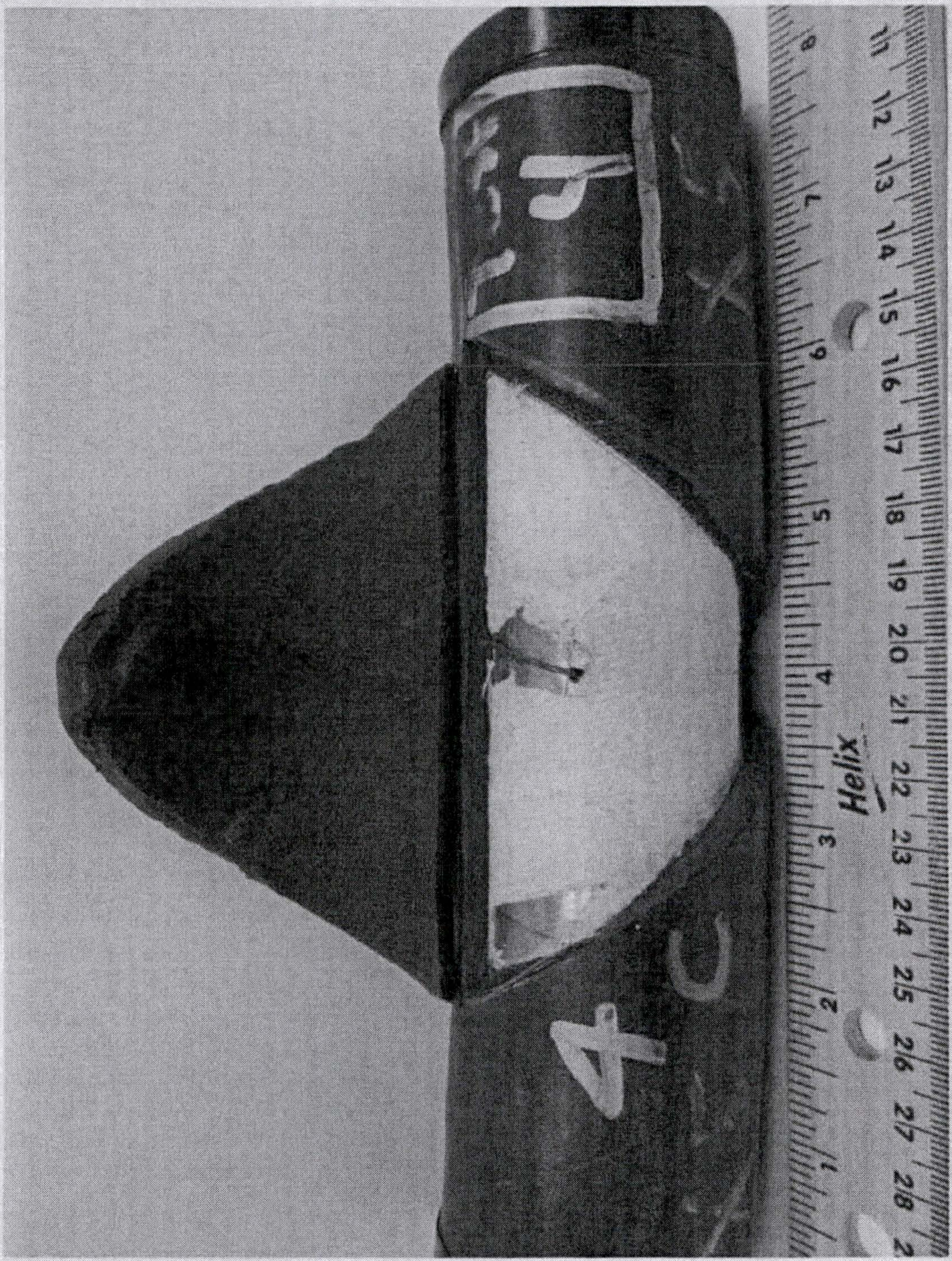
Test 2 C-Phase Cable
CT4 Configuration With Resistance Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:



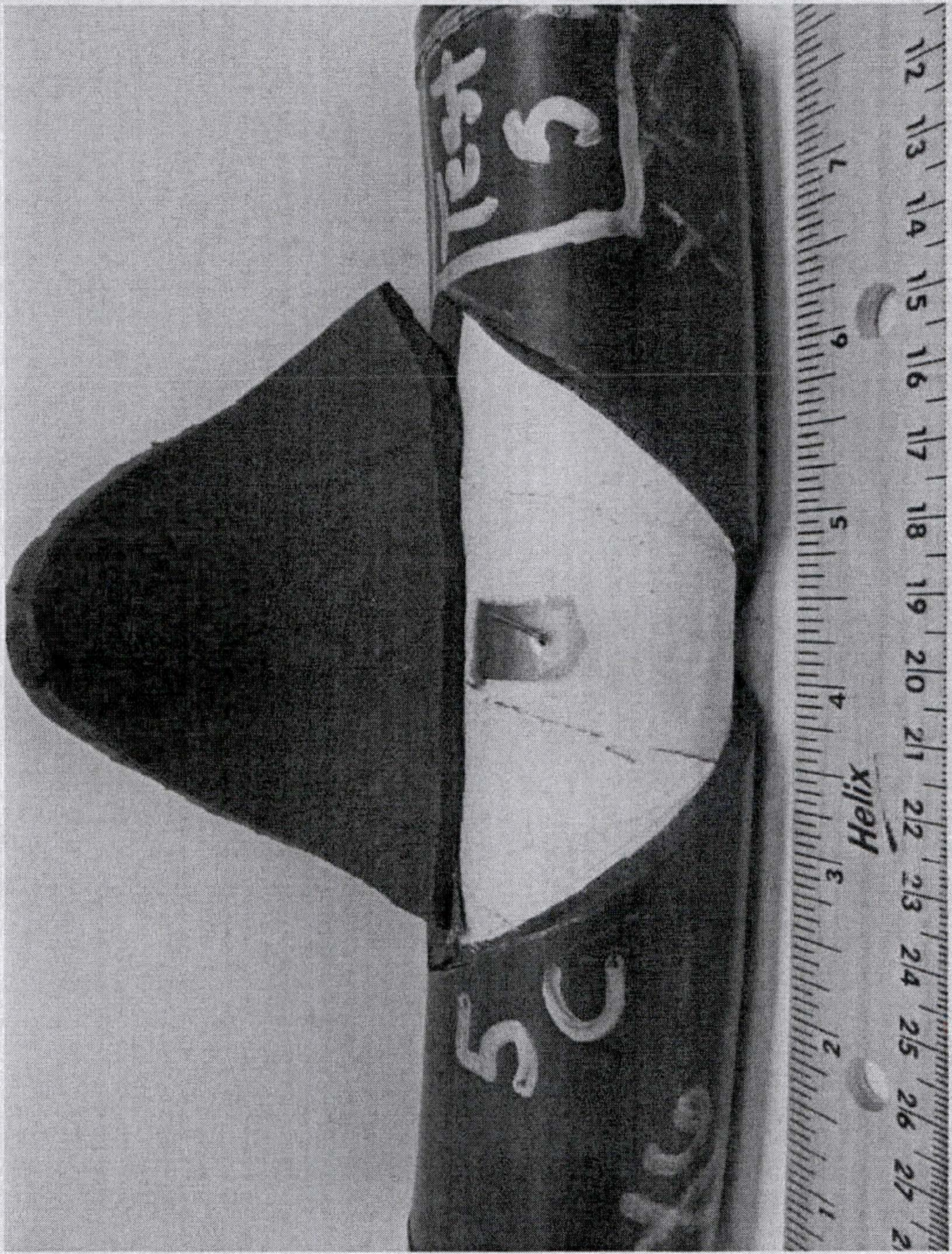
Test 3 C-Phase Cable
CT4 Configuration With Resistance Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:



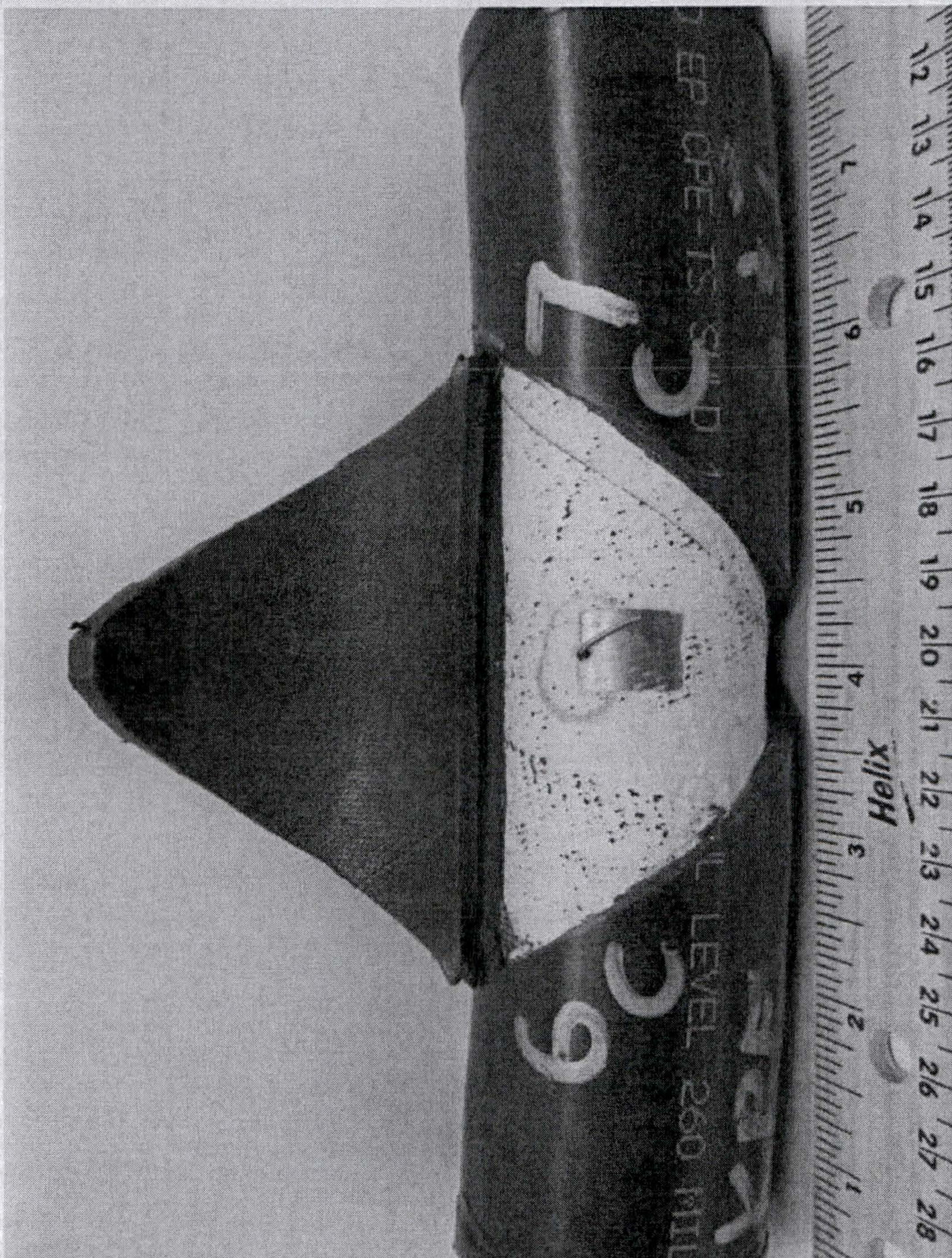
Test 4 CT4-Phase Cable
CT4 Configuration With Resistance Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:



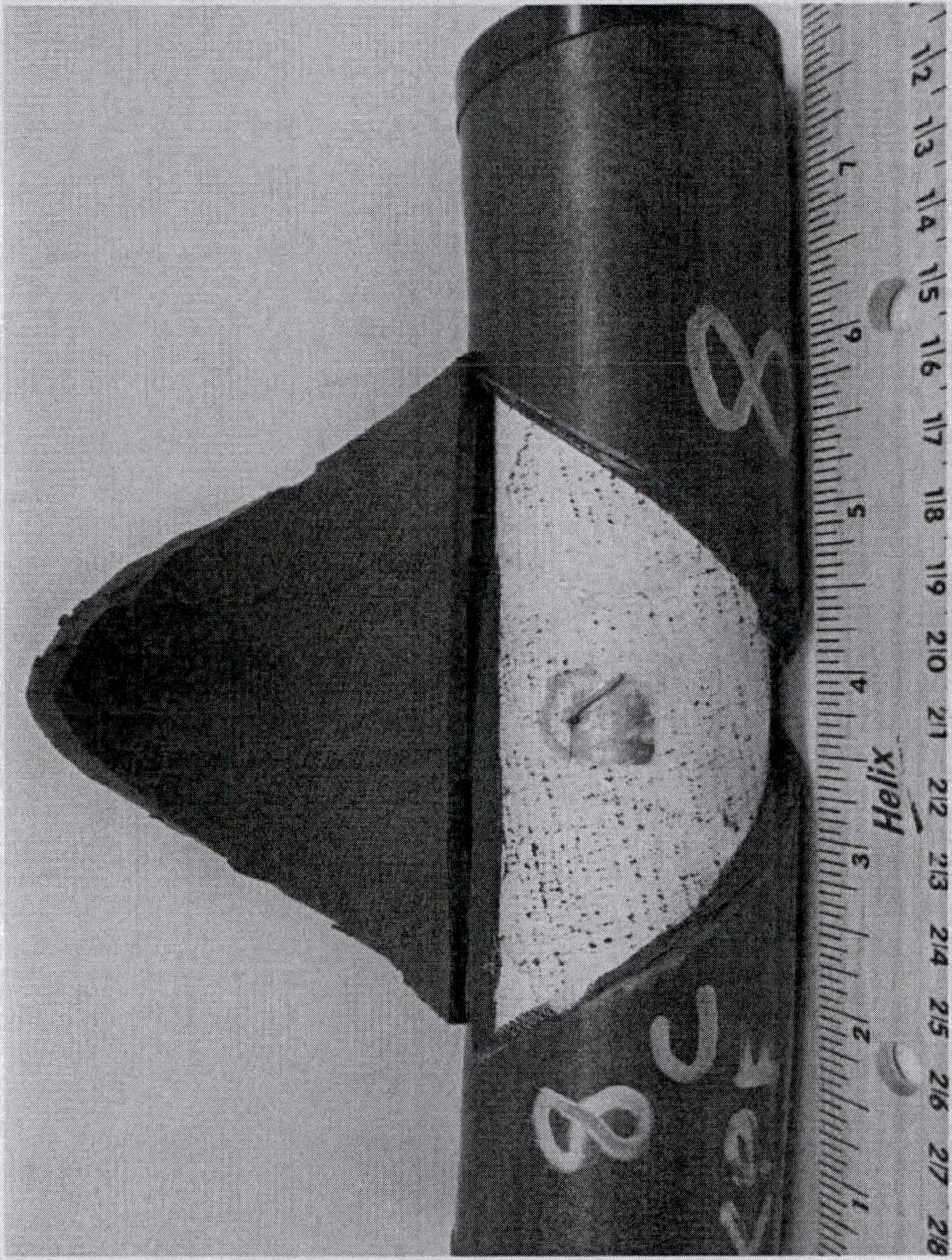
Test 5 C-Phase Cable
CT4 Configuration With Resistance Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:



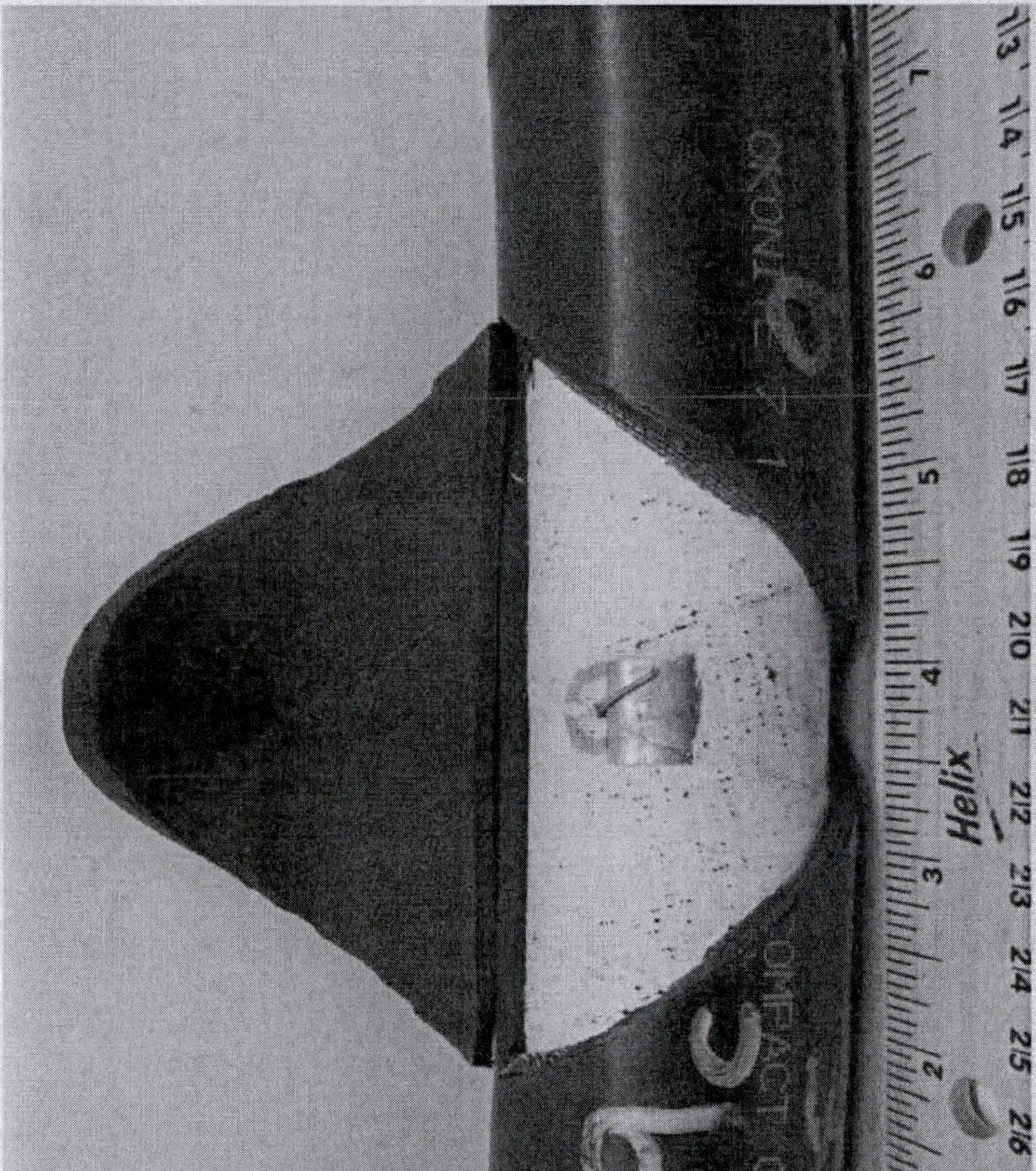
Tests 6 and 7 C-Phase Cable
KPF Configuration With Resistance Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:



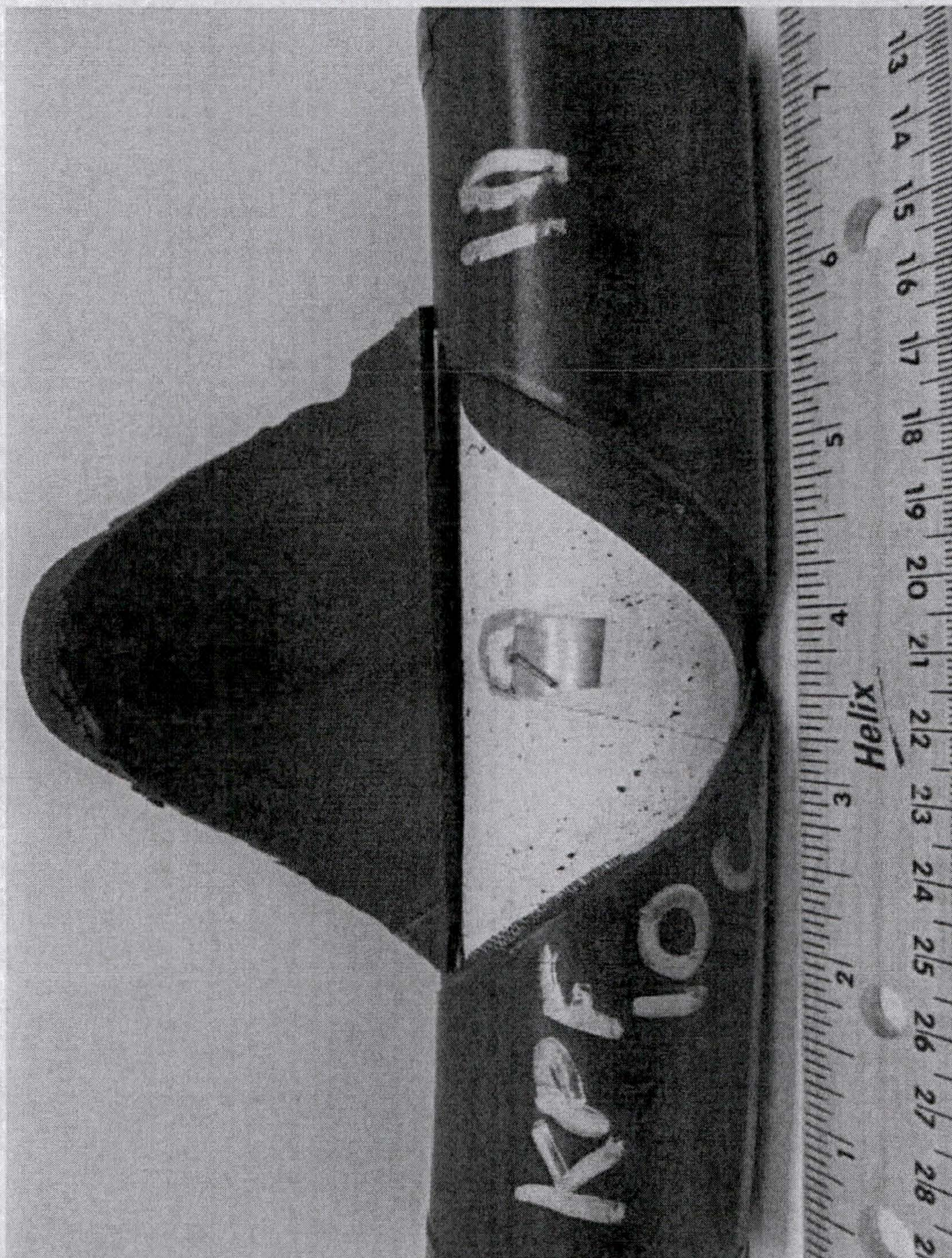
Test 8 C-Phase Cable
KPF Configuration With Resistance Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:



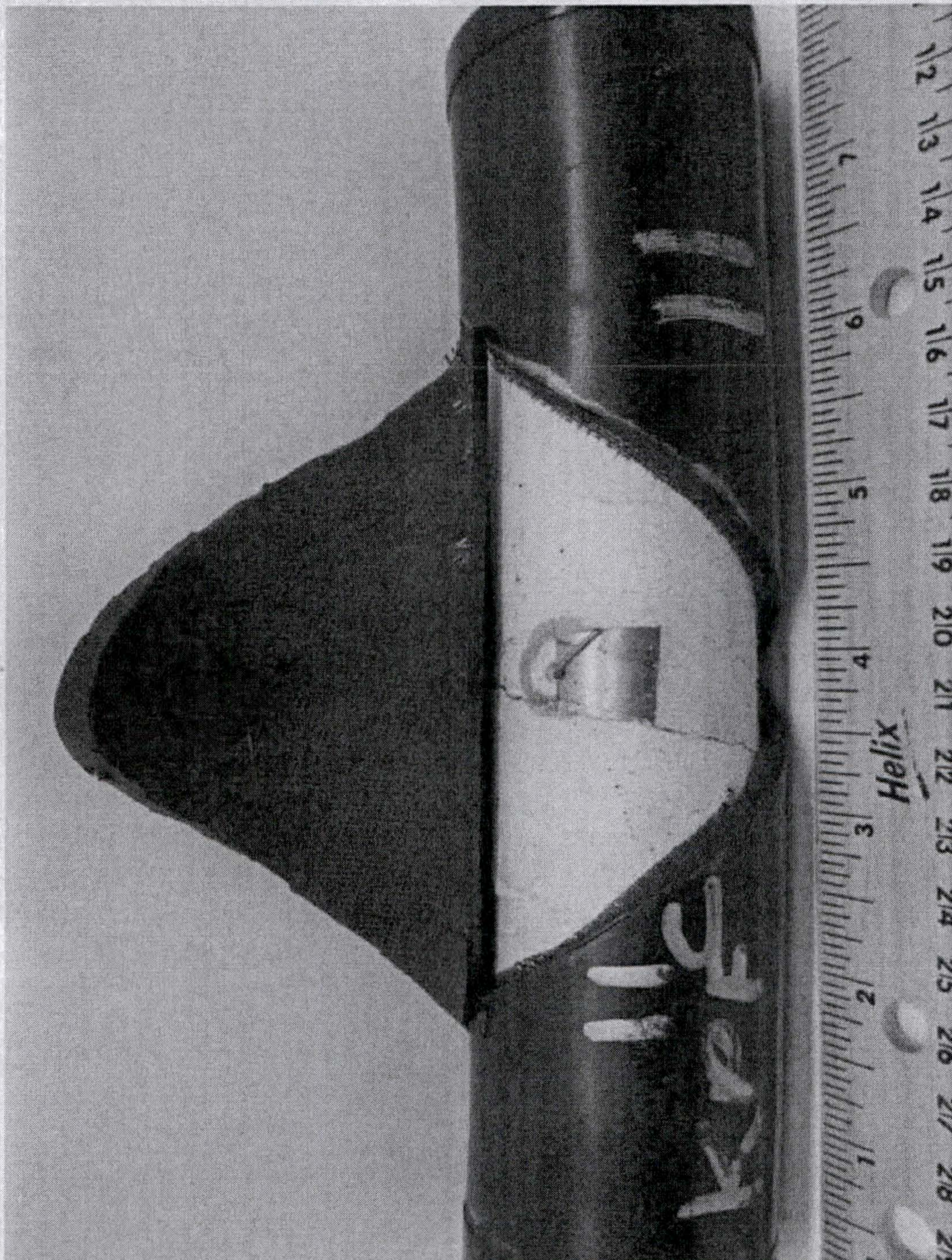
Test 9 C-Phase Cable
KPF Configuration With Resistance Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:



Test 10 C-Phase Cable
KPF Configuration With Resistance Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:

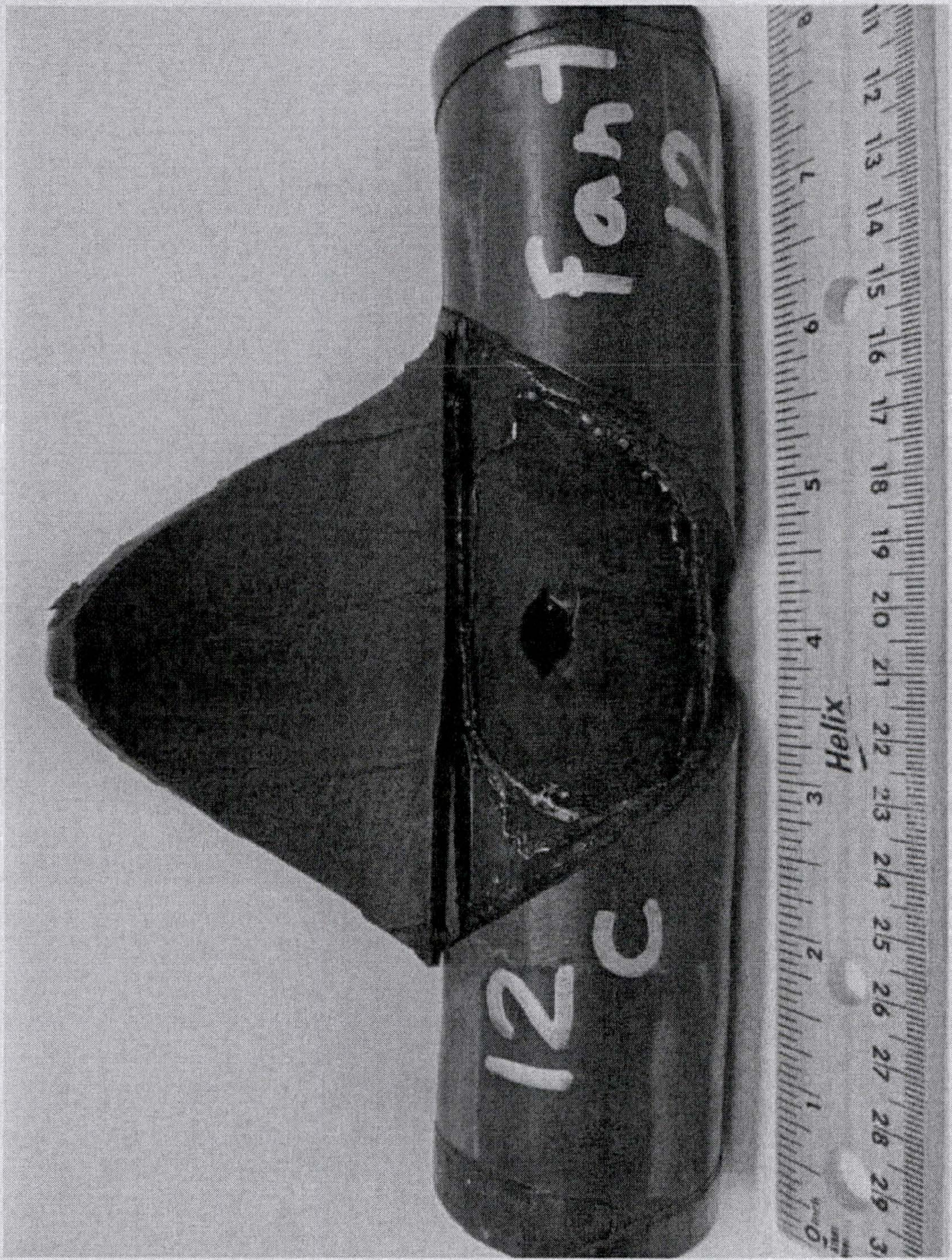


Test 11 C-Phase Cable
KPF Configuration With Resistance Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:

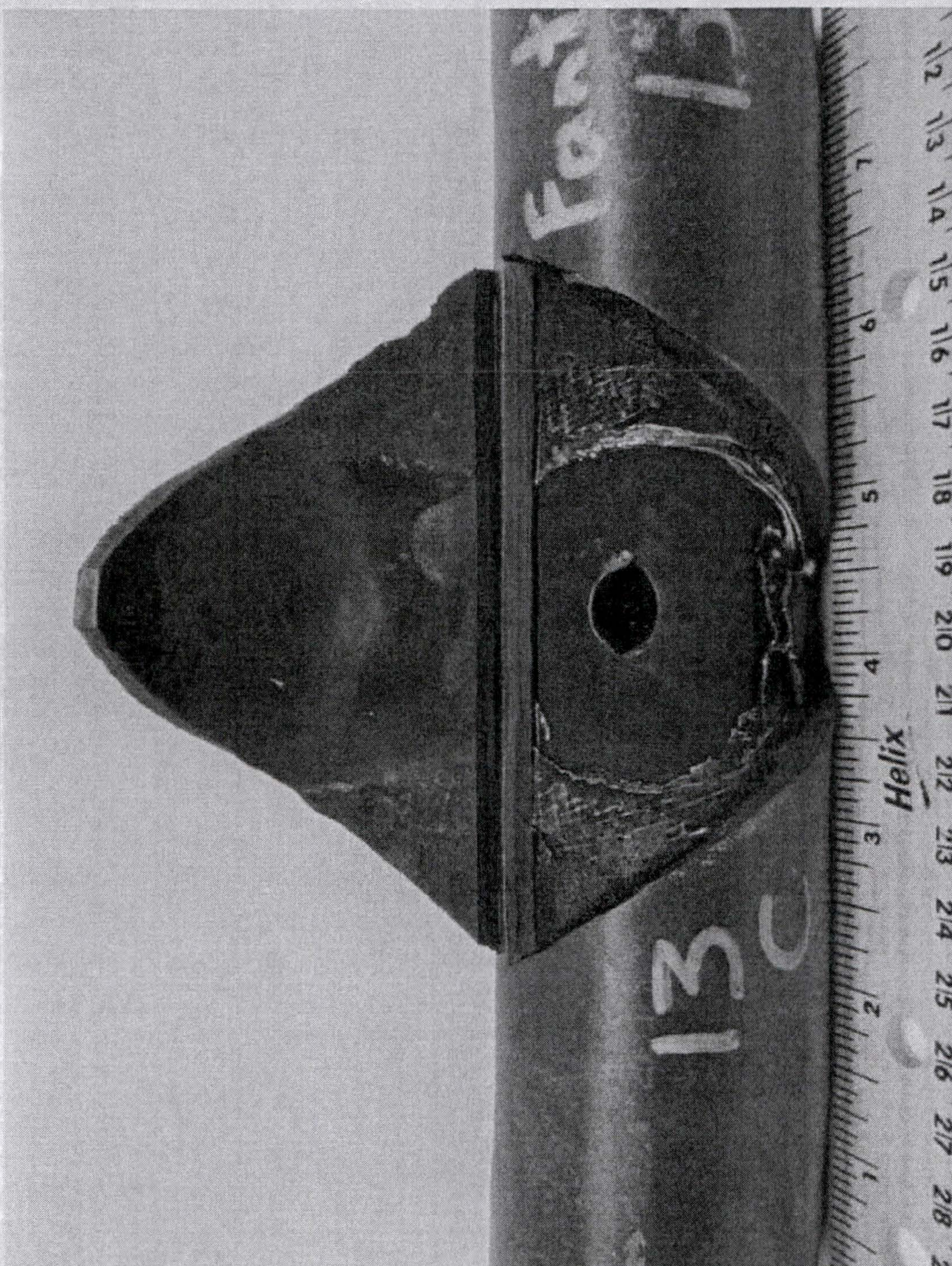
Test 12 A-Phase and B-Phase Cables
Fant Configuration With Solidly Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:



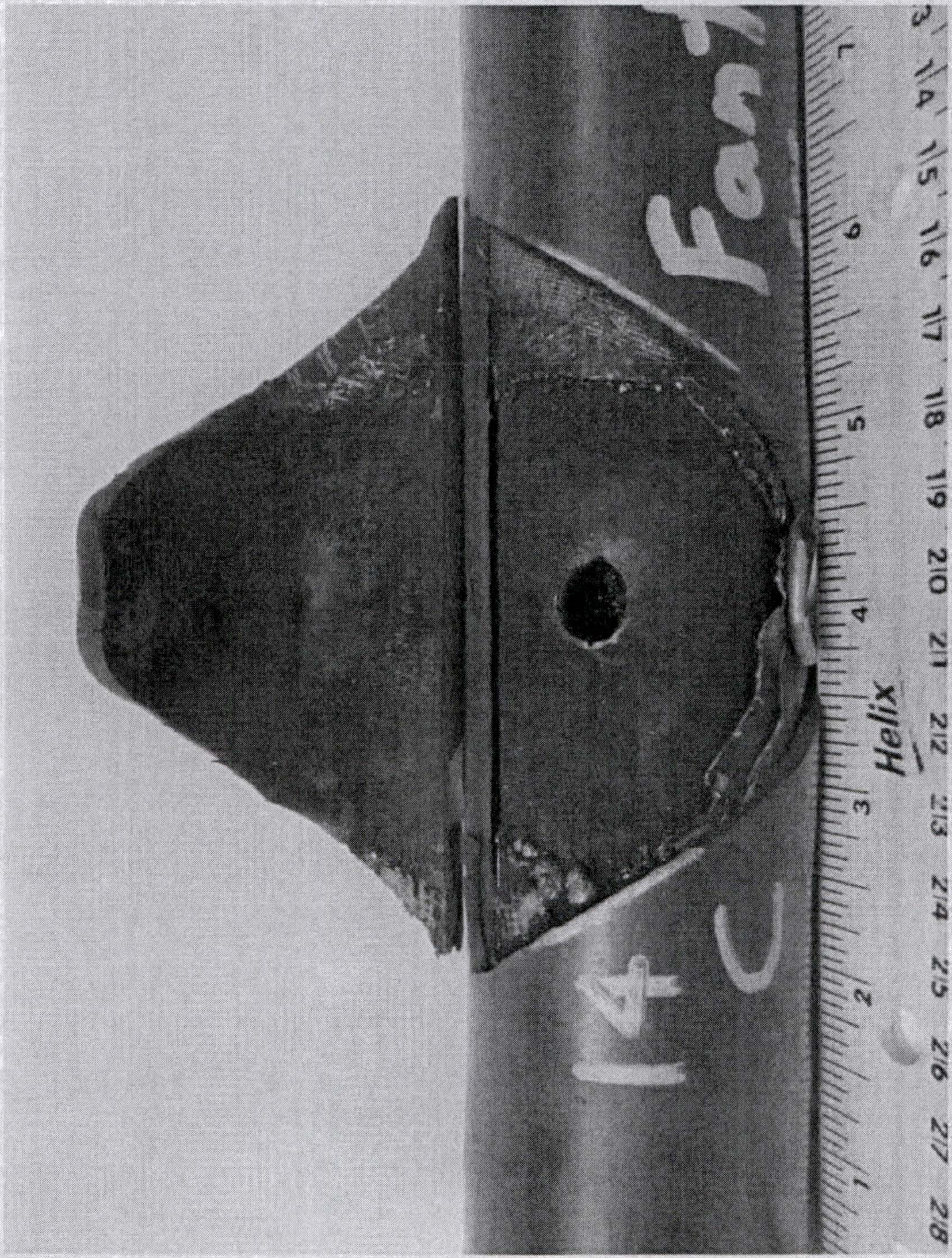
Test 12 C-Phase Cable
Fant Configuration With Solidly Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:



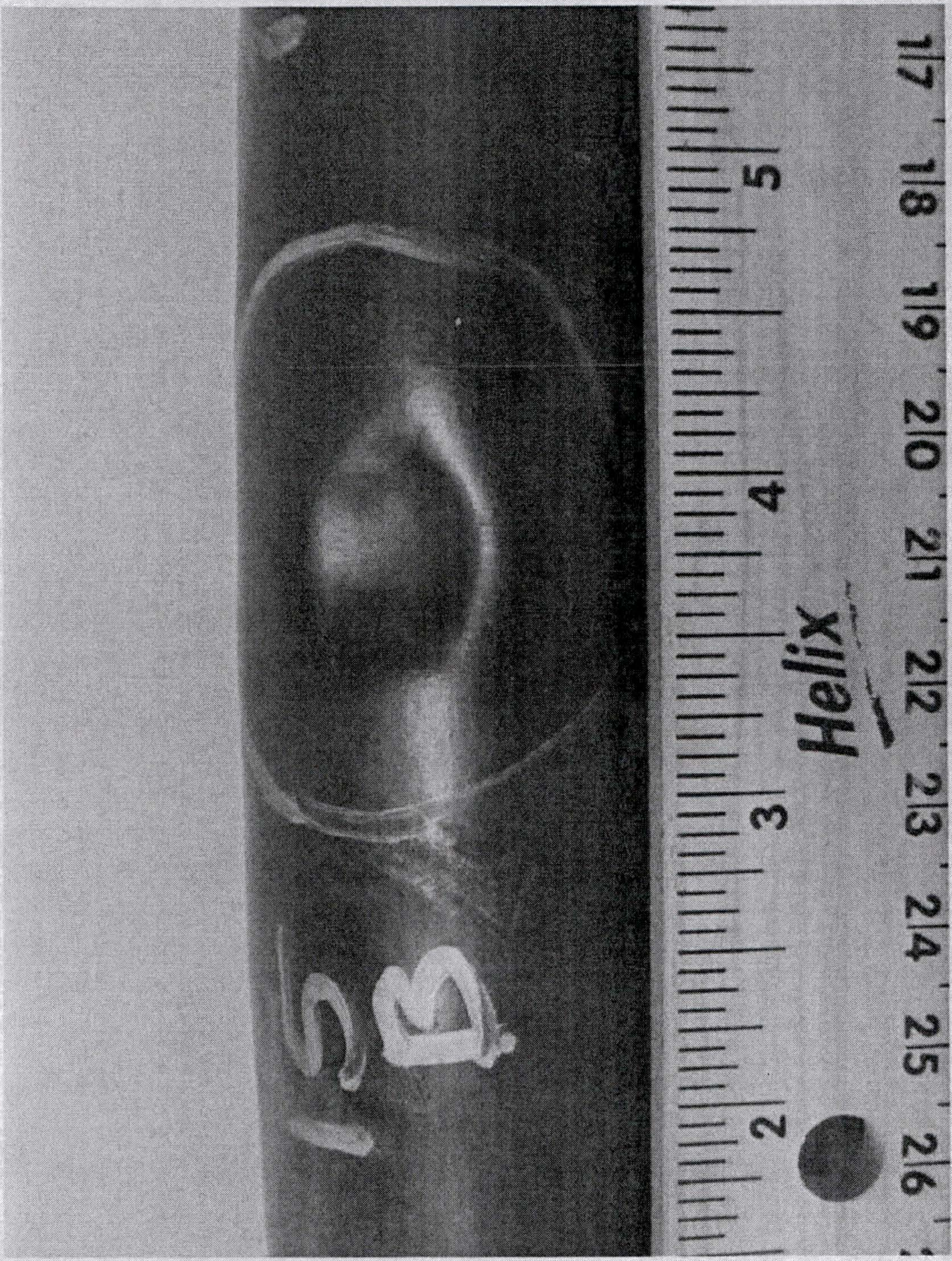
Test 13 C-Phase Cable
Fant Configuration With Solidly Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:



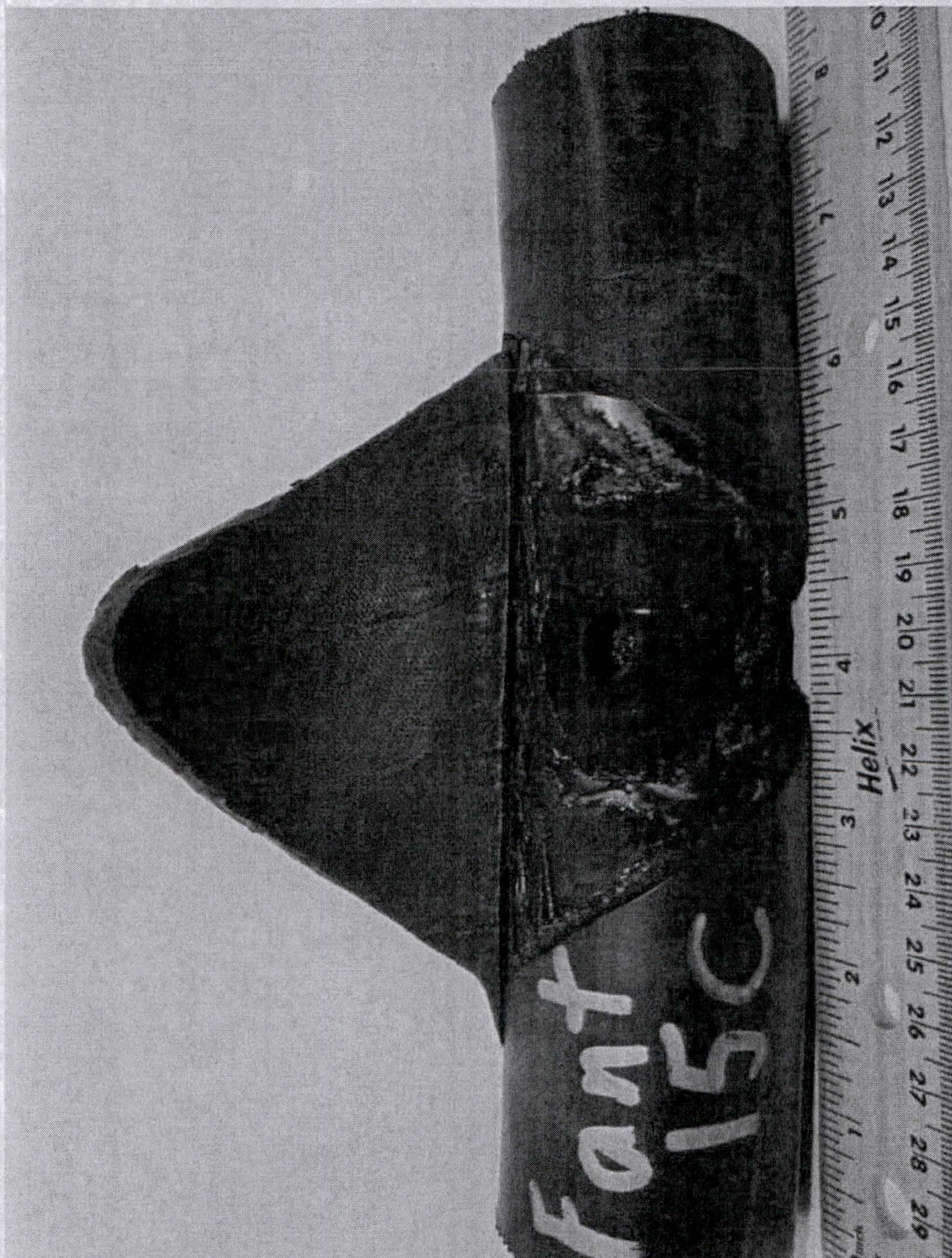
Test 14 C-Phase Cable
Fant Configuration With Solidly Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:



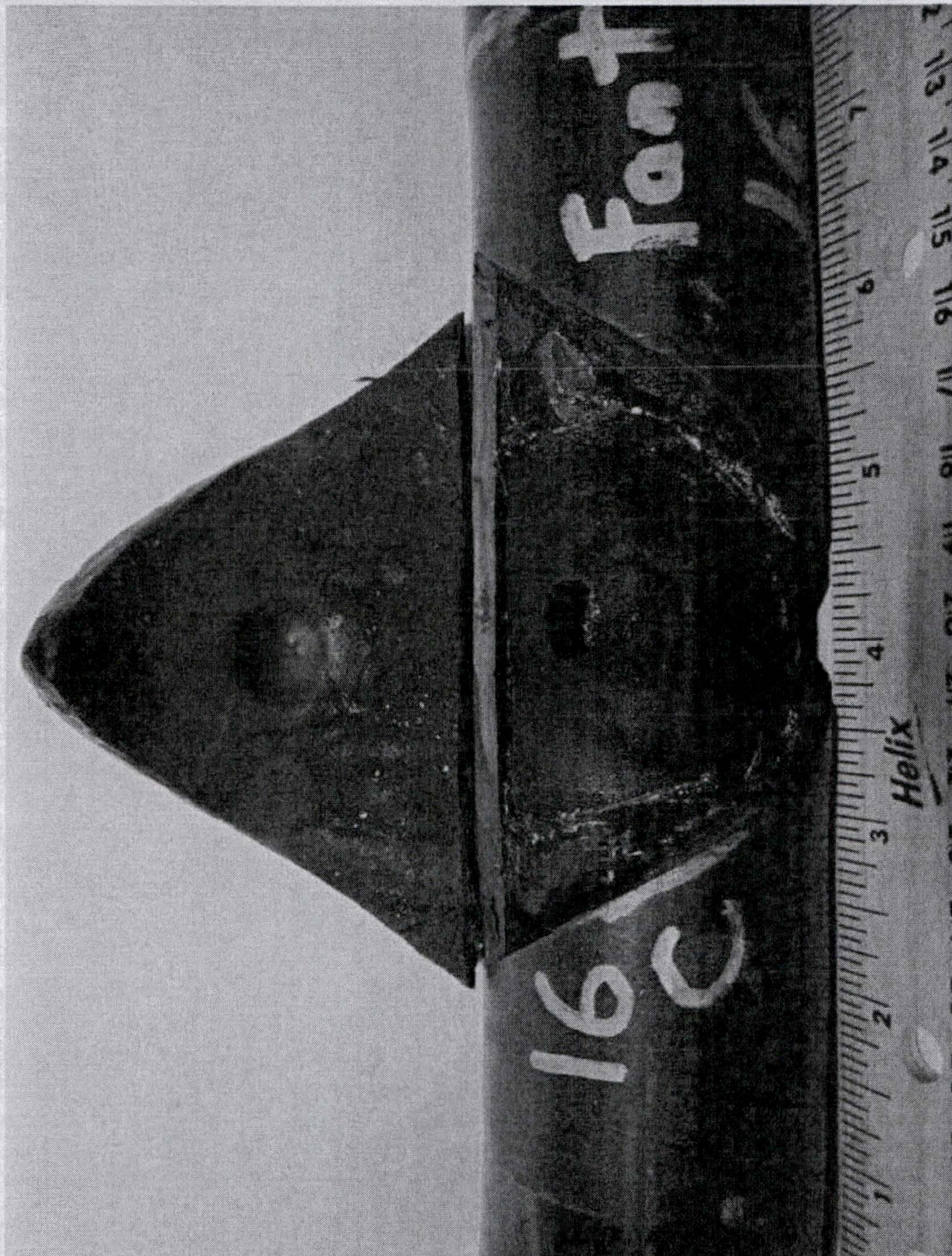
Test 15 B-Phase Cable
Fant Configuration With Solidly Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:



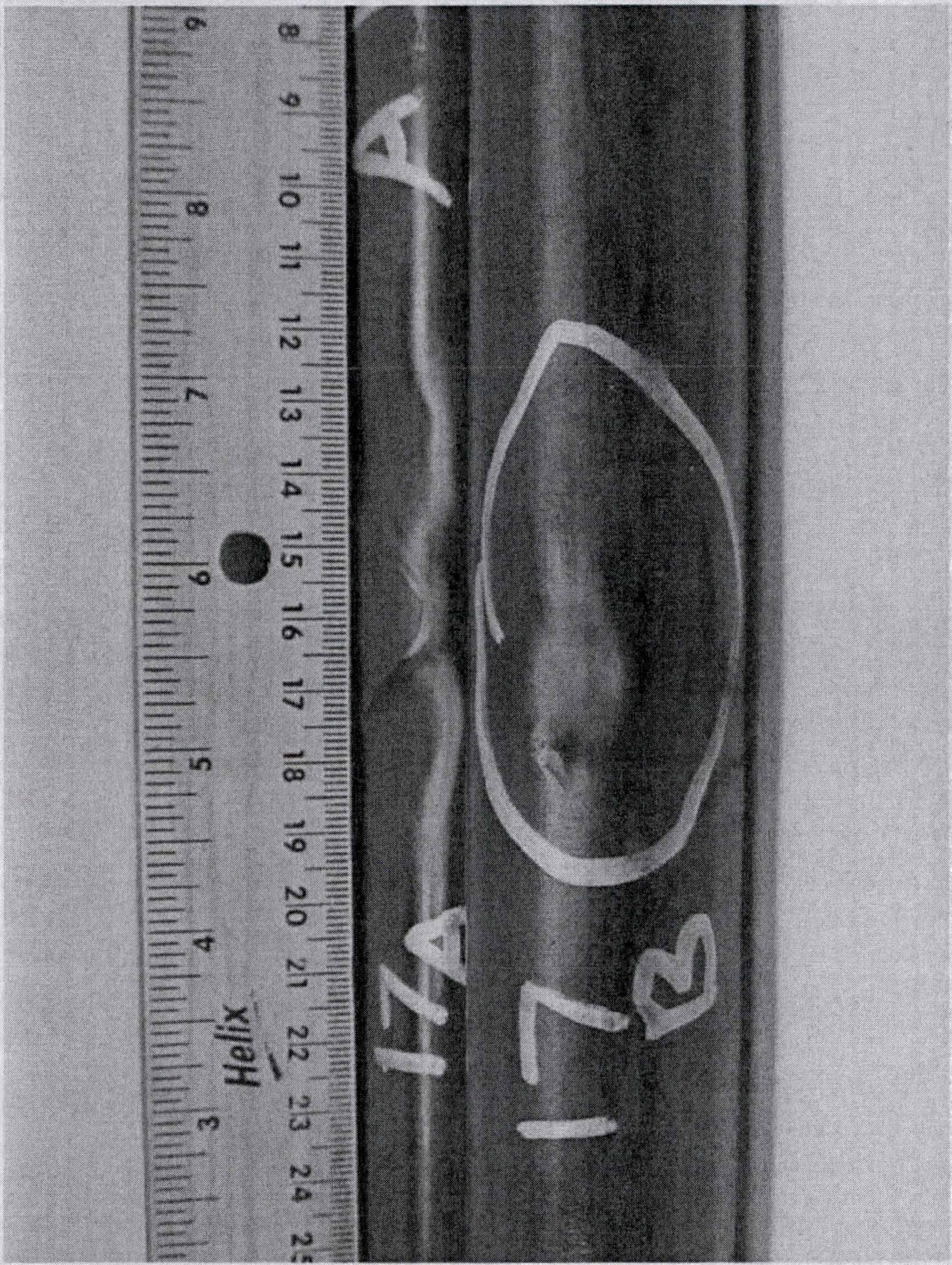
Test 15 C-Phase Cable
Fant Configuration With Solidly Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:



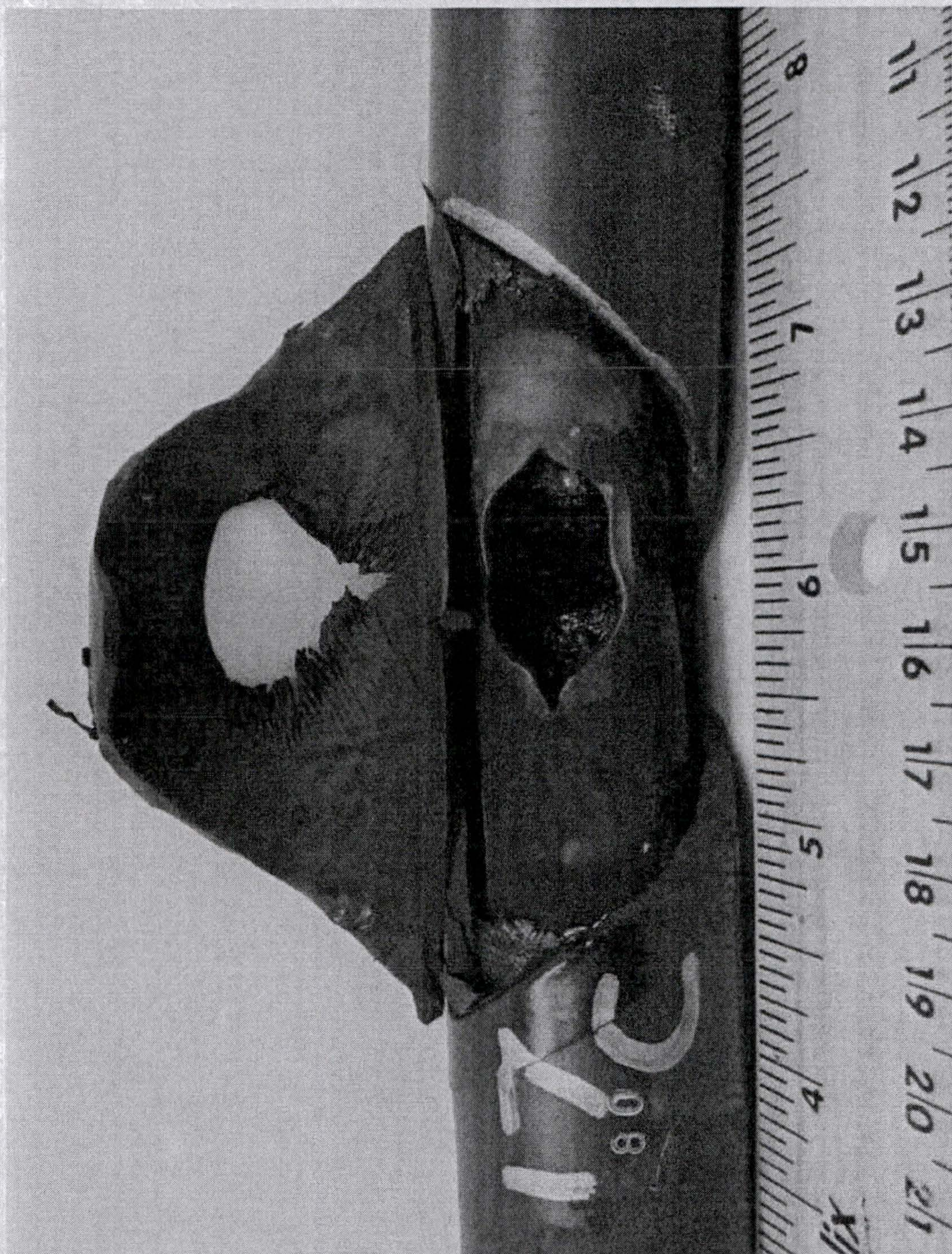
Test 16 C-Phase Cable
Fant Configuration With Solidly Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:



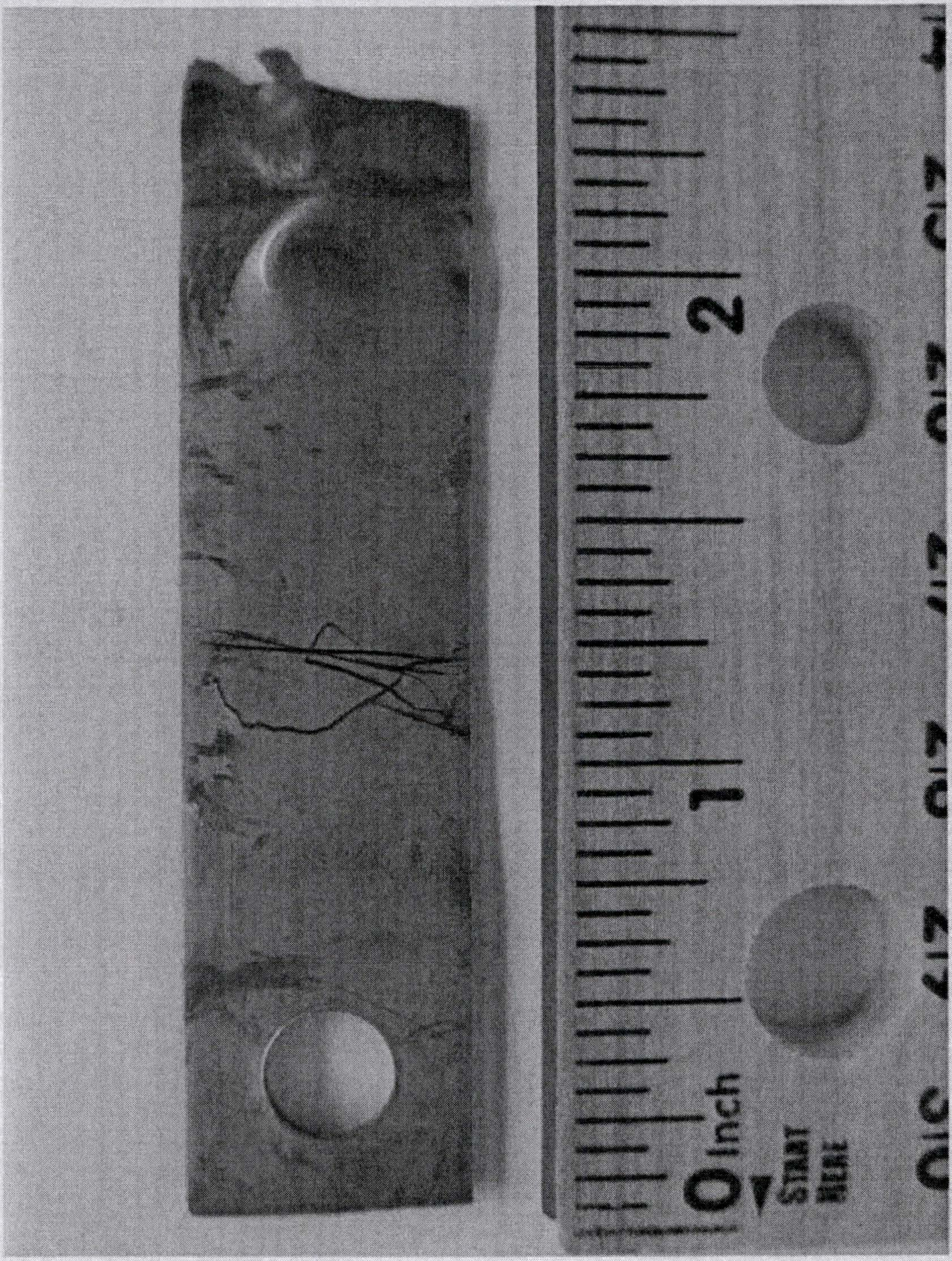
Test 17 A-Phase and B-Phase Cables
CX Configuration With Solidly Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:



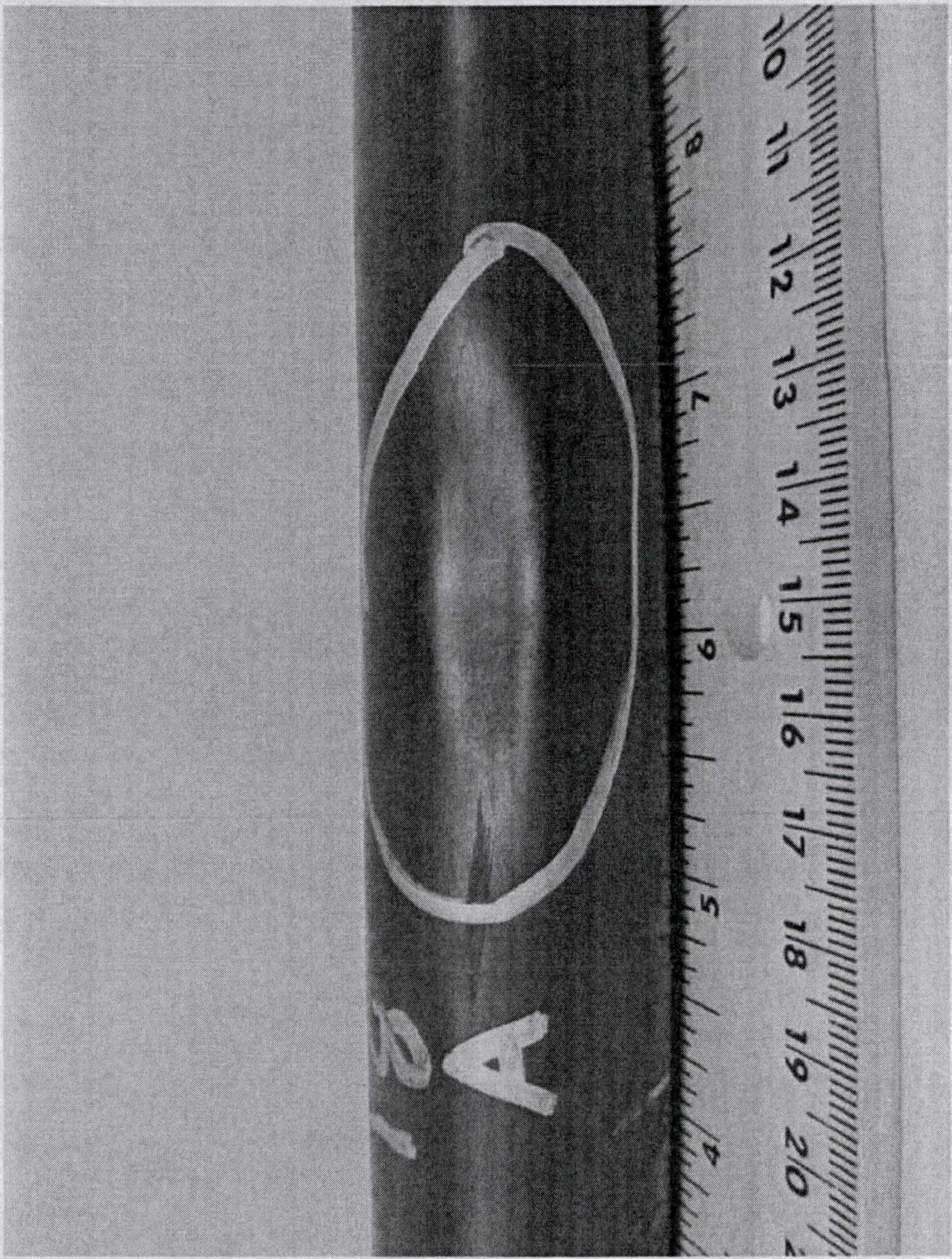
Test 17 C-Phase Cable
CX Configuration With Solidly Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:



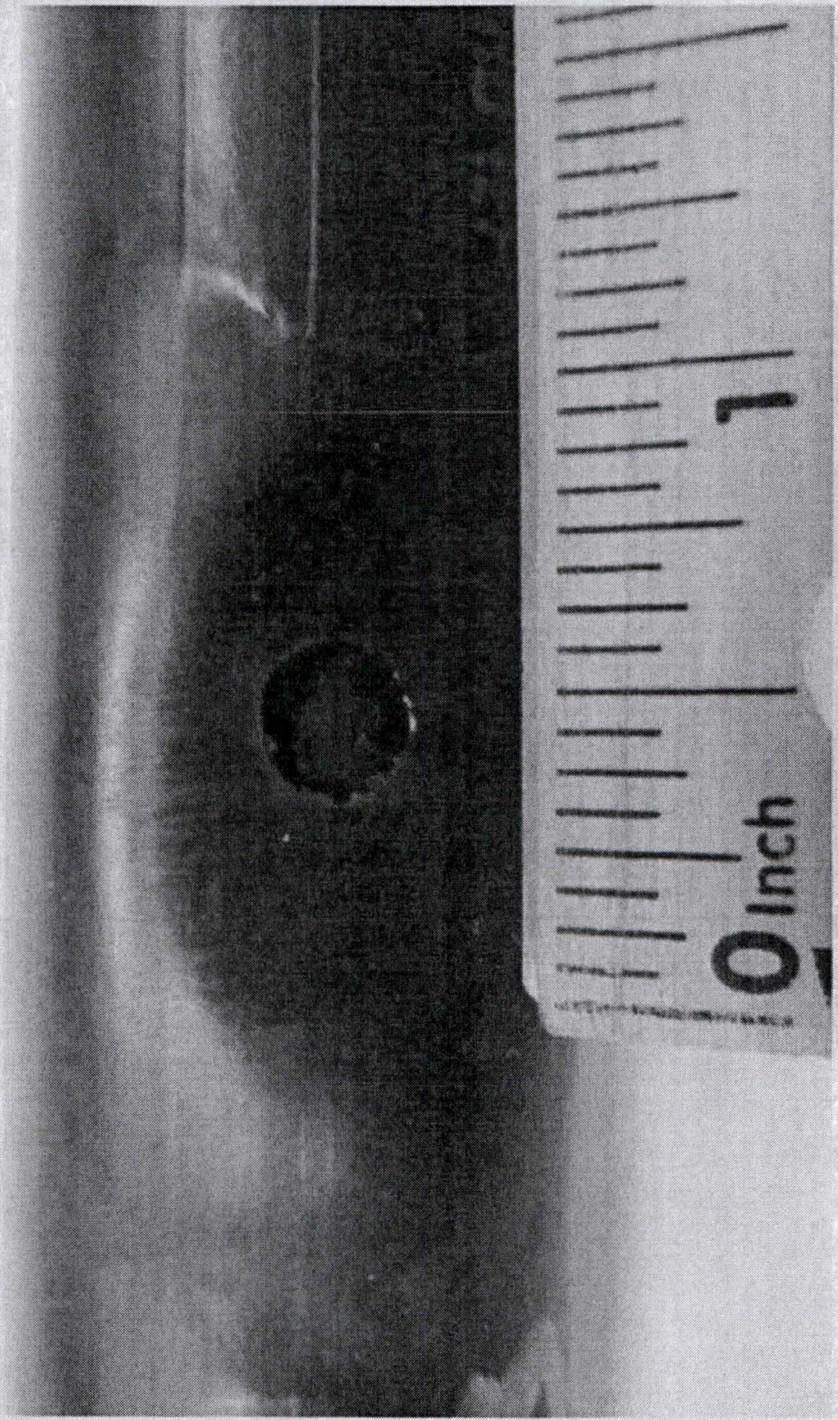
Test 17 C-Phase Load-Side Termination Ground Strap
CX Configuration With Solidly Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:



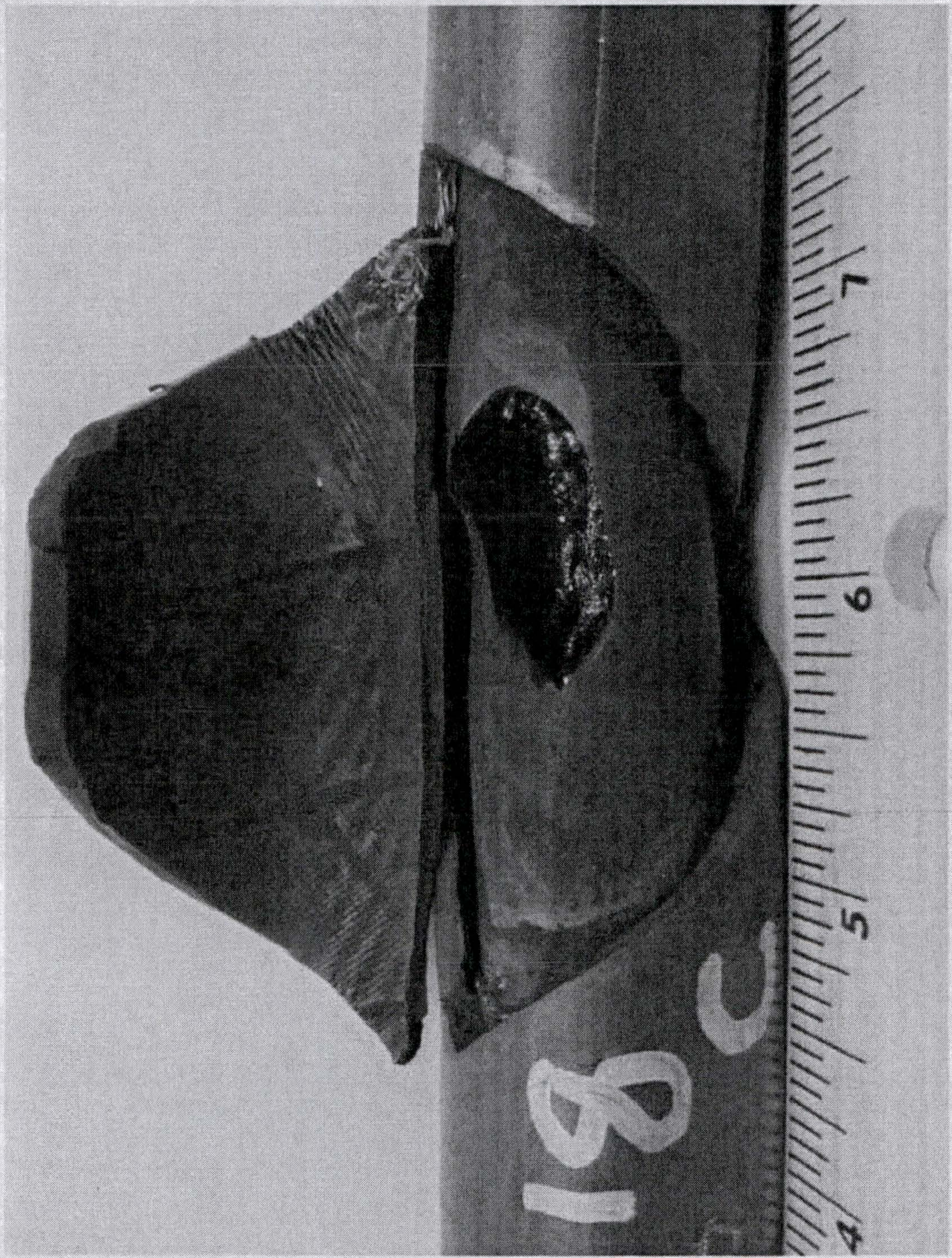
Test 18 A-Phase Cable
CX Configuration With Solidly Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:



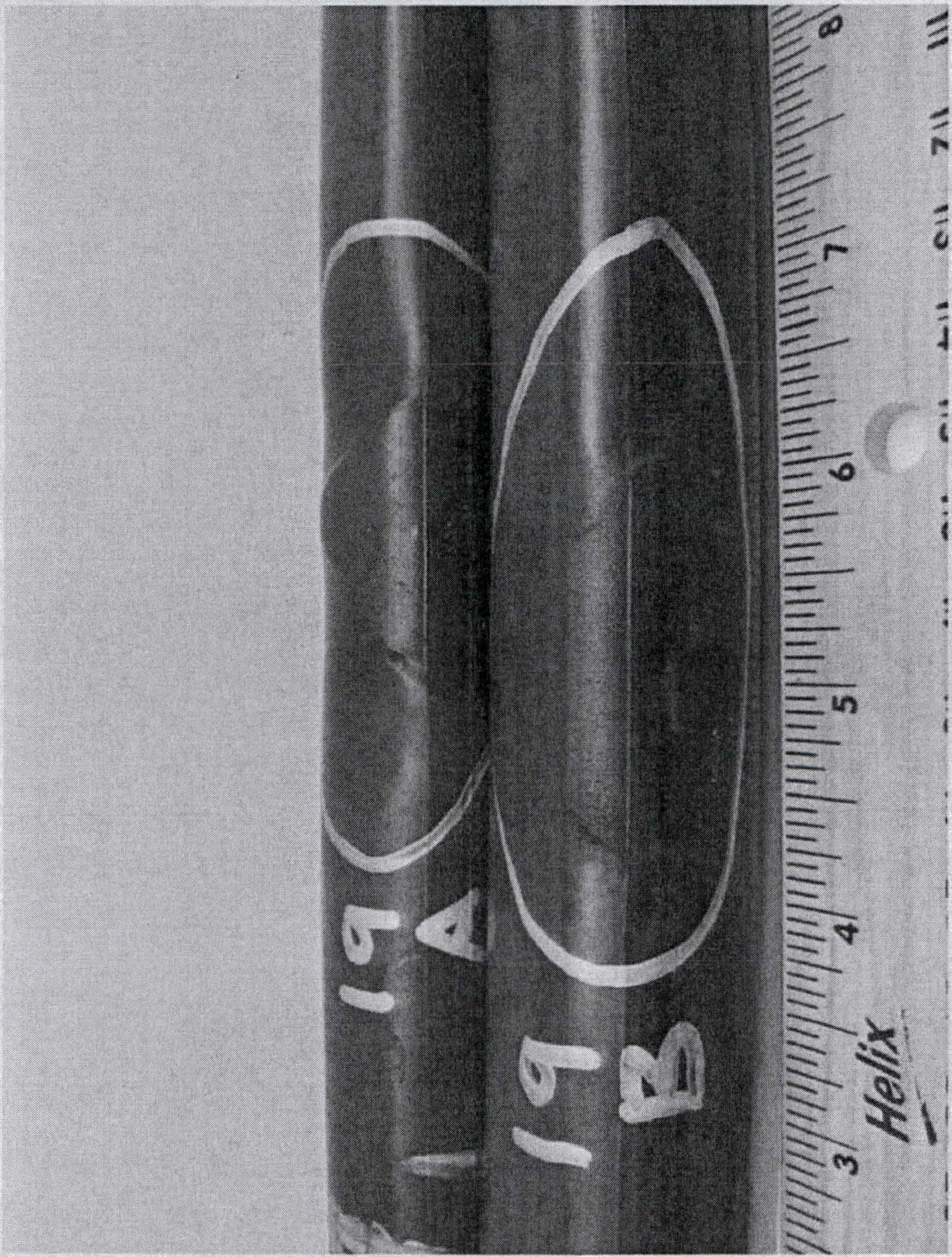
Test 18 B-Phase Cable
CX Configuration With Solidly Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:



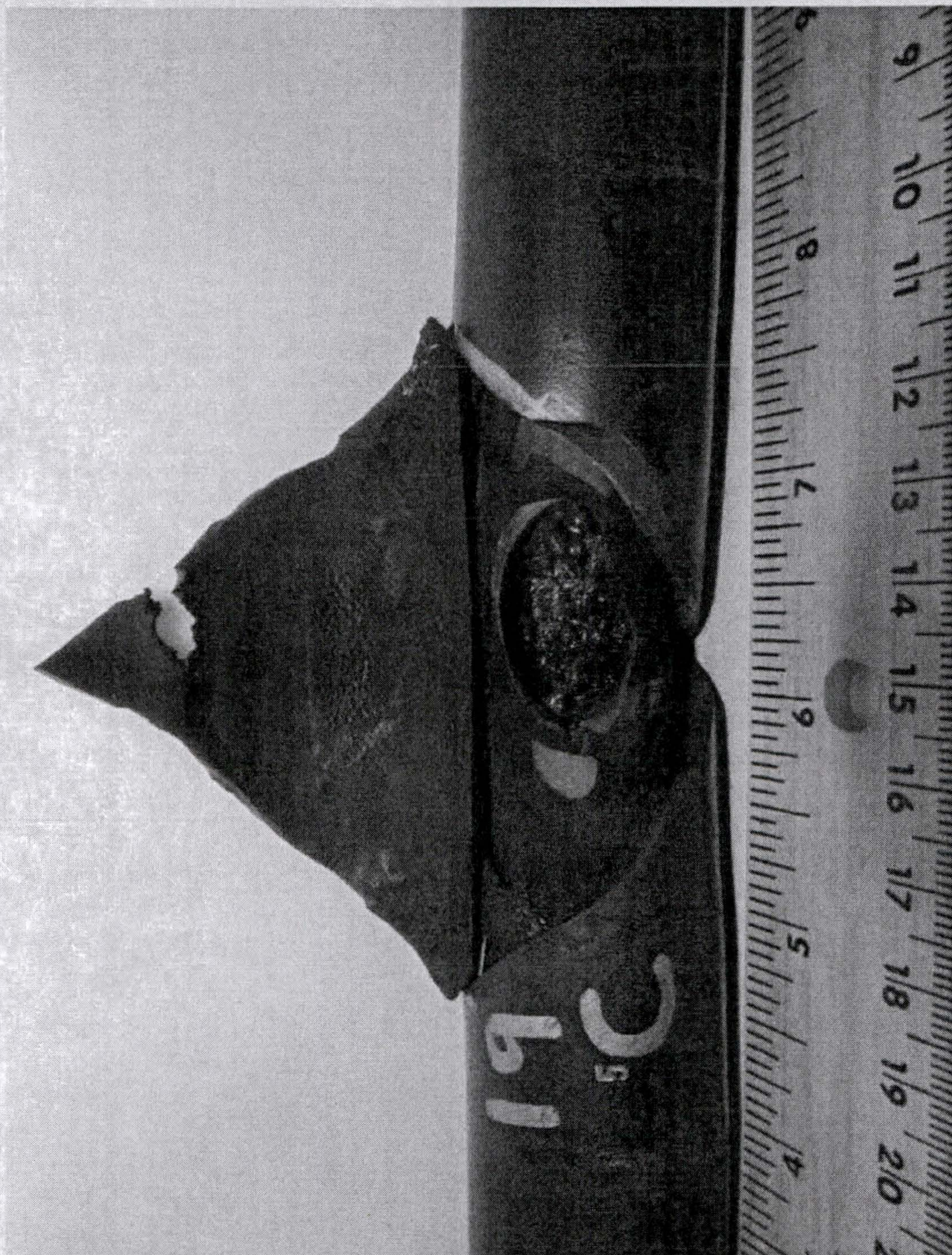
Test 18 C-Phase Cable
CX Configuration With Solidly Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:



Test 19 A-Phase and B-Phase Cables
CX Configuration With Solidly Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:



Test 19 C-Phase Cable
CX Configuration With Solidly Grounded Power Source

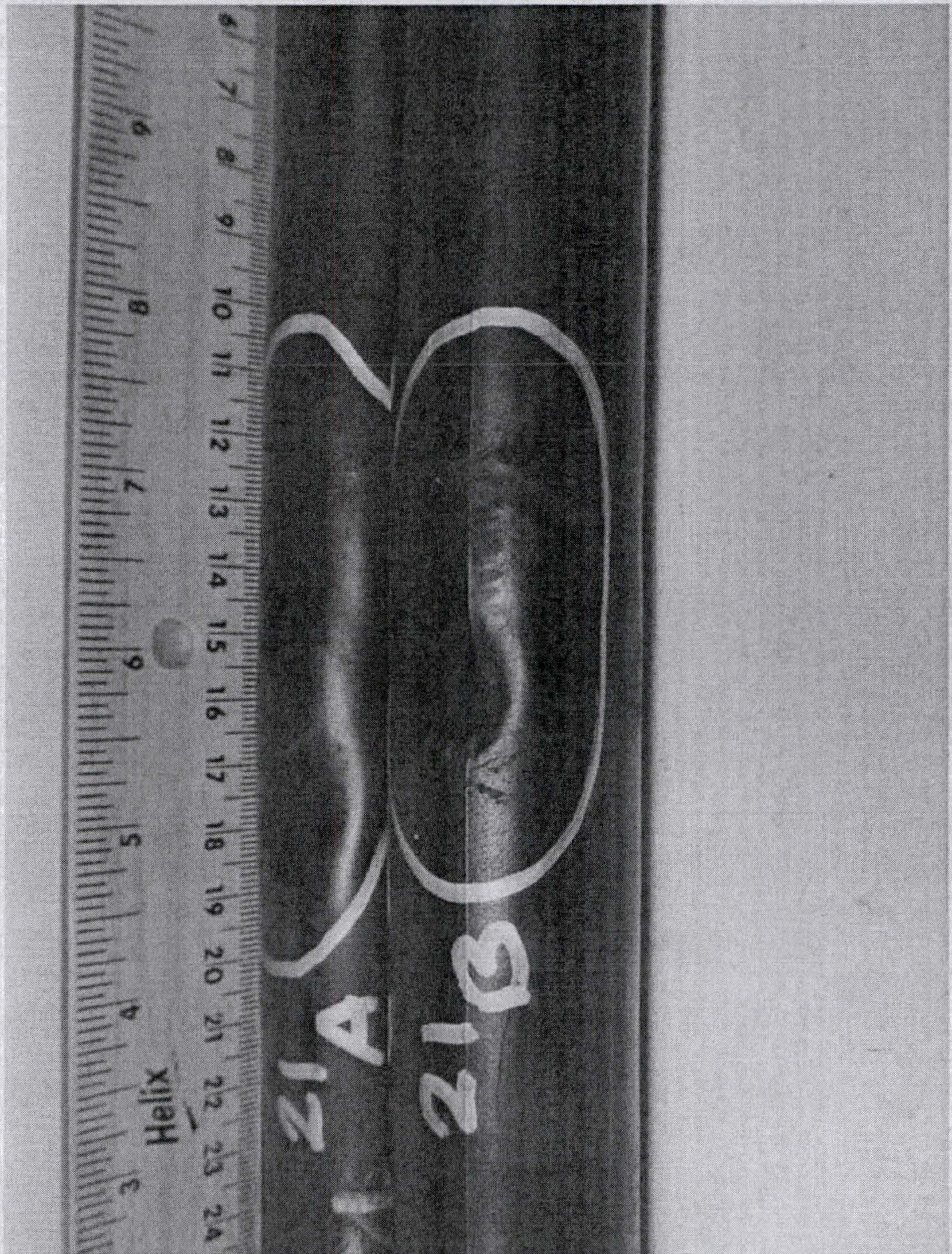
21.3. KEMA Post-Test Cable Photographs:

Test 20 A-Phase and B-Phase Cables
CX Configuration With Solidly Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:

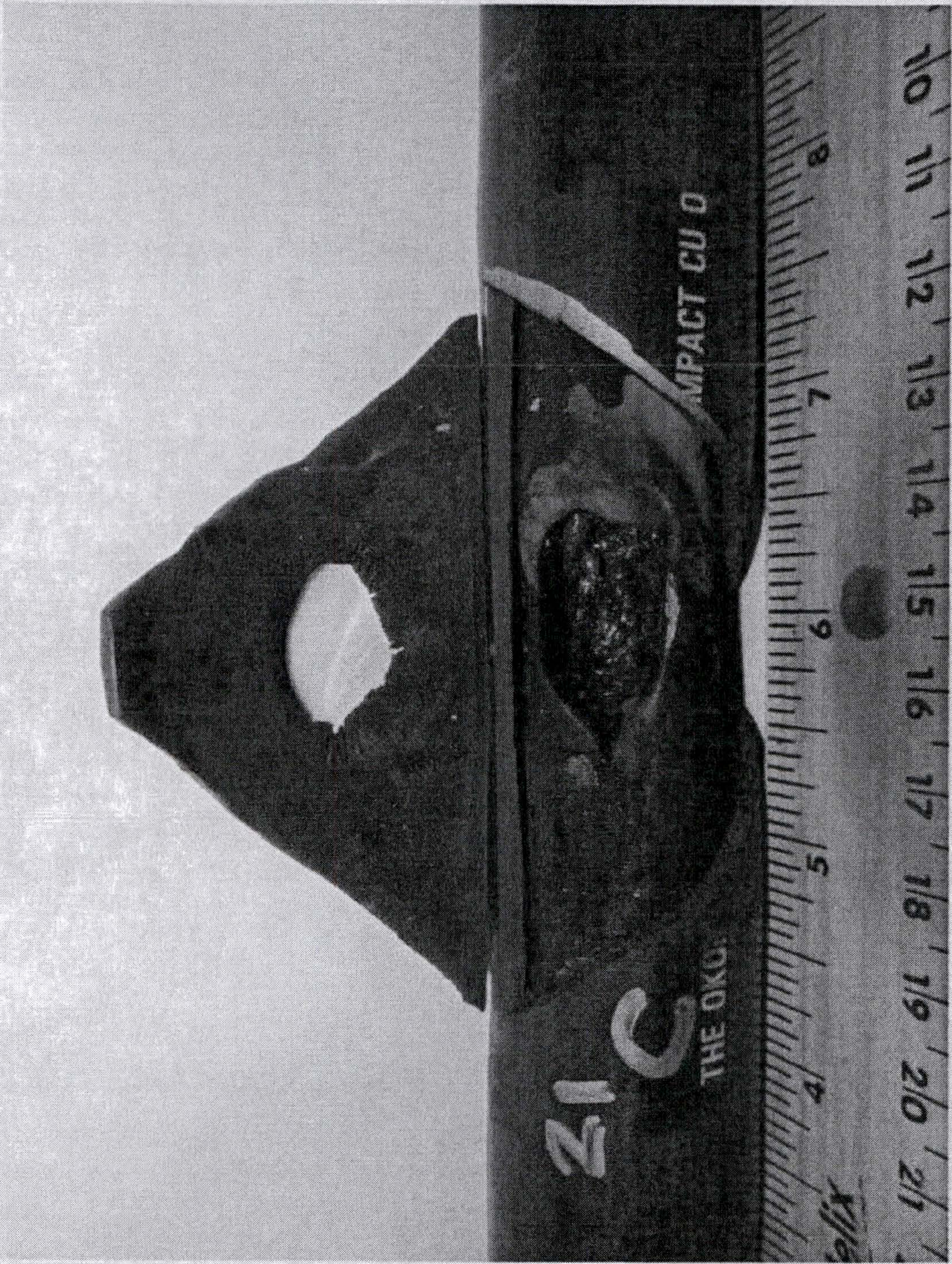
Test 20 C-Phase Cable
CX Configuration With Solidly Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:



Test 21 A-Phase and B-Phase Cables
CX Configuration With Solidly Grounded Power Source

21.3. KEMA Post-Test Cable Photographs:



Test 21 C-Phase Cable
CX Configuration With Solidly Grounded Power Source

21.4 Test 18 B-Phase VLF/Tan Delta Test Report:

ST2072 WO Task CompleteComment Report

WO Task Complete Comment Report

Report Executed: 1/28/2016 9:38:23 AM

WO NBR	TASK	WO TSK STATUS	START DATE	COMPL DATE	WORK AGAINST		
		NOTES AND COMMENTS				WO COMMT TYPE	LAST UPDATED
20021958	03	FINISHED	12/9/2015	12/9/2015	ONS MSCNI WO0001		
		Reviewed WO 20021958 Task 3 and I agree with the plan for VLF/Tan					12/7/2015
		Delta testing of 250 kcmil cable.					12/7/2015
		Performed Core 4					12/9/2015
		Tested cable per WO instructions. All test results SAT.					12/9/2015
		Bert Spear (responsible engineer) has test results.					12/9/2015
		To see test results use the following path in ONS sections.					12/9/2015
		"\MainTeam 41\Tan Delta Testing"					12/9/2015
		Test name is "KEMA Cable Test Trial 18 Phase B"					12/9/2015
		Workers: B Ricken, W Ramsay, TW Giles					12/9/2015
		NO PRINT				DL	12/9/2015

SQA Qualified Report, Commensurate with SWQL C — Page 1

HVA TD Report Summary
KEMA Cable Test Trial 18 Phase B

Report Information

Cable / Line ID: KEMA Cable Test Trial 18 Phase B
System Used: GH0300.11A006
Test Start: 12/9/2015 10:12:14 AM

Station / Location: ONS
From: N/A **To:** N/A
End Device: N/A
Comment: *Test Cable*

Device Under Test: Cable
DUT Voltage Rating: 5.0 kV
Length: 20ft **Size:** 250MCM
Insulation Type: EPR
Measurement Type: Maintenance
Manufacturer: Okonite

Company: Duke Energy
Operator: B Ricken
Region: South East
Work Order: 20021958-03

Phase A Summary

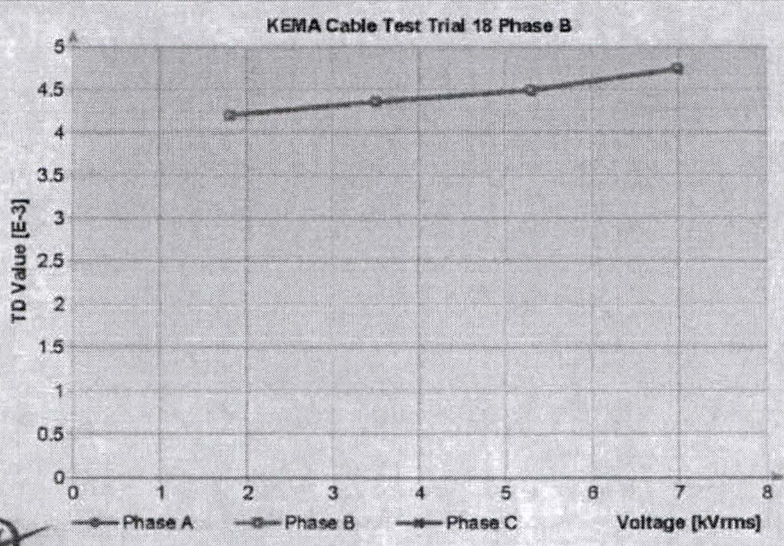
Voltage [kVrms]	-						
TD Value [E-3]	-						
Std. Dev. [%]	-						

Phase B Summary: 0.1 Hz, 2.5 nF

Voltage [kVrms]	1.8	3.5	5.3	7.0			
TD Value [E-3]	4.2	4.4	4.5	4.7			
Std. Dev. [%]	0.00	0.00	0.00	0.00			

Phase C Summary

Voltage [kVrms]	-						
TD Value [E-3]	-						
Std. Dev. [%]	-						



printed with TD Control Center, HV Diagnostics

21.4 Test 18 B-Phase VLF/Tan Delta Test Report:

TD Report for Phase B, KEMA Cable Test Trial 18 Phase B
System used SN: GH0300.11A006

Start 12/9/2015 10:12:14 AM **Phase B**
Mean (13): TD 4.2 E-3, Std.Dev. 0.00 %, 1.8 kVrms, 0.002 mArms, 0.1 Hz, 2 nF

#	TD [E-3]	Voltage [rms]	Current [rms]	Load Cap.	Duration
1	4.2	1.8 kV	0.002 mA	2 nF	0 min
2	4.2	1.8 kV	0.002 mA	2 nF	0 min
3	4.2	1.8 kV	0.002 mA	2 nF	0 min
4	4.2	1.8 kV	0.002 mA	2 nF	0 min
5	4.2	1.8 kV	0.002 mA	2 nF	0 min
6	4.2	1.8 kV	0.002 mA	2 nF	0 min
7	4.2	1.8 kV	0.002 mA	2 nF	1 min
8	4.2	1.8 kV	0.002 mA	2 nF	1 min
9	4.2	1.8 kV	0.002 mA	2 nF	1 min
10	4.2	1.8 kV	0.002 mA	2 nF	1 min
11	4.2	1.8 kV	0.002 mA	2 nF	1 min
12	4.2	1.8 kV	0.002 mA	2 nF	1 min
13	4.2	1.8 kV	0.002 mA	2 nF	2 min

Start 12/9/2015 10:15:40 AM **Phase B**
Mean (11): TD 4.4 E-3, Std.Dev. 0.00 %, 3.5 kVrms, 0.005 mArms, 0.1 Hz, 2 nF

#	TD [E-3]	Voltage [rms]	Current [rms]	Load Cap.	Duration
1	4.3	3.5 kV	0.005 mA	2 nF	0 min
2	4.3	3.5 kV	0.005 mA	2 nF	0 min
3	4.4	3.5 kV	0.005 mA	2 nF	0 min
4	4.3	3.5 kV	0.005 mA	2 nF	0 min
5	4.4	3.5 kV	0.005 mA	2 nF	0 min
6	4.4	3.5 kV	0.005 mA	2 nF	0 min
7	4.4	3.5 kV	0.005 mA	2 nF	1 min
8	4.4	3.5 kV	0.005 mA	2 nF	1 min
9	4.4	3.5 kV	0.005 mA	2 nF	1 min
10	4.4	3.5 kV	0.005 mA	2 nF	1 min
11	4.4	3.5 kV	0.005 mA	2 nF	1 min

Start 12/9/2015 10:18:26 AM **Phase B**
Mean (13): TD 4.5 E-3, Std.Dev. 0.00 %, 5.3 kVrms, 0.008 mArms, 0.1 Hz, 2 nF

#	TD [E-3]	Voltage [rms]	Current [rms]	Load Cap.	Duration
1	4.5	5.3 kV	0.008 mA	2 nF	0 min
2	4.5	5.3 kV	0.008 mA	2 nF	0 min
3	4.5	5.3 kV	0.008 mA	2 nF	0 min
4	4.5	5.3 kV	0.008 mA	2 nF	0 min
5	4.5	5.3 kV	0.008 mA	2 nF	0 min
6	4.5	5.3 kV	0.008 mA	2 nF	0 min
7	4.5	5.3 kV	0.008 mA	2 nF	1 min
8	4.5	5.3 kV	0.008 mA	2 nF	1 min
9	4.5	5.3 kV	0.008 mA	2 nF	1 min
10	4.5	5.3 kV	0.008 mA	2 nF	1 min
11	4.5	5.3 kV	0.008 mA	2 nF	1 min
12	4.5	5.3 kV	0.008 mA	2 nF	1 min
13	4.5	5.3 kV	0.008 mA	2 nF	2 min

21.4 Test 18 B-Phase VLF/Tan Delta Test Report:

TD Report for Phase B, KEMA Cable Test Trial 18 Phase B (continued) Page 4 of 7

Start 12/9/2015 10:21:32 AM **Phase B**

Mean (176): TD 4.7 E-3, Std.Dev. 0.00 %, 7.0 kVrms, 0.010 mArms, 0.1 Hz, 2 nF

#	TD [E-3]	Voltage [rms]	Current [rms]	Load Cap.	Duration
1	4.6	7.0 kV	0.010 mA	2 nF	0 min
2	4.6	7.0 kV	0.010 mA	2 nF	0 min
3	4.7	7.0 kV	0.010 mA	2 nF	0 min
4	4.6	7.0 kV	0.010 mA	2 nF	0 min
5	4.7	7.0 kV	0.010 mA	2 nF	0 min
6	4.7	7.0 kV	0.010 mA	2 nF	0 min
7	4.7	7.0 kV	0.010 mA	2 nF	1 min
8	4.7	7.0 kV	0.010 mA	2 nF	1 min
9	4.7	7.0 kV	0.010 mA	2 nF	1 min
10	4.7	7.0 kV	0.010 mA	2 nF	1 min
11	4.7	7.0 kV	0.010 mA	2 nF	1 min
12	4.7	7.0 kV	0.010 mA	2 nF	1 min
13	4.7	7.0 kV	0.010 mA	2 nF	2 min
14	4.7	7.0 kV	0.010 mA	2 nF	2 min
15	4.7	7.0 kV	0.010 mA	2 nF	2 min
16	4.7	7.0 kV	0.010 mA	2 nF	2 min
17	4.7	7.0 kV	0.010 mA	2 nF	2 min
18	4.7	7.0 kV	0.010 mA	2 nF	2 min
19	4.7	7.0 kV	0.010 mA	2 nF	3 min
20	4.7	7.0 kV	0.010 mA	2 nF	3 min
21	4.7	7.0 kV	0.010 mA	2 nF	3 min
22	4.7	7.0 kV	0.010 mA	2 nF	3 min
23	4.7	7.0 kV	0.010 mA	2 nF	3 min
24	4.7	7.0 kV	0.010 mA	2 nF	3 min
25	4.7	7.0 kV	0.010 mA	2 nF	4 min
26	4.7	7.0 kV	0.010 mA	2 nF	4 min
27	4.7	7.0 kV	0.010 mA	2 nF	4 min
28	4.7	7.0 kV	0.010 mA	2 nF	4 min
29	4.7	7.0 kV	0.010 mA	2 nF	4 min
30	4.7	7.0 kV	0.010 mA	2 nF	4 min
31	4.7	7.0 kV	0.010 mA	2 nF	5 min
32	4.7	7.0 kV	0.010 mA	2 nF	5 min
33	4.7	7.0 kV	0.010 mA	2 nF	5 min
34	4.7	7.0 kV	0.010 mA	2 nF	5 min
35	4.7	7.0 kV	0.010 mA	2 nF	5 min
36	4.8	7.0 kV	0.010 mA	2 nF	5 min
37	4.7	7.0 kV	0.010 mA	2 nF	6 min
38	4.7	7.0 kV	0.010 mA	2 nF	6 min
39	4.7	7.0 kV	0.010 mA	2 nF	6 min
40	4.7	7.0 kV	0.010 mA	2 nF	6 min
41	4.7	7.0 kV	0.010 mA	2 nF	6 min
42	4.7	7.0 kV	0.010 mA	2 nF	6 min
43	4.7	7.0 kV	0.010 mA	2 nF	7 min
44	4.7	7.0 kV	0.010 mA	2 nF	7 min
45	4.7	7.0 kV	0.010 mA	2 nF	7 min
46	4.7	7.0 kV	0.010 mA	2 nF	7 min
47	4.7	7.0 kV	0.010 mA	2 nF	7 min
48	4.7	7.0 kV	0.010 mA	2 nF	7 min
49	4.7	7.0 kV	0.010 mA	2 nF	8 min
50	4.7	7.0 kV	0.010 mA	2 nF	8 min
51	4.7	7.0 kV	0.010 mA	2 nF	8 min
52	4.7	7.0 kV	0.010 mA	2 nF	8 min
53	4.7	7.0 kV	0.010 mA	2 nF	8 min
54	4.7	7.0 kV	0.010 mA	2 nF	8 min
55	4.7	7.0 kV	0.010 mA	2 nF	9 min

21.4 Test 18 B-Phase VLF/Tan Delta Test Report:

TD Report for Phase B, KEMA Cable Test Trial 18 Phase B (continued)

56	4.7	7.0 kV	0.010 mA	2 nF	9 min
57	4.7	7.0 kV	0.010 mA	2 nF	9 min
58	4.7	7.0 kV	0.010 mA	2 nF	9 min
59	4.7	7.0 kV	0.010 mA	2 nF	9 min
60	4.8	7.0 kV	0.010 mA	2 nF	9 min
61	4.8	7.0 kV	0.010 mA	2 nF	10 min
62	4.8	7.0 kV	0.010 mA	2 nF	10 min
63	4.8	7.0 kV	0.010 mA	2 nF	10 min
64	4.7	7.0 kV	0.010 mA	2 nF	10 min
65	4.8	7.0 kV	0.010 mA	2 nF	10 min
66	4.8	7.0 kV	0.010 mA	2 nF	10 min
67	4.7	7.0 kV	0.010 mA	2 nF	11 min
68	4.7	7.0 kV	0.010 mA	2 nF	11 min
69	4.7	7.0 kV	0.010 mA	2 nF	11 min
70	4.7	7.0 kV	0.010 mA	2 nF	11 min
71	4.7	7.0 kV	0.010 mA	2 nF	11 min
72	4.7	7.0 kV	0.010 mA	2 nF	11 min
73	4.7	7.0 kV	0.010 mA	2 nF	12 min
74	4.7	7.0 kV	0.010 mA	2 nF	12 min
75	4.7	7.0 kV	0.010 mA	2 nF	12 min
76	4.7	7.0 kV	0.010 mA	2 nF	12 min
77	4.7	7.0 kV	0.010 mA	2 nF	12 min
78	4.8	7.0 kV	0.010 mA	2 nF	12 min
79	4.8	7.0 kV	0.010 mA	2 nF	13 min
80	4.7	7.0 kV	0.010 mA	2 nF	13 min
81	4.7	7.0 kV	0.010 mA	2 nF	13 min
82	4.8	7.0 kV	0.010 mA	2 nF	13 min
83	4.7	7.0 kV	0.010 mA	2 nF	13 min
84	4.7	7.0 kV	0.010 mA	2 nF	13 min
85	4.7	7.0 kV	0.010 mA	2 nF	14 min
86	4.7	7.0 kV	0.010 mA	2 nF	14 min
87	4.7	7.0 kV	0.010 mA	2 nF	14 min
88	4.7	7.0 kV	0.010 mA	2 nF	14 min
89	4.7	7.0 kV	0.010 mA	2 nF	14 min
90	4.8	7.0 kV	0.010 mA	2 nF	14 min
91	4.8	7.0 kV	0.010 mA	2 nF	15 min
92	4.8	7.0 kV	0.010 mA	2 nF	15 min
93	4.8	7.0 kV	0.010 mA	2 nF	15 min
94	4.8	7.0 kV	0.010 mA	2 nF	15 min
95	4.7	7.0 kV	0.010 mA	2 nF	15 min
96	4.7	7.0 kV	0.010 mA	2 nF	15 min
97	4.7	7.0 kV	0.010 mA	2 nF	16 min
98	4.7	7.0 kV	0.010 mA	2 nF	16 min
99	4.8	7.0 kV	0.010 mA	2 nF	16 min
100	4.8	7.0 kV	0.010 mA	2 nF	16 min
101	4.8	7.0 kV	0.010 mA	2 nF	16 min
102	4.8	7.0 kV	0.010 mA	2 nF	16 min
103	4.8	7.0 kV	0.010 mA	2 nF	17 min
104	4.7	7.0 kV	0.010 mA	2 nF	17 min
105	4.8	7.0 kV	0.010 mA	2 nF	17 min
106	4.8	7.0 kV	0.010 mA	2 nF	17 min
107	4.8	7.0 kV	0.010 mA	2 nF	17 min
108	4.8	7.0 kV	0.010 mA	2 nF	17 min
109	4.8	7.0 kV	0.010 mA	2 nF	18 min
110	4.8	7.0 kV	0.010 mA	2 nF	18 min
111	4.8	7.0 kV	0.010 mA	2 nF	18 min
112	4.8	7.0 kV	0.010 mA	2 nF	18 min
113	4.8	7.0 kV	0.010 mA	2 nF	18 min

21.4 Test 18 B-Phase VLF/Tan Delta Test Report:

TD Report for Phase B, KEMA Cable Test Trial 18 Phase B (continued)

114	4.8	7.0 kV	0.010 mA	2 nF	18 min
115	4.8	7.0 kV	0.010 mA	2 nF	19 min
116	4.8	7.0 kV	0.010 mA	2 nF	19 min
117	4.8	7.0 kV	0.010 mA	2 nF	19 min
118	4.8	7.0 kV	0.010 mA	2 nF	19 min
119	4.8	7.0 kV	0.010 mA	2 nF	19 min
120	4.8	7.0 kV	0.010 mA	2 nF	19 min
121	4.8	7.0 kV	0.010 mA	2 nF	20 min
122	4.8	7.0 kV	0.010 mA	2 nF	20 min
123	4.8	7.0 kV	0.010 mA	2 nF	20 min
124	4.8	7.0 kV	0.010 mA	2 nF	20 min
125	4.8	7.0 kV	0.010 mA	2 nF	20 min
126	4.8	7.0 kV	0.010 mA	2 nF	20 min
127	4.8	7.0 kV	0.010 mA	2 nF	21 min
128	4.8	7.0 kV	0.010 mA	2 nF	21 min
129	4.8	7.0 kV	0.010 mA	2 nF	21 min
130	4.8	7.0 kV	0.010 mA	2 nF	21 min
131	4.8	7.0 kV	0.010 mA	2 nF	21 min
132	4.8	7.0 kV	0.010 mA	2 nF	21 min
133	4.8	7.0 kV	0.010 mA	2 nF	22 min
134	4.8	7.0 kV	0.010 mA	2 nF	22 min
135	4.8	7.0 kV	0.010 mA	2 nF	22 min
136	4.8	7.0 kV	0.010 mA	2 nF	22 min
137	4.8	7.0 kV	0.010 mA	2 nF	22 min
138	4.8	7.0 kV	0.010 mA	2 nF	22 min
139	4.8	7.0 kV	0.010 mA	2 nF	23 min
140	4.8	7.0 kV	0.010 mA	2 nF	23 min
141	4.8	7.0 kV	0.010 mA	2 nF	23 min
142	4.8	7.0 kV	0.010 mA	2 nF	23 min
143	4.8	7.0 kV	0.010 mA	2 nF	23 min
144	4.8	7.0 kV	0.010 mA	2 nF	23 min
145	4.8	7.0 kV	0.010 mA	2 nF	24 min
146	4.8	7.0 kV	0.010 mA	2 nF	24 min
147	4.8	7.0 kV	0.010 mA	2 nF	24 min
148	4.8	7.0 kV	0.010 mA	2 nF	24 min
149	4.8	7.0 kV	0.010 mA	2 nF	24 min
150	4.8	7.0 kV	0.010 mA	2 nF	24 min
151	4.8	7.0 kV	0.010 mA	2 nF	25 min
152	4.8	7.0 kV	0.010 mA	2 nF	25 min
153	4.8	7.0 kV	0.010 mA	2 nF	25 min
154	4.8	7.0 kV	0.010 mA	2 nF	25 min
155	4.8	7.0 kV	0.010 mA	2 nF	25 min
156	4.8	7.0 kV	0.010 mA	2 nF	25 min
157	4.8	7.0 kV	0.010 mA	2 nF	26 min
158	4.8	7.0 kV	0.010 mA	2 nF	26 min
159	4.8	7.0 kV	0.010 mA	2 nF	26 min
160	4.8	7.0 kV	0.010 mA	2 nF	26 min
161	4.8	7.0 kV	0.010 mA	2 nF	26 min
162	4.8	7.0 kV	0.010 mA	2 nF	26 min
163	4.8	7.0 kV	0.010 mA	2 nF	27 min
164	4.8	7.0 kV	0.010 mA	2 nF	27 min
165	4.8	7.0 kV	0.010 mA	2 nF	27 min
166	4.8	7.0 kV	0.010 mA	2 nF	27 min
167	4.8	7.0 kV	0.010 mA	2 nF	27 min
168	4.8	7.0 kV	0.010 mA	2 nF	27 min
169	4.8	7.0 kV	0.010 mA	2 nF	28 min
170	4.8	7.0 kV	0.010 mA	2 nF	28 min
171	4.8	7.0 kV	0.010 mA	2 nF	28 min

21.4 Test 18 B-Phase VLF/Tan Delta Test Report:

TD Report for Phase B, KEMA Cable Test Trial 18 Phase B (continued)

172	4.8	7.0 kV	0.010 mA	2 nF	28 min
173	4.8	7.0 kV	0.010 mA	2 nF	28 min
174	4.8	7.0 kV	0.010 mA	2 nF	28 min
175	4.8	7.0 kV	0.010 mA	2 nF	29 min
176	4.8	7.0 kV	0.010 mA	2 nF	29 min

ATTACHMENT 3C

Associated with Response to RAI 3(a)

Attachment 6

MPR

January 7, 2016
0079-0191-LTR-002, Rev. 0

Alex Norwood
Duke Energy – Oconee Nuclear Station
155 East Pickens Highway
Seneca, SC 29672

Subject: Induced Control Cable Voltage During a Medium Voltage Short Circuit Event

Dear Mr. Norwood:

Oconee Nuclear Station (ONS) requested that MPR estimate the differential voltage induced on a control cable located in the vicinity of a medium voltage cable during a medium voltage short circuit event. The purpose of this letter is to summarize our work and submit the supporting calculations developed by MPR for this effort.

Our analysis indicates that the differential voltage induced on a galvanized steel interlocked armor (GSIA) control cable conductor pair is less than one volt for the analysis conditions specified by ONS. The analysis considered a 300 foot length of medium voltage cable running parallel with a low voltage control cable bundle in an embedded duct separated by a minimum distance of 3". The short circuit fault current considered was a 16,000 Amp-peak line to ground short circuit.

This differential voltage estimate includes several known conservatisms, including use of the most limiting cable separation (set to minimum allowable by the duct geometry) and intra-cable bundle low voltage conductor separation (set to the maximum allowable by the cable bundle diameter), neglecting control conductor helical twist along the length of the cable (has the effect of canceling magnetic coupling), and a conservatively high line-ground fault current (16,000 Amps-peak).

MPR prepared two calculations in support of this effort. The first calculation (0079-0191-CALC-003, Enclosure 1) uses finite element modeling of the control cable bundle and the medium voltage cables to estimate the magnetic field shielding effectiveness of the control cable GSIA. The shielding effectiveness is defined as the ratio of the maximum magnitude of the magnetic field within the control cable bundle due to the medium voltage cable fault current with and without the GSIA present. See Figure 1 and Figure 2 for the calculated magnetic field within the control cable bundle due to the medium voltage short circuit for the armored cable. See Figure 3 and Figure 4 for the calculated magnetic field within the control cable bundle due to the medium voltage short circuit for the un-armored cable.

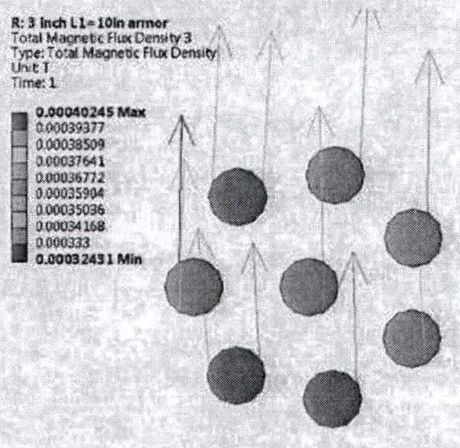


Figure 1. Control Cable B Field - Armored

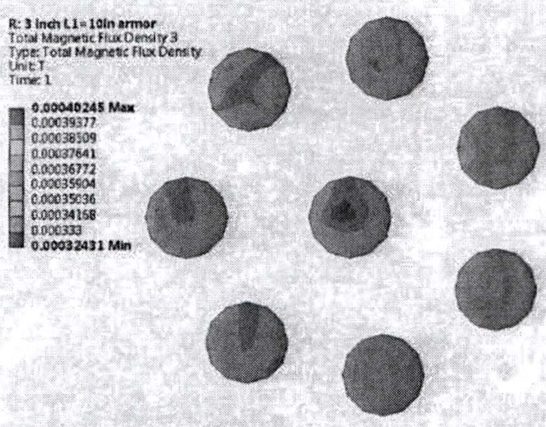


Figure 2. Control Cable B Field - Armored

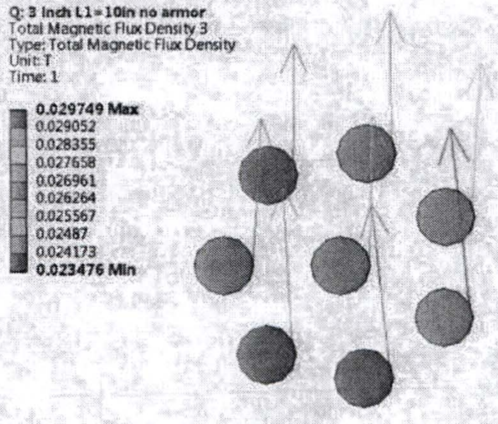


Figure 3. Control Cable B Field - No Armor

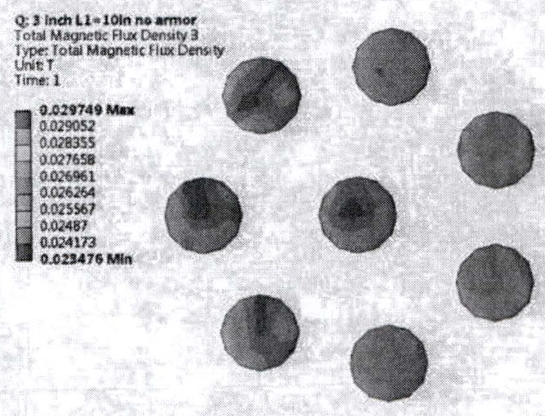


Figure 4. Control Cable B Field - No Armor

The finite element analysis results were compared against a simple theoretical case to validate the analysis results. Appendix B of 0079-0191-CALC-003 documents this comparison and shows good correlation between expected results and achieved results.

The second calculation prepared by MPR (0079-0191-CALC-002, Enclosure 2) determines the differential control cable load voltage induced by the medium voltage fault current. The load voltage function is dependent on the fault current, the overall control cable length, the length of the parallel control and faulted medium voltage cables, the separation between the medium voltage and control cable pair, and the separation of the control cable pairs. The load voltage calculation uses the partial self and mutual inductance method for determining the interaction between the medium voltage and control circuit cable bundle. The calculation relies heavily upon methods originally developed by Edward Rosa (Volume 4, Number 2, Bulletin of the

Bureau of Standards, *The Self and Mutual Inductances of Linear Conductors*) and summarized more recently by Clayton Paul in IEEE EMC Society Magazine (Enclosure 3).

MPR notes that the differential voltage calculation has not been validated against test data. However, applying the load voltage function to test results from the MV short circuit testing performed by ONS can provide an order of magnitude validation estimate. The load voltage function developed in 0079-0191-CALC-002 estimates less than one millivolt would be induced in a control cable pair routed adjacent to a medium voltage cable for test conditions similar to those described in the draft KEMA-Powertest LLC Test Report 15208-B, *Short Circuit Withstand Duke Energy 750KCMIL & 250 KCMIL Cables*. This voltage (i.e. near zero) is consistent with ONS personnel reports that no change in differential voltage was observed during the testing.

Please do not hesitate to contact me with any questions on this letter or its enclosures.

Sincerely,

Brian Curran

Enclosures:

1. MPR Calculation 0079-0191-CALC-003, *Finite Element Analysis to Calculate Shielding Effectiveness*. Revision 0.
2. MPR Calculation 0079-0191-CALC-002, *Induced Differential Voltage in Control Cables*. Revision 0.
3. Article by Clayton R. Paul, "Partial Inductance." IEEE EMC Society Magazine. 2010.