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Subject: Duke Energy Carolinas, LLC
Oconee Nuclear Station,
Docket Nos. 50-269, 50-270 and 50-287
Supplemental Information on TIA 2014-05, Potential Unanalyzed Condition Associated with Emergency Power System

References:

1. Oconee Nuclear Station - NRC Component Design Bases Inspection Report 05000269/2014007, 05000270/2014007, and 05000287/2014007, dated June 27, 2014 (ML14178A535).
2. Letter from Duke Energy (Scott Batson) to USNRC (Document Control Desk), "TIA 2014-05, Potential Unanalyzed Condition Associated with Emergency Power System," dated May 11, 2015 (ML15139A049).

The purpose of this letter is to supplement information provided by Duke Energy Carolinas (Duke Energy) in its May 11, 2015, letter (Reference 2) to the Nuclear Regulatory Commission (NRC). The focus of the May 11, 2015, letter was to provide additional Oconee licensing basis information associated with the 2014 Component Design Basis Inspection (CDBI) Unresolved Item that might not be readily available to NRC reviewers. Attachment 1 to the May 11, 2015, letter, "Review of the Design and Installation of Medium and Low Voltage Cables in Trench 3 at Oconee Nuclear Station," described the Oconee licensing basis. Duke Energy also provided Attachment 1 to summarize for the NRC, Oconee's licensing basis, which spans over 40 years of operation and includes numerous plant modifications, including the emergency power system cable configurations that are the subject of the TIA. Included in Attachment 1 was a comparison of the Oconee Trench 3 cable configuration to the Oconee licensing basis and to various NRC documents pertinent to cable design and cable faults. A key point made in the attachment is the difference between the Oconee single failure licensing basis and the single failure licensing requirements that currently exist but are not applicable to Oconee.

Attachment 2 (to Reference 2), "UL 1569 Impact and Crush Tests on Keowee Underground Trench Power Cables," provided the results of the cable armor testing conducted at the Okonite Company's High Voltage Laboratory in Paterson, New Jersey. This testing, performed in Spring 2015, confirmed the mechanical properties of the bronze tape shielded 13.8 kVac emergency power cables installed in Trench 3. More importantly, the testing demonstrated that the cable configuration with bronze tape shield provides adequate mechanical protection to perform as

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armored cable per Underwriters Laboratory Test 1569, Sections 24, 25, and 26. It is noteworthy that, during cable testing, there were no instances where electrical continuity between the cable conductor(s) and the metallic shield occurred.

Based on Oconee relevant licensing basis documents, cable testing results provided in Attachment 2 to Reference 2, the properties of the Keowee generator impedance grounding system, and the Operability Determination conducted for the Trench 3 configuration, Attachment 1 to Reference 2 concluded that the Trench 3 cables are capable of performing their intended functions and comply with the Oconee licensing basis.

During the week of July 7, 2015, an Office of Nuclear Reactor Regulation (NRR) Peer Review Team visited Oconee to conduct plant walkdowns and to review the Oconee design and licensing basis with respect to the TIA. As a part of this visit, Duke Energy held detailed discussions with the NRC team on plant design and licensing basis issues. NRC feedback to Duke during the discussions revealed that, during their visit, the NRC was provided new information of which they were previously not aware. Therefore, Duke Energy is supplementing the May 11, 2015, letter with the information provided herein to ensure the NRC has the pertinent facts and relevant information to support NRC development of the TIA.

Attachment 1 to this letter provides the following additional information to the May 11, 2015, Duke Energy submittal:

- A discussion of the Duke Power Company fleet design process with respect to the generic approach taken regarding cable separation and the impact of cable armor on fault propagation. This approach included the use of cable armoring to provide excellent prevention of cable to cable faults or failures.
- A discussion of how Oconee design is consistent with plant licensing basis. This supplements the information provided in Reference 2, Attachment 1 and provides the history of the licensing basis relevant to the TIA beginning with the construction permit preliminary safety analysis report (PSAR). It mirrors the information discussed with the NRR Peer Review Team on July 7, 2015.
- An outline of the failure sequence necessary to damage DC circuits. A cable fault occurs as a result of the failure of the insulation between the conductor and the bronze grounding tape on a single cable. If the fault is going to produce an interaction that will affect the control cables that are on the bottom of the trench, it must propagate to adjacent power cables and/or grounded cable supports. The control cables are routed below the power cables. For the power cable to control cable interaction to occur, the fault would have to bypass the various grounding systems associated with the power cables and control cables and the sequence of events would have to occur before the protective relaying cleared the fault(s).
- A discussion of certain design standards with respect to the Oconee licensing basis. Oconee was issued construction permits for all 3 units before January 1, 1971, and consequently 50.55a(h)(2) only requires that the design of the protection system be in accordance with the licensing basis.
- A discussion of industry operating experience with respect to power cable failures. This discussion outlines the data bases researched, the selection of the incidents that were similar/applicable, and a comparison of the cable design related to the failure with the Oconee design.

There are no new or revised regulatory commitments being made in this submittal.

Should the NRC require any additional information, please contact Chris Wasik, Oconee Regulatory Affairs Manager, at 864-873-5789.

Sincerely,

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Attachment 1- Supplemental Information Related to TIA 2014-05, Potential Unanalyzed Condition Associated with Emergency Power System xc (with attachments):

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Attachment 1

Supplemental Information Related to TIA 2014-05, Potential Unanalyzed Condition Associated with Emergency Power System

The 2014 Oconee Component Design Basis Inspection (CDBI) is documented in the Reference 1 NRC Inspection Report. This report initiated Unresolved Item (URI) 05000269,270,287/2014007-05, Potential Unanalyzed Condition Associated with Emergency Power System, which describes NRC concerns related to the design and installation of 13.8 kVac emergency power cables and 125 Vdc control cables within the Keowee underground concrete raceway system (Trench 3). As noted in the report, Region II has requested assistance from NRR via TIA 2014-05, to review the emergency power system licensing basis to determine the acceptability of the design.

Duke Power Company Design - Cable Separation

Similarity to Other Duke Power Company Plant-related Approvals by the NRC:

Duke Power Company was the Engineer/Constructor for the three Oconee Nuclear Station (ONS) units, as well as for the later units at McGuire Nuclear Station (MNS) and Catawba Nuclear Station (CNS). All three facilities used a similar design philosophy with respect to the use of armored cable to provide adequate cable separation.

ONS Updated Final Safety Analysis Report (UFSAR) Section 8.3.1.4.6.2, "Cable Separation," states, in part:

> "It should be pointed out that the cable armors used provide excellent mechanical and fire protection which would not be provided with conventional, unarmored cable systems. It is our intent wherever physically possible to utilize metallically armored and protected cables systems."

MNS UFSAR Section 8.3.1.4.1.5, "Cable Application and Installation," states, in part:

> "Armored cable which has been demonstrated to be an excellent barrier to externally and internally generated fires is used throughout the plant. Short circuit tests have been conducted on the interlocked armor cable by Duke Energy. These tests have demonstrated its acceptability as an adequate barrier by preventing damage to adjacent cables."

CNS UFSAR Section 8.3.1.4.5.2, "Cable Separation," states, in part:

> "Interlocked armor cable has been demonstrated through short circuit testing conducted by Duke Power Company to provide an adequate barrier for preventing damage to adjacent cables."

The basis of the statements in the MNS and CNS UFSARs regarding short circuit testing is a series of tests documented in a November 8, 1977, Duke Power Company report, *Report of Power and Control Cable Overload and Short Circuit Tests Performed for McGuire Nuclear Station*. This testing was performed by the High Power Laboratory of the Westinghouse Corporation.

A March 22, 1978, Duke Power Company letter to the NRC on the MNS docket stated the following (emphasis added):

> "Testing performed by Duke Power Company at the Westinghouse High Power Laboratory in East Pittsburgh, Pennsylvania demonstrated that adjacent armored cables within the same tray will not be damaged due to short circuiting of the power cables. <u>These test reports have been submitted to the NRC</u> and more than adequately demonstrate that these types of power cables pose no threat to the redundant safety trains."

An August 1, 1978, Duke Power Company letter to the NRC on the MNS docket responded, in part, to NRC questions on the High Power Laboratory testing. The letter states:

> "The test configuration was chosen to be ultraconservative with respect to actual power cable installations. Although power cable trays in the plant are installed above control trays, the power tray was purposely placed between two control trays for this test to increase combustible loading around the faulted cable."

Supplement No. 2, dated March 1, 1979, and Supplement No. 5, dated April, 1981, to the Safety Evaluation Report for the MNS Operating License (NUREG-0422) both state:

> "The applicant has conducted tests which demonstrate that no fire propagation from cable to cable or tray to tray occurs as a result of an electrically initiated fire."

Although the above discussion focuses on MNS, the same design philosophy was used on the ONS design. Oconee was built to Duke Power Company fleet design specifications that were also employed for the design and construction of the newer McGuire and Catawba nuclear power stations; therefore, consideration of the NRC's review of the design of these other Duke plants can inform a review of the Oconee design.

In summary, the testing, performed on interlocked steel armored cable, demonstrates that cable armoring provides excellent prevention of cable to cable faults or failures. While the ONS bronze tape shield/armor cable design configuration was outside of the scope of the 1977 testing, the results of crush testing completed on the ONS 13.8kV cable design provided in the Duke Energy letter dated May 11, 2015, demonstrated that the bronze tape design of the subject 13.8kV power cables provides equivalent mechanical protection as that provided by the armored cable design that is called for in the Duke Power Company design standards used during construction.

Previous NRC Inspection of ONS Specifically Reviewed the Cable Configuration Now At Issue:

ONS NRC Integrated Inspection Report 50-269/01-05, 50-270/01-05 and 50-287/01-05 dated April 29, 2002, documents an inspection of the then new Trench 3 cable installation. The Inspection Report notes the following:

"1R17 <u>Permanent Plant Modifications</u>

a. <u>Inspection Scope</u>

The inspectors evaluated NSM ON-53065 (Replace Underground Power, Auxiliary Power, & Control Cables from Keowee Hydro to Oconee Nuclear Station) to verify that the emergency power system design basis, licensing basis, and performance capability was not degraded due to the modification; and that the modification did not leave the plant in an unsafe condition.

The inspectors walked down the new trench and cables on several occasions during installation to verify that: (1) there was no effect on existing underground power path during installation; (2) the new cables were protected from the effects of external events, including tornados and water intrusion into the trench; (3) the ampere rating of the new cables met design requirements of the modification; and (4) there were no unintended interactions.

The inspectors observed post-modification testing to verify that no cable damage was done during installation or termination and that proper voltage and phase rotation was available after installation (i.e., the cables were not crossed)."

"b. Findings

No findings of significance were identified."

Based on the above-referenced inspection, Duke Energy reasonably relied on the acceptability of the current design and its consistency with the ONS licensing and design basis.

Compliance with the Oconee Licensing Basis

Armor as Separation

While physical separation (distance) is considered a reliable method of providing circuit separation and isolation, cable armoring has historically been an integral component of Oconee's design strategy. The Oconee licensing documentation has consistently credited the combination of a robust cabling system and defense-in-depth approach to power source availability [redundant power sources] to meet the requirements of the Oconee license. In a December 22, 1970 letter to the Atomic Energy Commission (AEC), Duke reiterated that "it is our intent wherever physically possible to utilize metallically armored and protected cable systems." This statement has existed in the ONS FSAR since Revision 4 and was present at initial licensing. NRC awareness of the use and benefit of cable armoring is evidenced by statements within Duke/NRC correspondence (e.g., "the cable armors used provide excellent mechanical and fire protection which would not be provided with conventional, unarmored cable systems," "[t]he applicant is taking credit for armor on cables as barrier," and the "Safety significance of running two cables in the same tray was mitigated by a unique design feature at Oconee of installing cable in armored jackets"). Context for these examples is provided in the licensing excerpts cited below.

Cable installation and routing requirements are documented in the ONS Updated Final Safety Analysis Report (UFSAR), OSS-0218.00-00-0019, "Cable and Wiring Separation Criteria," and Design Criteria (DC) 3.13 "Oconee Nuclear Station Cable and Wiring Separation Criteria." These requirements are based on the use of armored cable. Most recently, DC 3.13 was provided as the basis for cable separation in Duke Energy submittals associated with NFPA 805, Protected Service Water (PSW), and Tornado/HELB submittals. The installation of the cabling within the trench adheres to these specifications that reflect the UFSAR requirements. Duke Energy's position has been and continues to be that the current design configuration meets the design and licensing requirements for cable routing and cable separation at Oconee and will not create a condition that impacts the ability of the emergency power system to perform its intended function.

Routing of Control and Power Cables

An abbreviated chronology of correspondence related to the role of cable armor at ONS, which highlights NRC awareness of the subject configuration since initial licensing as it relates to separation, and supplemental information on Oconee's single failure criteria are provided below. Additionally, key interactions that shape the Oconee license, including single failure discussions, are included in the timeline below. The information is generally presented in chronological order followed by a summary of industry guidance. PSAR/FSAR Chapters 7 and 8 are highlighted to compare and contrast how the single failure requirements and IEEE-279 discussions in these two sections are presented in the licensing history.

December 31, 1967 Preliminary Safety Analysis Report

PSAR Section 7.1.1.2.3:

"Redundant protective channels and their associated elements shall be electrically independent and packaged to provide physical separation."

PSAR Section 8.2.2.9, "Evaluation of the Physical Layout, Electrical Distribution System Equipment," part (e) states:

"The application and routing of control, instrumentation and power cables will be such as to minimize their vulnerability to damage from any source. All cables will be applied using conservative margins with respect to their current carrying capacities, insulation properties and mechanical construction. Cable insulations in the Reactor Building will be selected so as to minimize the harmful effects of radiation, heat and humidity. Appropriate instrumentation cables will be shielded to minimize induced voltage and magnetic interference. Wire and cables related to engineered safeguards and reactor protective systems will be routed and installed in such manner as to maintain the integrity of their respective redundant channels and protect them from physical damage."

On February 13, 1970, the Atomic Energy Commission's (AEC's) Division of Reactor Licensing (DRL) sent a letter to Duke requesting additional information on numerous sections of the FSAR as part of their ongoing operating license review. Part 7.3 of this request questioned the level of detail in the FSAR on the installation of the reactor protection systems and is copied in part below.

"Submit your cable installation design criteria for independence of redundant RPS and ESF circuits (instrumentation, control and power). (The protection system circuits should be interpreted to include all sensors, instrument cables, control cables, power cables, and the actuated devices, e.g., breakers, valves, pumps.) Include the following:

(a) Separation of power cables from control and instrument cables. (Describe any intermixing within a tray --- conduit, ladder, etc.-- of control and instrument cables, of different protection channel cables, or of nonprotection cables with protection cables.)
(b) State how your design accomplishes separation of electrical penetration assemblies within the penetration rooms into areas, grouping of these assemblies in each area, and the separation of assemblies with mutually redundant circuits.
(c) Describe cable tray loading, insulation, derating, and overload protection for the various categories of cables.
(d) Describe your design with respect to fire stops, protection of cables in hostile environments, temperature monitoring of cables, fire detection, and cable and wireway markings."

On April 20, 1970, Duke responded to the AEC's request. The Duke letter included FSAR Supplement 1 (part of FSAR Revision No. 4) which detailed a listing of FSAR sections and the corresponding questions they answered. Question 7.3, answered by FSAR Rev 4, changes included the following:

FSAR Section 7.1.2.3.5 stated

"Located under the control rooms between the outside of the reactor buildings and the cable and equipment rooms, four separate trays are provided per unit which carry nothing but nuclear, RPS and ES instrumentation cables. Three separate routes are followed by these trays...

...Equipment locations in the auxiliary building provide the basis for vertical arrangement of trays following the same route from the reactor buildings. Switchgear for power equipment is located at lower elevations and instrumentation cabinets are located at higher elevations. Therefore, vertical separation of classes of cables in trays is as follows from top trays down:

a. Instrumentation cable trays
b. Control cable trays
c. Power and control cable trays
d. Power cable trays

Inside the cable rooms cables from each protective channel are routed in trays separate from those carrying cables from any other protective channel. Included in these trays are instrumentation cables from the reactor building, control and interconnecting cables associated with that protective channel, and non-protective instrumentation and control cables. Both protective and non-protective cables are individually armored and are flame retardant."

FSAR Section 8.2.2.12 (h) "Evaluation of the Physical Layout, Electrical Distribution System Equipment" changes included the addition of the statement:

"It is our intent wherever physically possible to utilize metallically armored and protected cable systems. By this we mean the use of rigid and thin wall metal conduit, aluminum sheath cables, bronze armored control cables, steel interlocked armor power and control cables and either interlocked armor or served wire armored instrumentation cables.

Power cable trays are loaded with a single layer of cable. Each cable is clamped in place with a spacing being maintained between cables equal to 1/4 the diameter of the cable. Power cables are derated based on IPCEA recommendations for Interlocked Armor Power Cables when installed with one quarter cable diameter spacing in cable trays. The maximum fill in control and instrumentation· cable trays is such that trays will be filled to the top of the tray rails."

The December 22, 1970, Duke response to item #1 regarding cable protection of the AEC letter dated November 25, 1970, is copied in part below:

"1) Physical Protection Provided Safety-related Cables.

a) We agree that Sections 7.1, 7.3, and 8.2 require that safety-related cables be routed and protected from physical damage.

In our opinion, the installations for safety-related cables are adequately protected and do conform to the designs described in the "Final Safety Analysis Report" and with Appendix B to 10 CFR 50, as well as those described in meetings with DRL.

b) The cable system designs are described generally in Section 8.2 of the FSAR and states that: 'It is our intent wherever physically possible to utilize metallically armored and protected cable systems. By this we mean the use of rigid and thin wall metal conduit, aluminum sheath cables, bronze armored control cables, steel interlocked armor power and control cables and either interlocked armored or served wire armored instrumentation cables. With this type of construction fire stops as such are not required.' Other references in Section 7 and Section 8 also state the requirements for routing in cable trays to achieve separation and isolation of redundant circuits.

The primary method which has been used to achieve physical protection from damage is the metallically armored and protected cable systems. With these systems, either the cables are armored or they are installed in metal conduits. Armoring added to cables in various forms provides additional mechanical physical protection in much the same manner as does flexible conduit. Essentially, each cable with its armor has its own 'built-in' conduit...

Without the armors, the cables would be suitable for cable tray installations as has been installed in existing nuclear power plants. However, with the armors, the cables use cable trays and other adequate means for support; i.e., cables strapped to beams, etc. The cables are suitable for running outside of the cable trays since each cable has its own physical protection built in."

The response is lengthy and discusses the various types of armor employed and cable installation requirements.

Subsequently, on December 29, 1970, the AEC issued the initial Safety Evaluation for Oconee Nuclear Station Unit 1, licensing Oconee as described in the above correspondences. Included in the Safety Evaluation was the following:

"Section 8.5 Cable and Equipment Separation and Fire Prevention
We have reviewed the applicant's design provisions and installation arrangement plans relating (1) to the preservation of the independence of redundant safety equipment by means of identification and separation, and (2) to the prevention of fires through derating of power cables and proper tray loading. We have found these design provisions and installation arrangements to be acceptable."

Following Oconee Unit 1 initial licensing, construction inspections continued on Units 2 and 3. An AEC letter dated January 26, 1972, documents "a problem regarding adequate separation of redundant instrumentation and control cables" that was observed during a site visit on November 30, 1971. The letter states that, during a meeting between AEC and Duke personnel, the following actions were discussed with the intent to resolve the issue:

"1. Install 'Glastic' fire resistant barriers to the bottom of Oconee Unit 1 cable trays in all areas where the minimum spacing between the cables in the bottom of one tray is less than three inches from the cables in the top of the tray immediately below it.
2. Institute a cable temperature checking program in the critical areas of cable tray overfill in Oconee Unit 1. This program will be carried out for a reasonable but limited period of time and will include temperature checks during initial startup, normal and adverse operating conditions.
3. Revise the FSAR to incorporate the above Unit 1 cable tray modifications and the cable temperature checking program and to show that for Oconee Units 2 and 3 the original cable separation criteria will be met including no cable tray overloading and a minimum of five inches rail-to-rail space between all vertical trays."

[Note: The identified issue is with inadequate spacing from the bottom of one tray to the top of the tray below (see item 1); therefore, the five inch reference is the minimum vertical spacing between horizontal trays.]

The January 26, 1972, letter concluded:

"Based on our review of this matter, we conclude that your proposal as noted above is acceptable."

Duke staff responded by incorporating the requirements into FSAR revision 18, Section 3.2.2.13, "Evaluation of the Physical Layout, Electrical Distribution System Equipment," dated March 10, 1972.

> "The maximum fill in control and instrumentation cable trays is such that trays will be filled to the top of the tray rails except in some Unit 1 locations. Units 2 and 3 cable trays will not be filled above the side rails. A minimum of five inches rail to rail separation will be maintained between all vertical trays on Units 2 and 3...
>
> ...Armored cable was used at Oconee to achieve better mechanical protection and fire retardance. This caused the trays to fill faster than anticipated and in several locations the fill became excessive. Steps have also been taken to insure that no additional cables are routed through trays which are already overfilled.
>
> Where overfill situations exist in Unit 1 between vertically adjacent cable trays to the extent that the top cable in the lower tray is within three (3) inches of the bottom cable in the tray immediately above, a 1/8" fire retardant fiberglass reinforced polyester barrier will be placed between the trays. These barriers will be attached to the bottom of the upper tray and fitted around cables which may pass through the barrier."
>
> [Note: Again, minimum tray spacing is with respect to the vertical spacing between horizontal trays as supported by references to tray <u>above</u> overfilled tray. Also see note with item 3 above.]

On July 6, 1973, the AEC issued the initial Safety Evaluation for Oconee Nuclear Station Units 2 and 3. Section 8.0, Instrumentation, Control and Power System, of the evaluation opened with the statement:

> "The staff review of the Oconee instrumentation, control, and power system on pages 49-54 [Chapter 8] of the Oconee Unit 1 SER is applicable to Units 2 and 3. Additional matters related to the Units 2 and 3 review are discussed below."

Section 8.5.1, Cable Separation, contained the following additional information:

> "The applicant has supplemented his cable installation criteria. Cable trays in Units 2 and 3 will not be filled above the tray side rails; additional cable trays were installed to assure compliance with this commitment. The staff concluded that the provisions for separation of cables are acceptable."

To summarize, by July 1973, all three Oconee Units had received Operating Licenses. Cable trays were identified as being utilized for separation and isolation of redundant circuits. Additionally, armored cable was introduced as providing physical protection, similar to 'built-in' conduit. Oconee's cable routing and separation practices have been documented, reviewed, and found acceptable during issuance of the Oconee licenses. Also, oversight in the area of cable routing and installation was evidenced by inspection issues with adequate cable separation which were addressed by the installation of "glastic" where required and future cable tray fill requirements.

Single Failure Criteria
Subsequent to Oconee licensing, in January 1974, Appendix K to Part 50—ECCS Evaluation Models, was issued to define the Required and Acceptable Features of Evaluation Models. All licensees who were not under this rule were required to perform the evaluation. On August 5, 1974, Duke submitted an evaluation of ECCS cooling performance calculated in accordance with an evaluation model developed by the Babcock and Wilcox Company.

However, the regulatory staff concluded that B&W's evaluation model was not in complete conformity with the requirements of Appendix K. The December 27, 1974, Safety Evaluation Report required that Duke submit a re-evaluation of ECCS cooling performance calculated in accordance with an acceptable evaluation model. It is within the on-going discussion of the re-evaluation of ECCS cooling performance that the discussion of single failure arises. In the March 10, 1976, letter to the NRC, Duke stated:

> "In Section 4.6 of BAW 10103 and Section 3.5 of the specific Oconee Unit 1 analysis, the worst single failure postulated is the loss of a diesel, following loss of off-site power, which results in the operation of only one LPI and one HPI pump. The Oconee emergency power system uses two hydro-electric generating units instead of diesels and a single failure of one of these sources will have no effect upon ECCS performance. However, failure of a 4160 volt switchboard could cause the loss of one HPI and one LPI pump, but there is no possibility of a common mode failure which will result in the loss of more than one 4160 volt switchboard. Therefore, although the failure mechanism for the Oconee units is different from that described in BAW 10103 and the specific Oconee 1 analysis, the worst case single failure still results in the operation of only one HPI and one LPI pump, and the conclusions of the analyses remain valid."

During this same time period, Duke and B&W were communicating as to how IEEE-279 should be applied for single failure. In response to an April 6, 1976 RAI, B&W provided the following explanation of IEEE-279 to Duke:

> "IEEE-279 provides general, rather than specific, criteria for single failure analysis, so that the real acceptance standard is NRC approval of the analysis."

The B&W response provides insight into industry perspective of how such criteria were historically interpreted using licensing correspondence. Information in support of Duke's application of the single failure criteria can be found in a May 13, 1976, response to the April 6, 1976, RAI regarding the ECCS analysis for Oconee. Duke was asked to describe the design of the ECCS actuation system and identify any non-conformance of this design with the single failure requirements of IEEE Std 279-1971. Duke replied:

> "The design of the Oconee Nuclear Station Engineered Safeguards Protective System (ESPS) is described in FSAR Section 7.1.3. The ESPS includes the Emergency Core Cooling System in addition to the Reactor Building Isolation, Spray and Cooling Systems. The system logic for the ESPS is described in FSAR Section 7.1.3.2.1, and the specific discussion for the ECCS components is provided in FSAR Section 7.1.3.2.2. The safety evaluation for the ESPS is provided in FSAR Section 7.1.3.3.
>
> The Oconee ECCS actuation system conforms to the single failure requirements of IEEE 279-1971."

Similarly, Duke was requested to describe the design of the onsite emergency power system, a-c and d-c and to identify any non-conformance of this design with the single failure requirements of IEEE Std 279-1971. Duke replied:

> "The Oconee Nuclear Station onsite emergency AC power sources and distribution system are described in FSAR Section 8.2.3. The emergency power distribution through the switchboards is described in FSAR Sections 8.2.2.4, 8.2.2.5, and 8.2.2.6. The onsite emergency DC power system is described in FSAR Section 8.2.2.7. A single failure analysis of these systems is provided in Table 8.7.

The design of the Oconee onsite emergency AC and DC power systems conforms to the single failure requirements of IEEE 279-1971."

Duke provided effectively the same response with respect to IEEE-279 Single Failure requirements to both questions, with a high level statement regarding conformance to the generic criteria and specific references to the FSAR defined system descriptions and bases in the responses. These responses are consistent with the perspective that the IEEE-279 criteria as a general description with the details as listed in the FSAR references.

In 1976, the Oconee licenses were amended based upon an acceptable Emergency Core Cooling System evaluation model conforming to the requirements of 10 CFR Section 50.46 and the operating restrictions imposed by the Commission's December 27, 1974, Order for Modification of License was terminated. The ECCS Reanalysis was accepted in three separate Safety Evaluations. Within the Safety Evaluation for the amendments (with Unit 2 quoted), the following excerpts are highlighted:

- "We reviewed the design of this system on the following basis: The design of the entire emergency electric power system, including generating sources, distribution system and controls, is such that a single failure of any single electric component will not preclude the Emergency Core Cooling System of either Units 2 or 3 from performing its function."
- "We requested that the licensee determine if any single failure could compromise redundant trains. The licensee provided a control circuit schematic typical of that which would be used for all safeguards equipment actuated by redundant trains. Since two relay failures in redundant safeguards cabinets would be required to compromise redundant trains, this design provides adequate isolation between trains. This configuration is similar to that used in other nuclear power plants whose designs have been found acceptable. Therefore, this portion of the actuation system is in conformance with the fundamental single failure criterion at the electric component level."
- "To preclude the likelihood of an undetected failure, Technical Specifications will be required to include a monthly surveillance of this interlock [Keowee Underground Breaker]. By including periodic testing of this interlock, we are satisfied that the same level of safety has been achieved for this interlock as exists for all other safeguards equipment that are tested monthly."
- "Single Failure Conclusion - On the basis of our review, including the above indicated changes to Technical Specifications and commitments by the licensee, we find that there is sufficient assurance that the ECCS will remain functional after the worst damaging single failure of ECCS equipment at the component level has occurred."

The wording within this Safety Evaluation supplements the IEEE-279 single failure criteria with an understanding that, at the component level, the requirements are met by means of redundant and isolated trains. As designed and analyzed, Oconee met the single failure requirements and would survive the plant designed single failure.

McGuire - Cable Separation Licensing Basis
An August 30, 1977, NRC-authored McGuire Site Visit Summary associated with a construction related inspection clarified Duke's position with regard to cable armoring:

"During our site visit, the staff has verified that routing of redundant safety related cables conformed with the criteria described in the FSAR. The applicant is taking credit for armor on cables as barrier. The staff has requested the applicant to document the test results and conclusions reached with regard to the barrier integrity of the armored cables used in the plant. The evaluation of cable separation and identification will remain open till the fire protection review for this plant is completed."

Duke Power performed testing on armored cable with the intent to demonstrate the acceptability of interlocked armor cable as an adequate barrier to internally generated faults for both power and control cables. The initial test report was issued November 8, 1977, and a follow up report was issued March 3, 1982, all as MCM 1354.00-0029.001. The results have been referenced in various correspondences between Duke and the NRC. The test report was provided to the NRC for review as part of McGuire's Fire Protection licensing efforts. The March 28, 1978, RAI response stated:

> "Testing performed by Duke Power Company at the Westinghouse High Power Laboratory in East Pittsburg, Pennsylvania demonstrated that adjacent armored cables within the same tray will not be damaged due to the short circuiting of the power cable. These test reports have been submitted to the NRC and more than adequately demonstrate that these types of power cables pose no threat to the redundant safety trains."

Subsequent RAIs and responses demonstrate that NRC personnel scrutinized the test method and results. In a January 31, 1979, Fire Protection Review, McGuire stated:

> "The use of armor on cables ensures they are more resistant to mechanical damage and electrostatic and electromagnetic interferences. The armor also provides protection from short circuits and overloads."

On March 1, 1979, the NRC issued Supplement 2 to the McGuire FSAR, indicating acceptance of the Duke position on armored cable as supported by testing, stating

> "At the time the Safety Evaluation Report was issued we had not completed our review of the fire protection program. This review has now been completed. We find the applicant's fire protection program to be acceptable and this item is resolved."

Although the above references are in regard to McGuire, the design philosophy advocating the use of armored cable, licensed at McGuire, was applied to the Duke fleet. The cable test results have been referenced in correspondence between Oconee and the NRC.

Note: While the bronze tape shield/armor cable design at Oconee was outside of the scope of the 1977 testing, the robust design of the medium voltage power cables provides a commensurate level of protection from cable to cable faults or failures based on the current analysis and testing.

ONS SSF Licensing
During the fire protection review for McGuire, the Oconee fire protection review was also ongoing. On August 8, 1978, the NRC issued Oconee Amendment Nos. 64, 64, and 61 to add license conditions relating to the completion of facility modifications for fire protection. Within the Safety Evaluation, the NRC recognized that the majority of the cables used in construction at Oconee are of the metallic armored type, reiterated the cable separation requirements as stated in the FSAR, and repeated the Duke position that the cable armors used provide excellent mechanical and fire protection which would not be provided with conventional, unarmored cable systems. Within the SE, the construction cable separation practices were specifically called out and the commitment to install a separate and independent facility to shut down the units (i.e., Standby Shutdown Facility) was documented.

> "Throughout most of the plant there is good separation between redundant divisions such that a fire would not cause loss of redundant safe shutdown equipment. During the site visit, it was determined that in a number of locations, redundant safe shutdown cables could be jeopardized due to a lack of sufficient separation. The separation criteria used in the

installation did not preclude the routing of redundant cables vertically over one another in adjacent trays."

In 1981, the design and licensing requirements for the SSF were being established. During this review, a question was raised as to whether it was considered credible for a 4 or 7 kV voltage source to be applied to one of the associated circuits as a result of a fire and subsequently propagate to and damage components of the shutdown train which was otherwise unaffected by the postulated fire. Internally, Duke considered the cable routing criteria, robust cable design, and grounded cable armor and determined that this type of event could not credibly result from a fire. In a letter from Duke Power to the NRC dated March 18, 1981, concerning licensing of Oconee's Standby Shutdown Facility, Duke continued to credit the armor when discussion required separation of associated circuits. The letter stated:

> "The cable used by Duke Power is of the armored type. We have performed tests that demonstrate the armor provides adequate protection to prevent a fault within a cable from propagating into an adjacent cable, even if the breaker feeding the faulted cable fails to trip."

Inspection Report 50-269, 270, 287/89-05, dated March 14, 1989, noted a potential problem involving safety related cabling. Two sets of redundant Main Feeder Bus control cables for lockout relaying were inappropriately routed through the same cable trays, in violation of FSAR Section 8.3.1.4.6.2. The inspection report further documents the results of the operability analysis, with the first two items being "All cables concerned are grounded armored cables...Internal fault propagation from one cable to another in a common tray will not occur. This is supported by testing performed by DPC [Duke Power Company] and documented in Test Report MCM 1334.00-0029(sic)..." The report concluded "No violations or deviations were identified." Oconee submitted LER 269/89-04 dated March 29, 1989, on the issue, characterizing it as a Design Deficiency, Electrical Equipment Configuration Deficiency. The subsequent corrective actions were to reroute the control cables through different cable trays and to perform a random inspection of selected safety related cables throughout the plant.

Electrical Distribution System Functional Inspection
During the first quarter of 1993, the NRC conducted an approximately six week inspection to assess the capability of the Oconee Electrical Distribution System (EDS), including Keowee, to perform its intended functions during all plant operating and accident conditions. The team reviewed the Oconee EDS design with respect to regulatory requirements, licensing commitments and pertinent industry standards. The review included the examination of EDS equipment size and rating, EDS as-built configuration, EDS material condition, maintenance, testing and calibration program for EDS components, root cause analysis of EDS deviation reports, and the adequacy of the EDS design documentation.

Three items of relevance were noted in NRC Inspection Report No. 50-269/93-02, 50-270/93-02, and 50-287/93-02, "Notice of Violation and Notice of Deviation," dated May 7, 1993. During the inspection a deviation from the requirements of FSAR, Section 8.3.1.4.6.2, "Cable Separation," was identified. The power cables for the mutually redundant emergency core cooling recirculation sump isolation valves 2LP-19 and 2LP-20 were run in the same cable trays. However, the benefit of armored cable with respect to cable separation requirements was documented in the report with the authors stating:

> "The safety significance of running the two cables in the same tray was mitigated by a unique design feature at Oconee of installing cables in armored jackets."

Another indication that the inspection team reviewed the Oconee design philosophy of utilizing armored cable is provided by the observations quoted below from the same inspection report:

"Rigorous separation between the control and electrical cables of the units was not employed. In many cases, cables for the two units occupy the same trays. However, armored cables are used with voltage and current carrying ratings in excess of that required."

"The team was concerned about cable size #2 that was used for most of the safety motors. If a ground fault occurred near the feeding end of the #2 cable, the system short circuit current could exceed 45 kA. The temperature rise in the #2 size cable would well exceed 250C limit. The team requested the licensee to verify that such a fault at the #2 size cable would not cause a generated fire or source of propagation to its adjacent cables, which might belong to another safety load group. At the end of the inspection, the licensee provided a copy of the fault test report, which was done for the McGuire Nuclear Station. The team reviewed this report and determined that the cables size was adequate."

Keowee Underground Breaker Modification
In this same time period, Oconee submitted a license amendment request associated with a modification to the Keowee underground power path breakers. RAIs associated with the change clarified the Oconee single failure licensing basis. The RAI noted that Oconee's position was that "'smart failures' within the control system are not considered in failure analyses." In response, to this and subsequent RAIs, the failure-on-demand position was communicated.

> May 25, 1994 RAI: "In general, it has been the Oconee position to not consider smart failures within control systems. The system is assumed to control as designed or to fail to its as-designed state."
>
> NRC in January 26, 1995 letter: "The design basis for the Keowee emergency power system was then presented as the ability to provide emergency power to the Oconee Nuclear Station within the committed time under all applicable conditions assuming a single failure. After some discussion, the licensee stated the position that the switchyard yellow bus is part of the onsite power system at all times. Thus, a component failure which could cause a loss of this bus would be considered the single failure of the onsite electrical system. In addition, the licensee stated that any single failure was assumed to occur simultaneously with the initiating event."
>
> March 8, 1995 response: "The second statement is that any single failure was assumed to occur simultaneously with the initiating event. This should be changed to indicate that any single failure was assumed to occur immediately upon demand. Therefore, a failure was assumed to occur when the equipment was called upon to perform its safety function. This failure could be simultaneous to the initiating event or at some time during the mitigation event."

NRC acceptance that the modified system addressed the NRC's single failure concerns was evidenced in the August 15, 1995 SER which stated:

> "It finds that the new circuitry, intended as part of the long-term corrective action for overfrequency and overspeed concerns, does indeed eliminate those concerns, introduces no new single-failure vulnerabilities, and is acceptable conditioned on the proposal of technical specifications as discussed above."

ONS Emergency Electrical Power System Review
In August 1995, the Office of Nuclear Reactor Regulation (NRR) undertook a formal review of the Oconee Nuclear Station, Units 1, 2, and 3 (Oconee), Emergency Electrical Distribution System (EDS). The purpose of the review was to assess the overall reliability of the Oconee emergency

power system (EPS) and determine whether any additional staff actions might be required to address vulnerabilities or risks that may exist in the design or operation of the system and the standby shutdown facility. In the Final Report issued in 1999, the staff did not identify any vulnerabilities in the design or operation of the Oconee Emergency Power System or standby shutdown facility that would require immediate corrective actions to be taken. Also, within the report, the NRC recognized that the Oconee single failure criteria is plant-specific, with the original focus being on mechanical systems:

> "With regard to single failure, Oconee uses a plant-specific definition. The original staff review of the ECCS for compliance with 10 CFR 50.46 and 10 CFR 50, Appendix K checked for single failure vulnerabilities in the piping system. It ultimately concluded that the plant should be analyzed assuming the limiting single failure was the same as the generic B&W analysis that assumed the loss of an emergency bus (actually a DG). The emphasis of the ECCS rulemaking, and the individual reviews at the time, was on the thermal hydraulic and physical treatment of LOCA analysis models in addition to the acceptance criteria, not on the electrical design or the basis of the single failure criterion. Plants licensed after 10 CFR 50, Appendix A, were required to meet requirements of GDC 17 for electrical systems (onsite and offsite) that encompass any single failure requirements on electrical systems from 10 CFR 50, Appendix K or GDC 35. Because Oconee was not licensed to 10 CFR 50, Appendix A, the plant-specific single failure definition for Oconee remains valid and in effect with no additional requirements on the electrical power systems as a result of 10 CFR 50.46 or 10 CFR 50, Appendix K."

ONS Licensing

As part of ongoing licensing reviews (i.e., License Renewal, NFPA 805, Protected Service Water, and Tornado/High Energy Line Break), Oconee's cable system design continued to be thoroughly reviewed.

License Renewal

The Oconee units were issued Renewed Operating Licenses on May 23, 2000, prior to the Trench 3 and PSW modifications. As a part of the license renewal process, aging management programs were established. Plant changes implemented subsequent to license renewal are required to consider impacts on aging management programs. While not directly related to cable separation, the review and associated requirements indicate that the cables of concern are not subject to significant aging effects. UFSAR Section 18.3.14 states:

> "The Insulated Cables and Connections Aging Management Program includes accessible and inaccessible insulated cables within the scope of license renewal that are installed in adverse, localized environments...which could be subject to applicable aging effects from heat, radiation or moisture...Inaccessible or direct-buried, medium-voltage cables exposed to significant moisture and significant voltage will be tested...Significant moisture exposure is defined as periodic exposures to moisture that last more than a few days (e.g., cable in standing water). Periodic exposures to moisture that last less than a few days (i.e., normal rain and drain) are not significant. Significant voltage exposure is defined as being subjected to system voltage for more than twenty-five percent of the time."

These definitions are echoed in NUREG 1723, "Safety Evaluation Report Related to the License Renewal of Oconee Nuclear Station, Units 1, 2, and 3," Section 3.9.3.2.1, "Aging Management Program for Insulated Cables and Connections." Based upon these criteria, the 13.8 kV feeder cables from Keowee to CT-4 and the 4.16 kV cables from Oconee to Keowee transformer CX were evaluated and screened out from periodic testing due to lack of aging stressors from heat, radiation, or significant moisture exposure.

Tornado/High Energy Line Break Licensing Efforts
The next major licensing effort under NRC review, with relevance to this cable issue, was associated with Tornado and High Energy Line Break (HELB). Numerous references were identified where the design and installation of cables was questioned. Duke repeatedly referenced DC 3.13 in response. Bronze tape was first introduced in licensing space as a part of this exchange.

In a September 2, 2009, response to a Request for Additional Information regarding LAR 2006-09, Tornado Licensing Basis, Duke provided the following responses:

> "RAI -3: In Enclosure 2, Section 3.3.4 of the LAR, the licensee states that the Keowee Hydroelectric Units (KHUs) will provide power supply to the PSW switchgear through underground cables. Provide analyses to show the kilo volt ampere (kVA) loading, new circuit breaker rating, short circuit values, and voltage drop. In addition, provide information on the electrical protection and coordination, and the periodic inspection and testing requirements. Further, explain how the redundancy and independence of the Class 1E power system is maintained as a result of the proposed modification. Provide applicable schematic and single line diagrams.
>
> Duke Response:
>
> ... 4. The PSW electrical system has a normal (13.8kV Fant Line) and alternate (13.8kV Keowee Hydro Unit) 13.8kV power source breaker to each PSW Unit Substation. The redundancy of the PSW power system is provided through these two power sources. The Keowee Hydro Unit 13.8kV power source cables to the PSW electrical system will be routed in a combination of precast concrete trench boxes, duct banks, and manholes. The power feeds from Keowee Hydro Unit to both Oconee Nuclear Station and the PSW electrical equipment are isolated by separate breakers and disconnect switches. Independence is maintained as required by Duke Design Criteria DC 3.13.
>
> RAI -5: Provide information on how the licensing basis for physical independence and separation criteria are met for the PSW electrical system.
>
> Duke Response:
>
> The licensing basis for physical independence and separation criteria for the PSW electrical system meet the requirements of Duke Design Criteria DC 3.13, "Oconee Nuclear Station Cable and Wiring Separation Criteria," that provides guidance for cable routing and installation. Refer to DC 3.13 [Enclosure]."
>
> [NOTE: Section 6.4 of DC 3.13 (provided in RAI response) states "Trenches may simultaneously contain power, control and instrumentation cables. If cable tray, electray, or conduit is not provided for cable support, power cables within a trench shall be racked on the side of the trench or on unistrut cross members per Section 6.2 of this criteria. Control and instrumentation cables shall be laid in the bottom of the trench. Mutually redundant safety cables shall be located on opposite sides of the trench."]

In a June 24, 2010, response to additional Tornado RAIs, the following was provided to the NRC:

> "RAI 2-31: Provide information on how the licensing basis for physical independence and separation criteria are met for the PSW electrical system.

Duke Energy Response [again referencing DC 3.13]

"... Implementation of the physical independence and separation criteria for the PSW electrical system will be controlled by Duke Energy Design Criteria DC 3.13, "Oconee Station Cable and Wiring Separation Criteria." DC 3.13 provides guidance for cable routing and installation which has been revised to include PSW-related cables."

In an August 31, 2010, response to additional Tornado RAIs Duke addressed trench and cable design and construction, including the use of bronze tape, as well as long term monitoring practices:

"RAI 2-32: The licensee states in the June 26, 2008, LAR that the new PSW system switchgear will receive power from the KHUs via a tornado-protected underground feeder path. Provide the following Information:

1) the type of underground cable installation, i.e., direct burial or in duct banks, manholes etc., 2) how the licensee will ensure that the proposed new underground cables remain in an environment that they are qualified for, 3) periodic inspections and testing planned for cables to monitor their performance, and 4) details regarding cable size, type, maximum loading requirements, and cable protection devices.

Duke Energy Response

1. The underground cable route from Keowee Hydro to the PSW building will be a combination of precast concrete trench boxes, duct banks and manholes. This new route will be an extension of the existing underground path from Keowee to the CT-4 block house at the plant. Spare cables in the existing underground path will be spliced to new cables in the underground path extension to the PSW building. None of the cables will be direct buried.

2. The Keowee underground path to the PSW switchgear will be designed to preclude water entry that could wet the cables. The concrete trenches will have drains. The new duct bank conduits will be sloped towards manholes where drains are provided. Periodic inspections will be performed on the Keowee to PSW underground path to evaluate the condition of the trenches, duct banks, manholes and drainage system.

3. The cables will be evaluated for inclusion in the ONS Insulated Cables and Connections Aging Management Program. Since the underground path from Keowee to the PSW building is designed to prevent significant exposure to moisture and most of the path is inaccessible, it is expected that the cables won't meet the criteria for periodic diagnostic testing. If subsequent periodic inspection of the Keowee to PSW building underground path determines that these inaccessible cables are exposed to significant moisture, testing will be in accordance with the ONS Cable Aging Management Program.

4. The two (2) 13.8 kV circuits from Keowee to the PSW building consist of six single conductor cables. Each conductor is 750 kcmil copper with Class B compact round stranding. The conductor shield is a thermoset semi-conducting compound extruded over the conductor. The insulation is ethylene propylene rubber (EPR) that provides an insulation level of 173% above the 15 kV nominal insulation rating. The insulation is rated at 90°C continuous and 130°C emergency overload. The insulation shield is a semi-conducting thermoset compound applied over the insulation. Two layers of non-magnetic bronze tape shield are applied over the insulation shield. A thermoset chlorosulfonated polyethylene (Hypalon) jacket is applied over the cable core.

Maximum allowable cable loading will not exceed the continuous conductor insulation temperature rating. Depending on the cable loading scenario, anticipated cable loading is expected to range from 193 A to 559 A.

Cable protection will be provided by Keowee and PSW switchgear breakers and protective devices, which includes time-overcurrent, instantaneous overcurrent and ground fault relays."

In a December 7, 2010, response to additional RAIs on the Tornado/HELB licensing effort, RAI 2-31 and 2-32 responses were again provided as the responses to new RAIs 47 and 48 [T/H]. RAI 47 [T/H] requested that Duke Energy provide information on how the licensing basis for physical independence and separation criteria are met for the PSW electrical system. The Duke Energy response referred back to RAI 2-31. RAI 48 [T/H] requested information on the 1) Type of underground cable installation, i.e., direct burial or in duct banks, manholes etc.; 2) How the licensee will ensure that the proposed new underground cables remain in an environment that they are qualified for; 3) Periodic inspections and testing planned for cables to monitor their performance; and 4) Details regarding cable size, type; maximum loading requirements, and cable protection devices. The Duke Energy response was to refer to the RAI 2-32 response of August 31, 2010.

NFPA 805
During this same time period, Oconee was pursuing transition from Appendix R to NFPA 805 license. During this effort, Duke once again highlighted that armored cable is the prevalent cable utilized at ONS, and its use is addressed in the Duke design criteria.

"RAI 3-27:

Provide a justification for your assumption that the use of armored cables, without further consideration of their current installed configuration, is adequate to prevent inter-cable faults due to fire or, alternatively, provide information that reasonably demonstrates that the as-installed configuration of the armor cable grounding scheme is consistent with the original plant design.

The LAR credits armored cables for precluding the occurrence of inter-cable shorts. As a result, only the effects of conductor-to-conductor shorts (intra-cable) within multi-conductor cables were considered. Recent (CAROLFIRE) test results demonstrate that this assumption may not be valid if the armored cables are not appropriately grounded. From the CAROLFIRE Report, Volume 1, Section 7.2.5, Grounded versus Ungrounded CPTs, "Grounded versus ungrounded circuits may be a significant factor influencing the likelihood of spurious actuation for armored cables," and Section 9.2.3, Grounded Versus Un-grounded Power Supply. It appears likely that the presence of the armor itself, which is grounded in typical applications, makes it more likely that a short to ground and fuse blow failure will occur for the grounded power supply cases. In the absence of the armor, the ground plane is available only through either a grounded conductor or the raceway itself. For an un-grounded circuit, a single short to ground will not trip the circuit protection (fuse) and therefore the likelihood of spurious actuation is somewhat higher.

RAI 3-27 RESPONSE:

Armored cable is the prevalent cable utilized at ONS. The interlocked armor on the cables at ONS are terminated and grounded as per drawings OEE-014-04 and OEE-015 series. These drawing series were in effect during the plants original construction. In addition, Section 6.4.1 in

Engineering Design Criteria DC-4.11, Generating Station Grounding, states that "The armor of interlocked armor cable shall be electrically continuous and grounded to equipment enclosure at each end of the cable." A similar design document exists for the Standby Shutdown Facility (OSS-0218.00-00-0010) and Radwaste (OSS-0218.00-00-009)."

The NFPA 805 Safety Evaluation dated December 29, 2010, repeated the RAI 3-27 response and concluded:

> "...the NRC staff finds that the licensee has adequately addressed the issue of grounding of armored cable to preclude inter-cable shorts."

The Protected Service Water licensing review resulted in RAI response dated December 16, 2011. This question and response are copied below:

"RAI 78: Provide a detailed discussion on how the electrical power systems of the PSW system will be installed such that they are physically separate and independent.

Duke Energy Response

The PSW electrical system is a single train system; however, the PSW Main pump circuits, Booster pump circuits and associated valve circuits are mutually redundant to the SSF ASW pump and valve circuits. Red PSW cables are not to be routed in the West Penetration Rooms or the Cask Decontamination Rooms to ensure the mutually redundant cables are kept physically separate. The alternate feeder from the PSW to the SSF may be routed without any separation requirements from SSF cables. This will be controlled by Duke Energy Design Criteria DC 3.13, "Oconee Nuclear Station Cable and Wiring Separation Criteria." DC 3.13 provides guidance for cable routing and installation which has been revised to include PSW-related cables. DC 3.13 references IEEE Standard 603-1980, IEEE Standard Criteria for Safety Systems for Nuclear Power Generating Stations."

Finally, the August 13, 2014 PSW Safety Evaluation stated:

"This SE provides the technical bases for the staff's approval of the changes to the ONS licensing basis within the scope of these amendments. These amendments and the related SE do not approve nor endorse the as-installed PSW electrical system cable configurations. Duke Energy analyzed the PSW electrical system configurations and installed the PSW electrical cables and power supplies under the provisions of 10 CFR 50.59, and thus those parts of the system were not included in the scope of the staff's review for these amendments. The installed configurations of the PSW cabling and associated onsite power supply systems are the subject of a pending NRC inspection activity, as documented as an unresolved item in the NRC Component Design Basis Inspection Report, dated June 27, 2014, Section 1.2.b.v. (ADAMS Accession No. ML14178A535)."

During the NRC's review of the PSW design, Duke Energy provided details on cable design and installation, again citing Duke Energy Design Criteria DC 3.13 as had been done in previous licensing reviews. The RAI response provided in 2011 was not questioned by NRC reviewers until the final PSW Safety Evaluation was being drafted and a question was raised in the 2014 CDBI, ultimately leading to the TIA.

Applicable Industry and Regulatory Guidance

In the numerous engagements between NRC and Duke Energy there have been discussions involving various design standards associated with cable separation and single failure criteria.

Oconee Nuclear Station was designed, constructed, and licensed prior to the development of many of the standardized requirements. Because of this, understanding of the Oconee license often requires knowledge of context (i.e., other ongoing discussions between Duke and the NRC via meetings, inspections, etc.). The listing below provides dates when NRC and industry guidance and/or requirements were issued. Key dates associated with Oconee design and licensing are superimposed on the list to demonstrate which requirements are applicable to Oconee and which may only be applicable to newer plants. For these reasons, review of Oconee's design against current NRC design and licensing requirements is not an accurate reflection of Oconee's adherence to licensing basis requirements.

Timeline

- 11/22/1965 - AEC press release H-252 27 documenting proposed General Design Criteria (GDC)
- **12/1/1966 - Oconee Nuclear Station Preliminary Safety Analysis Report (PSAR) submitted**
- 7/11/1967 - Proposed rule-making, AEC updated the GDC's from the original 27 to 70 criterion
- **11/6/1967 - Construction Permits issued for Units 1, 2,and 3** [but the GDC are still in a proposed state]
- **12/29/1970 - Initial Safety Evaluation for ONS Unit 1 -** issued, evaluated against proposed GDC, dated 7/11/67, and Proposed IEEE -279, dated 8/28/68.
- 1971 - IEEE Std 279-1971, Criteria for Protection Systems for Nuclear Power Generating Stations [includes the commonly applied single failure definition]
- June 1973, Reg Guide 1.53, Application of the Single-Failure Criterion to Nuclear Power Plant Protection Systems, "It is recognized that IEEE Std 379-1972 has been published only for trial use and as a draft American National Standard. As experience is obtained in its use, the standard may be modified to improve its usefulness by deleting provisions which prove to be unacceptable or by appropriately supplementing those provisions in which inadequacies are found."
- **7/6/1973 - Initial Safety Evaluation for ONS Units 2 and 3**
- 1974 - IEEE Std 308-1974, Criteria for Class 1E Power Systems for Nuclear Power Generating Stations
- 1/1975 - Regulatory Guide (RG) 1.75, Revision 1 - Physical Independence of Electric Systems. This guide describes a method acceptable to the Regulatory staff of complying with IEEE Std 279-1971 and Criteria 3, 17, and 21 of Appendix A to 10 CFR Part 50 and endorses, with certain exceptions, IEEE Std 384-1974. RG 1.75 is "to be used by the Regulatory staff in evaluating all construction permit applications for which the issue date of the Safety Evaluation Report is February 1, 1974, or after." [Note: Timing makes this RG not applicable to Oconee.]
- 6/30/1977 - IEEE Std 384 - 1977, IEEE Standard Criteria for Independence of Class 1E Equipment and Circuits
- 11/8/1977 - MCM 1354.00-0029.001, "Report of Power and Control Cable Overload and Short Circuit Tests Performed for McGuire Nuclear Station," performed by the High Power Laboratory of the Westinghouse Corporation.
- **5/23/00 - Issuance of Renewed Facility Operating Licenses for ONS Units 1, 2 and 3**
- July 2001 - NUREG 1801, Rev 0 - Generic Aging Lessons Learned (GALL) Report (NUREG-1801, Initial Report)
- 9/2005 - NUREG/CR-6850 (EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities) endorsed by Oconee's NFPA 805 Safety Evaluation, endorsed by RG 1.205
- 5/2006 - RG 1.205 - Risk-Informed, Performance-Based Fire Protection for Existing Light-Water Nuclear Power Plants

10 CFR 50.55a(h)(2), Protection Systems, requires that, for plants with construction permits issued before January 1, 1971 (e.g., Oconee), protection systems must be consistent with their licensing basis. Thus, the requirements of the subsequently issued regulatory documents (e.g., IEEE 279-1971, IEEE 308-1974, RG 1.75) are not generically applicable to Oconee. For example, the Oconee Emergency Power System, as presented in FSAR prior to the initial Unit 1 Safety Evaluation (SE), described a system with diverse power sources. The design was accepted by the NRC. Instrumentation and Control cable installation requirements, as re-stated in FSAR Chapter 8, were accepted by the NRC in a 1972 letter and the 1973 SE's for Units 2 and 3. Oconee's cable routing and separation practices have been documented, reviewed, and found acceptable since the original licensing of Units 2 and 3. At the component level, when applied to cabling design criteria, this has translated to UFSAR-specified separation for cables supplying redundant functions. Subsequent Oconee design and licensing actions have, for the most part, remained consistent with the philosophy/approach licensed in the 1960s and 1970s. Components of later, applicable guidance documents have been referenced or adopted as described in the UFSAR.

Within the August 11, 1978, Safety Evaluation Report, armored cable was discussed with regard to electrical cable combustibility. However, it was also covered within the section on separation of equipment and consequences.

> "It should be pointed out that the cable armors used provide excellent mechanical and fire protection which would not be provided with conventional, unarmored cable systems."
>
> "...An unmitigated fire in the containment penetration areas could cause loss of redundant safe shutdown instrumentation though this is unlikely due to the armor on the cable."

With the migration of the Oconee license to NFPA 805, the governing documents were reviewed for applicability or insights into this issue. NUREG/CR-6850 (EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities), as endorsed by NRC RG 1.205. NUREG/CR-6850 was cited in Oconee's NFPA 805 Safety Evaluation.

RG 1.205 states:

> "The NRC and the Electric Power Research Institute (EPRI) have documented a methodology for conducting a fire PRA in NUREG/CR-6850/EPRI 1011989, "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities," issued September 2005 (Ref. 17). However, recognizing that merely using the methods explicitly documented in NUREG/CR-6850/EPRI 1011989 may result in a conservative assessment of fire risk, licensees may choose to perform more detailed plant-specific analyses to provide greater realism in the fire PRA model."

As an NFPA 805 licensed facility, this guidance was also incorporated. Per NFPA 805, 2001 Edition:

> "Plant-specific design features can preclude certain circuit failures from occurring. For example, the use of grounded, metallic, armored cable or dedicated conduit, shorting switches, or rugged (e.g., braided metal) shielding are considered in most cases to preclude external hot shorts from further consideration. However, multiple ground faults might still energize conductors within a grounded conduit, shield or armor if those conductors are associated with ungrounded circuits."

NUREG-6850 contains the following statements on rugged grounded shields precluding certain cable failure mechanisms used to govern circuit analysis methodology:

1) "Three-phase proper polarity hot shorts on AC power systems: Case 3: Armored cable or cable in dedicated conduit. Three-phase proper polarity faults are not considered credible for armored power cable or a single triplex cable in a dedicated conduit. The basis for exclusion is that multiconductor-to-multiconductor hot shorts are not plausible given the intervening grounded barrier (i.e. the armor or conduit)."
2) "Plant specific design features can preclude certain circuit failures from occurring. For example, the use of grounded, metallic, armored cable or dedicated conduit, shorting switches or rugged (e.g. braided metal) shielding are considered in most cases to preclude external hot shorts from further consideration."
3) "If the cable design can be verified as one that employs a rugged grounded metallic shield (e.g. armor, braid, etc.), then the analysis need only consider the effects of shorting between the conductors within the shield and shorting the conductors to ground, i.e., the effects of shorts from external sources need not be considered."

NUREG-6850 also contains the following statements which support the consideration of a three phase bolted fault only at the terminations:

1) "Cable ducts: A power conductor configuration that provides a function like a bus duct but uses a length of insulated electrical cable in lieu of metal bus bars ... Cable ducts may be used in application conditions similarly to either a segmented or non-segmented bus duct." The medium voltage power cables in Trench 3 meet this definition of a cable duct.
2) "Because nonsegmented bus ducts (category 1) and cable ducts (category 3) have no transition points other than the terminations at the end device, no treatment of bus duct faults/fires independent from the treatment of fires for the end devices is required. That is, arc faults for these two categories of bus ducts, 1 and 3, are inherently included in the treatment of the end device, and no further treatment is needed."
3) "segmented bus ducts (category 2), a number of the identified fire events were manifested at bus transition points (a point where two segments of the bus duct are bolted together) rather than at the bus termination points. These events were generally attributed to loose bolted connections, to failed insulators, or to the accumulation of dirt/debris/contaminants in the bus duct. The key, however, is that the effects of the fault are manifested at transition points along the bus duct length. Fire scenarios for segmented bus ducts should, therefore, be postulated to occur at duct transition points (i.e., bolted connections)."

Frequently Asked Question (FAQ) 07-0035, Rev 2, determined to be acceptable for use by licensees in transition (ML091620572), provides additional information:

> "For segmented bus ducts (category 2), a number of the identified fire events were manifested at bus transition points (a point where two segments of the bus duct are bolted together) rather than at the bus termination points. These events were generally attributed to loose bolted connections, to failed insulators, or to the accumulation of dirt/debris/contaminants in the bus duct. The key, however, is that the effects of the fault are manifested at transition points along the bus duct length. Fire scenarios for segmented bus ducts should, therefore, be postulated to occur at duct transition points (i.e., bolted connections)."

<u>Failure Sequence Necessary to Damage DC Circuits</u>

In order to qualify the potential sequence of consequential damages resulting from a cable failure in Trench 3, one must consider the failure mechanism itself, the design of the cable system, and the design of the protection system.

As noted in NUREG 1723, "Safety Evaluation Report Related to the License Renewal of Oconee Nuclear Station, Units 1, 2, and 3" Section 3.9.3.1.3 "medium-voltage cables (2-kV to 15-kV) are subject to changes in electrical properties from moisture, excessive heat, and radiation." No significant cable stressors related to radiation or temperature exist in Trench 3; therefore, this discussion will focus on moisture. The widely postulated cause of a cable failure in Trench 3 is a breakdown in cable insulation due to moisture induced water treeing resulting in a fault. NUREG 1723 states:

> "The effects of moisture on medium-voltage cables can result in water trees when the insulating materials are exposed to long-term, continuous voltage stress and moisture, eventually resulting in breakdown of the dielectric and failure. The growth and propagation of water trees is somewhat unpredictable and few occurrences have been discovered in cables operated below 15 kV."

NEI 06-05, "Medium Voltage Underground Cable White Paper," contains further discussion on water treeing, stating:

> "This water-enhanced degradation does not cause direct breakdown of the [cable] insulation, but rather reduces the dielectric strength of the insulation, eventually weakening the material to the point where it is susceptible to voltage surges that can initiate partial discharging. Partial discharging causes relatively rapid electrical degradation, leading to an electric tree and a faulted condition in weeks to months."

The medium voltage cables in Trench 3 were constructed with 173% of rated voltage Pink ethylene propylene rubber (EPR) insulation which, as stated in NEI 06-05,

> "...has treated clay fillers to preclude water absorption that makes the insulation less prone to water-enhanced degradation."

In addition, the conditions for significant moisture exposure, as defined in NUREG 1723, do not exist in Trench 3 due to the passive drainage system, as verified by periodic inspection. Referring again to NEI 06-05:

> "In systems provided with adequate and well-maintained drainage, short-term submergence consistent with post-storm runoff does little more than wet the surface of the cable, given the slow diffusion of the moisture through common jacketing systems."

Therefore, based upon the factors of the cable insulation design (i.e. 173% Pink EPR) and the design of the trench drainage system, it can be concluded that the occurrence of a moisture induced water tree resulting in a cable fault is of extremely low likelihood.

However, for the purposes of this discussion, one can assume that a medium voltage power cable line to ground fault due to insulation degradation does occur so that the possible consequential effects can be examined. After the initial single failure (e.g. the proposed line to ground fault) occurs, it falls to the protection systems in place to limit the effects of damage. When evaluating the protection systems in place for this scenario, one must consider the protective relaying, the system grounding schemes, and the physical protection provided by both barriers and distance. In the event of a cable fault, in order for there to be any significant energy transfer, there must exist a path back to the energy source to generate current flow. For the scenario of a line to ground fault in Trench 3 this path back to source would be created by the conductor of one of the medium voltage power cables faulting to its grounded shield, which is tied to the same station ground as the neutral grounding of the source. For the 13.8 kV power cables in Trench 3, the neutral grounding scheme is a high resistance ground designed with the express purpose of limiting both the fault current and any system overvoltage occurring as a result of the fault until the protective relaying can rapidly clear the fault, thereby severely limiting any consequential damages as a result. Meanwhile, the 4.16 kV power cables in Trench 3 have a solidly grounded neutral which does provide overvoltage protection but without the same fault current limiting capabilities. Therefore, the 4.16 kV cable line to ground fault will experience comparatively higher fault currents; however, this in turn inherently means that the protective relaying will actuate even faster (on the order of two-tenths of a second), thus limiting damage. As the energy released during a fault is a function of both the square of the current and the time the fault exists, it can be seen that as long as the protective relaying functions properly consequential damages can be limited as a result. Damage resulting from a fault in one of the 4.16 kV cables will also be directly related to the distance from the energy source to the fault location. As the overall shield resistance increases with distance from the source, the available fault current will decrease, thus causing distance to be the determining factor in whether or not the fault current will exceed the shield's short circuit withstand capability.

If one were to further progress down the sequence of consequential effects and assume that the fault energy is not contained within the initially faulted cable, either as part of the initial failure or by failure of the protective relaying, one must take a wider look at the other protective systems in place. As stated above, each medium voltage cable has a grounded shield (furnished as bronze tape layered 20 mils thick instead of the typical 5 mils and connected to the same station ground) that any fault would have to bypass before propagating to an additional phase, while also providing another path to ground to quench the fault energy. In addition, each medium voltage cable is specified with 173% of voltage rating conductor insulation which would provide a greater dielectric for any adjacent faulted cable to overcome. The 173% rating is the greatest of the three conductor insulation ratings discussed in IEEE-141 and is specified for situations where a fault could remain on a system indefinitely. Beyond the cables themselves, each trefoil bundle of medium voltage cables then rests on a set of unistrut supports, spaced horizontally in four foot intervals, that are furnished with their own #2/0 bare copper grounding conductors also connected to station ground, thus providing another low resistance path to divert the fault energy. If one were to postulate further that some force or event happened to cause the faulted power cable(s) to come into direct contact with the DC control cables at the bottom of Trench 3, the fault energy would first have to bypass the outer jacket and the layer of galvanized steel interlocked armor for each affected cable. Bypassing the galvanized steel interlocked armor of the DC control cables would be complicated by both the armor being grounded on both ends to station ground, thus providing another low resistance fault path, and by the general material property of steel having a higher melting temperature than the copper in the conductor(s) of the medium or low voltage cable(s) purportedly transmitting the fault energy. Thus, if an event were to occur with the energy necessary to affect both the AC and DC circuits within Trench 3, it is much more probable for it to cause an open circuit than to create any electrical continuity between the two systems.

However, if one were to suppose that the steel interlocked armor were to be bypassed and electrical continuity were to exist between the medium voltage cables and the low voltage cables, then one would have to consider that the DC system itself is a floating, ungrounded system (except for the high resistance, ground detection circuit) and does not provide the same low resistance path back to the source for fault energy to traverse, as compared to the other exposed metallic surfaces within the trench. In addition, the spare conductors in the low voltage cables are grounded at the ends of the trench and would provide yet another low resistance path to quench the fault energy. The lack of a low resistance path back to source within the DC system itself for current to flow would instead result in an overall rise in the electrical potential of the system as it equalized with the voltage of the faulted conductor. As the low voltage cables enter termination cabinets on either end of Trench 3, the most likely outcome of this voltage rise on the system would be shorting or arcing from the terminal strips in the cabinet to the grounded walls of the cabinet itself due to their voltage rating being exceeded. The same supposition could then be made for each subsequent cabinet as you progress down the DC system.

Therefore, for a medium voltage power cable fault in Trench 3 to impart a transient on both sets of low voltage DC cables, the following sequence of events would be necessary: A line to ground fault would occur, bypass the grounded metallic shield of the faulted cable, propagate to the adjacent medium voltage power cables and bypass their respective insulation and grounded metallic shields, bypass the grounded unistrut and bare copper grounding wires running the length of the trench, all to arc across the distance remaining between the faulted cable(s) and the DC cables following the event. This arc would then require the energy necessary to bypass the outer jacket and grounded galvanized steel interlocked armor of the DC cables while still keeping the copper conductors intact for the electrical continuity needed to impart energy on the DC system without creating an open circuit, all while bypassing any grounded spare conductors within the cables. For the fault to propagate further into the DC system, the voltage present would have to stay within the rating of the terminal blocks in each DC terminal cabinet, else arcing to the grounded surface of the cabinet could occur. In addition, for both sets of DC cables to be affected, the arc energy would require the size necessary to spread the width of the trench. This entire sequence of events would have to transpire either within the time it would take the protective relaying to clear the fault, or subsequent to an additional failure of the relaying. Due to both the multitude of grounded metallic surfaces and the protective relaying present, this sequence of events is considered to be improbable to the point of lacking credibility.

Industry Operating Experience

Operating Experience was reviewed to determine applicability to the current concern. The applicability of two specific items highlighted by NRC personnel to Duke Energy (i.e., the Swedish paper and the German paper) is discussed first. Following these two items, the Duke Operating Experience search criteria, evaluation, and results are presented.

Swedish paper - "Distribution System Component Failure Rates and Repair Times" [1]

The applicability of this paper to the medium voltage power cables in question at Oconee is limited. The paper presents a literature search of reliability information for the period 1993 - 2003 for electrical transmission and distribution system components. Its purpose is focused on retail transmission and distribution system outages and repair times with no apparent consideration of data from power generation plants. Specific to underground cables, the paper cites a failure rate of 0.95 per 100 km /year from a Norwegian paper published in 2002 for 33–110 kV cables. This is equivalent to a failure rate of 3E-03 per year per 1000 feet of cable, and is significantly higher than suggested by other data. The 33-110 kV voltage levels almost certainly indicate cables of a different design (likely to be of XLPE or PILC insulation) and subject to external influences such as lightning, switching surges, dig-ins, underwater routing, etc., and thus would not seem to be directly comparable to the Keowee Trench 3 installation. The more applicable failure rate information is that provided in the NRC Generic Letter (GL) 2007-01 industry response, the related Nuclear Energy Institute (NEI) documents and the EPRI technical reports. This information is based on US commercial nuclear power plant data for cables using similar designs, installation and operational modes.

[1] F. Roos, S.Lindah, "Distribution System Component Failure Rates and Repair Times – An Overview" Nordic Distribution and Asset Management Conference 2004, Finland August 2004

German Paper - "Investigation of High Energy Arcing Fault Events in Nuclear Power Plants"[2]

This paper is focused on the phenomenon of High Energy Arch Faults (HEAF) events and the potential effects on plant equipment around them. It is specific to nuclear power plants and provides a very broad review of the published literature (US and International) and describes a number of significant HEAF events that have occurred. The point of the paper is that HEAF events can cause much more severe damage than typical fire events and deserve special attention and more research. Interestingly, a point is made in the paper is that "fault clearing time plays the largest role in the arc-fault hazard category." Of the HEAF events described in the paper, the cases of severe plant damage all involved a failure or delay of the circuit protection system to clear the fault in a timely manner. In one particular example, an unisolated transformer fault resulted in a short circuit that lasted for about 7.5 minutes. The fault overloaded downstream power cables which caught fire and damaged adjacent control cables in the turbine building cable duct. In this case, the control cables were damaged as the result of the circuit breaker failure that lead to the cable fire but were not failed by the HEAF directly. This paper generally supports the Duke position that ground faults do not cause significant damage to surrounding cables as long as the relay protection scheme operates as designed.

Operating Experience Search Review

Operating Experience related to medium voltage cable faults was reviewed to determine applicability to ONS Keowee related cabling systems. In particular, incidents where faults propagated to phase-to-phase faults and/or resulted in damage to nearby cables was evaluated. Operating Experience was reviewed as described below. OE deemed as most applicable to ONS Keowee cabling systems are described in greater detail within Table 1 of this document. OE which resulted in phase-to-phase fault or was viewed as particularly noteworthy is further described in results section of this document following Table 1.

I. INPO ICES database with the following parameters:

Database:	INPO ICES	Documents:	Search All Document Types
Time Frame:	Anytime	Keywords:	medium voltage cable fail

The search specified above yielded OE from within the Construction Experience and Operating Experience areas within ICES. The ICES search engine uses an "And" operator for keywords specified above, but the words do not need to be in the exact order as above. This search yielded 299 ICES incidents.

The following types of incidents were omitted from further applicability consideration:

- Faults caused by equipment failures that damaged medium voltage cables
- Faults which occurred outside of the cable run (e.g. connection points, in equipment, etc.),
- Faults due to non-electrical issues that are not applicable to the Keowee trench or PSW Busduct (e.g. cable cut with a back hoe), and
- Faults where there was insufficient information available to make any determination of the cause of the cable fault.

II. While reviewing the River Bend event (May 2012) additional OE references that were not identified by the ICES search were identified. These additional OE items were included as part of this OE review.

[2] Heinz Peter Berg and Marina Röwekamp (2011). Investigation of High Energy Arcing Fault Events in Nuclear Power Plants, Nuclear Power - Operation, Safety and Environment, Dr. Pavel Tsvetkov (Ed.), ISBN: 978-953-307-507-5, InTech, DOI: 10.5772/20497. Available from: http://www.intechopen.com/books/nuclear-power-operation-safety-and-environment/investigation-of-high-energy-arcing-fault-events-in-nuclear-power-plants

III. EPRI data, INPO Topical Report TR10-69 "Cable Aging and Monitoring" (May 2010), and INPO SEN 272 "Underground Cable Ground Fault Causes Forced Shutdown" were researched. The only unique OE which was determined as applicable was an incident involving rodent damage at Browns Ferry which was seen as an anomaly. This OE was included in results, however, as rodent damage cannot be categorically disqualified.

IV. Attachment to GL 2007-01 was reviewed to determine if there were additional failure causes that were not already identified as part of the ICES search. No additional causes were identified.

V. Oconee response to GL 2007-01 — This Generic Letter requested licensee information on failures of inaccessible or undergound power cables. The response for Oconee included a single failure of the power cable for HPSW Pump B. Details below:

Cable Type:	Ethylene Propylene Rubber (EPR) cable insulation, semi-conductive and copper tape shielded.
Manufacturer:	Okonite.
Date of failure:	January 10, 1980.
Type of service:	Normally de-energized, High Pressure Service Water Pump B, 1/c-#2AWG
Voltage class:	Nominal system voltage 4160 VAC, cable rating voltage 5000 VAC.
Years of service:	Approximately 7 years.

Causes: No formal root cause was performed. Failure was discovered during periodic DC voltage testing of the pump motor. The feeder cable was included in the test circuit and its insulation "broke down" at a voltage above the operating level. Since the results were deemed unacceptable, the cable was replaced before the pump was placed back in service. The investigation report indicated that the most likely contributors were excessive exposure to moisture combined with a problem on the cable jacket.

In addition, Corrective Action Program searches identified another Oconee medium voltage cable failure. This cable provides switchyard 4.16 kV auxiliary power. During security upgrades, a guardrail post penetrated this cable which resulted in opening of the feeder breaker. Due to the nature of the cable failure (i.e. external mechanically-induced damage with no evidence of prior degradation), this was excluded from the response to GL 2007-01 and from further consideration of this review.

VI. Oconee Corrective Action Program was searched for period after NRC GL 2007-01 response to May 22, 2015 (where PIP system was retired). This research identified the CT-5 cable failure. This failure was in the cable run, was caused by a cut in the outer jacket which allowed water entry into the cable with formation of insulation water trees and a subsequent a single phase to ground fault. The cable insulation is black EPR.

Background – Oconee Cabling System Overview:

Description of Power Cable Installation in Trench 3:
The medium voltage cables in Trench 3 are installed in a precast reinforced concrete trench/duct bank system and are protected from external influences such as seismic events, tornadoes, excessive heat and lightning strike. None of the cables are direct-buried. The power cables are racked on elevated unistrut supports that comply with the cable vendor's recommendations.

The trench/duct bank system is sealed to preclude water entry and is provided with a passive drainage system at the low points. The drains are periodically inspected for proper operation. The cables have been evaluated by the Oconee Cable Aging Management Program to ensure that there are no environmental stressors that would cause premature aging or degradation.

The power cables are rated for wet or dry applications and have a modern pink EPR formulation that is less susceptible to water treeing than other insulation systems such as black EPR or XLPE. The power cables were installed and inspected using QA-1 procedures. Rigorous factory and post-installation cable testing was performed to provide assurance that the cables are defect free and were not damaged during shipment or installation. There are no cable splices.

Description of Power Cable Installation in Protected Service Water Manholes 1-6:
PSW Manholes 1-6 are sealed to preclude water entry and are provided with a passive drainage system at the low points. The drains are periodically inspected for proper operation. Per the PSW license amendment dated August 13, 2014, the accessible 13.8 kV PSW cables will be inspected every 10 years and have electrical testing every 6 years. The power cables are supported by cable tray and/or unistrut.

The power cables are rated for wet or dry applications and have a modern pink EPR formulation that is less susceptible to water treeing than other insulation system such as black EPR or XLPE. The power cables were installed and inspected using QA-1 procedures. Rigorous factory and post-installation cable testing was performed to provide assurance that the cables are defect free and were not damaged during shipment or installation. Due to the length of the cable pulls, there are cable splices in Manholes 1 and 5; however, post installation testing confirmed that the cable splices are discharge-free per IEEE standards.

Results
The following OE are the medium-voltage cable faults (21) where the fault occurred in a cable run and are determined to be most applicable to ONS underground cable system attributes. Armor type was not consistently documented in the OE items, so all cables were reviewed regardless of the fact the cable was armor or unarmored. Table 1 provides a summary applicability review of these OE. Additional detail is included following Table 1 for OE which resulted in phase-to-phase faults or where the OE description indicated damage to adjacent cables.

TABLE 1: Medium-Voltage Cable Faults Identified in ICES Search

Station	ICES Report #	Month Year	Fault Location	Fault / Propagation Cause	Propagated from L-G to L-L	Portion of Event Evaluated Against Oconee Configuration
Robinson	242331	Mar-2010	Cable run into 4 kV Cabinet	• Cause #7 • Cause #14 • Cause #6	Yes	• Cause #6
Trillo	297938	Oct-1993	Connection	• Cause #13 • Cause #6	Yes	• Cause #6
Brunswick	216026	May-2005	Cable run	• Cause #1 • Cause #2	Yes	• Cause #1 • Cause #2
Limerick	309779	Feb-2014	Cable Run	• Cause #1 • Cause #8	Yes	• Cause #1
Sequoyah	198929	June-2002	Cable Run	• Cause #1	No	• Cause #1
Browns Ferry	225047	Feb-2007	Cable Run	• Cause #1	No	• Cause #1
North Anna	237341	Apr-2009	Cable Run	• Cause #7	No	N/A
Chaulk River	238157	Jun-2009	Cable Run	• Cause #5	No	• Cause #5
Harris	251793	Nov-2011	Cable Run	• Cause #1	No	• Cause #1
River Bend	254057	May-2012	Cable Run	• Cause #3 • Cause #1 • Cause #2	No	• Cause #3 (PSW) • Cause #1 • Cause #2
Beaver Valley	308418	Nov-2013	Cable Run	• Cause #12	No	N/A
Quad Cities	311048	Apr-2014	Cable Run	• Cause #10	No	N/A
Harris	314044	Nov-2014	Cable Run	• Cause #3 • Cause #9	No	• Cause #3 (PSW)
Oconee CT5	PIP-O-11-15323	Dec-2011	Cable Run	• Cause # 1 • Cause #5	No	• Cause #1 • Cause #5
Quad Cities	300595	Jul-2012	Cable Run	• Cause #1 • Cause #9	No	• Cause #1
Callaway	219822	Feb-2006	Cable Run	• Cause #3 (In manhole)	No	• Cause #3 (PSW)
North Anna	225471	Mar-2007	Cable Run	• Cause #4 • Cause #7	No	• Cause #4
Prairie Island	237726	May-2009	Cable Run	• Cause #1 • Cause #8 • Cause #9	No	• Cause #1
Point Beach	230369	Jan-2008	Cable Run	• Cause #1	No	• Cause #1
North Anna	242196	Mar-2010	Cable Run	• Cause #15	L-G (Arcing Damaged Cable Tray)	N/A
EPRI – Browns Ferry	EPRI Report		Cable Run	• Cause #11	No	N/A

Causes:

1) Wetting / Water Tree
2) Contaminants in water accelerated Water Tree
3) Inadequate Cable Splice
4) Damaged during installation
5) Additional Damage (Cut by knife, Walking on, etc)
6) Breaker Out of Service / Failure (Mechanically or electrically) – This cause did not result in the fault, but contributed to the propagation of the fault.
7) Inadequate Support (Vertical or Horizontal)
8) Cable Manufacturer Defects
9) Direct Bury Application
10) Cable Bend Radius Exceeded
11) Rodent Damage
12) High Ambient temperature
13) Hot Spot in shunt connector
14) Installed Cable did not comply with cable specification
15) Shield Grounded on one end of the cable

Additional Details of Selected OE Items
The following OE resulted in phase-to-phase faults or indicated damage to adjacent cables.

The line to ground fault at Robinson propagated to a line to line due to the breaker being out of service and the next upstream breaker was required to clear the fault. This additional time that the fault was present increased the probability that the fault would propagate. This OE identified that the cables adjacent to the faulted cable were damaged. The damaged cables jackets were damaged due to the heat generated during the event but the cables would have been capable of providing their safety function (i.e. power or control) to mitigate a design basis event.

The line to ground fault at Trillo propagated to line to line due to the a breaker mechanical failure and the next upstream breaker was required to clear the fault. This additional time that the fault was present increased the probability that the fault would propagate. This OE did not identify that the cables adjacent to the faulted cable were damaged.

The line to ground fault at Brunswick propagated to a line to line in the three conductor cable feeding the Fire Protection System pump motor. The breakers are designed to trip once the ground faults on two phases were connected by a low impedance path. The breakers did trip as designed. This OE did not identify that the cables adjacent to the faulted cable were damage.

The line to ground fault at Limerick propagated to a line to line. Troubleshooting identified two of the three phases of the power feed cables failed due to water treeing caused by a manufacturer defect. The ground fault overcurrent relay did trip to isolate the fault. No cables adjacent to the faulted cable were damage.

The line to ground fault at Beaver Valley occurred in the Husky Bus Enclosure. The cable had been installed for 35 years and experienced diminished service life due to chronic exposure to ohmic heating. The Arc Flash event due to the fault damaged the cable within the cubical in addition to cubicle itself.

The line to ground fault on the 120VAC system at Quad Cities in 2014 did not propagate to a line to line fault. This cable was damaged due to a bend exceeding the bend radius requirement and a subsequent steam leak injected moisture into the damaged section of cable. This OE did identify that the cables adjacent to the fault cable were damaged when the rung of the cable tray began heating due to the Steam Leak and the line to ground fault. This heating led to the additional cables' insulation to melt and the cables eventually shorted as well.

OE Summary
For the 13.8kV ONS cables, the 18 Amps fault current due to a line to ground fault is well within the capability of the cable shield current capacity. Additionally, fault currents of this magnitude are not sufficient to result in damage to nearby cables should the fault penetrate the cable jacket. For the fault to propagate to a phase-to-phase fault (and thus the fault current be sufficient to expect damage to nearby cables), the initiating cable's shield and jacket would have to fail coincident with simultaneous failure of additional (phase) cable or ACB breakers.

The shielding on the 4kV cable feeding transformer CX is not capable of carrying the worst case line to ground fault. The fault current may cause a breach of the outer cable jacket. For this fault to further propagate, breaker 1TC-04 breaker would have to fail, allowing the fault to continue until the upstream breaker 1TC-14 isolated switchgear 1TC to clear the fault. The adjacent cables may be damaged if the fault is allowed to propagate. It was not immediately clear in all cases from the four OE events that did propagate to a line to line fault the extent of the damage or the cause of the damage. Since adjacent cables were damaged, it can be assumed that if the adjacent cables were control cables then they would be damaged by the fault. Damage due to the transient voltage induced on the low voltage cable due to the fault on the medium voltage cable was not discussed in any case.

Based upon the reviewed OE the line to ground faults that propagated to line to line faults occurred due to breakers being out of service, breaker failure, or detection was configured to detect line to line faults.

Conclusions

As can be seen in the licensing history of Oconee, there were several instances where the NRC reviewed the Oconee electrical design and even recognized the plant-specific single failure criteria. The plant-specific nature of the design is not surprising, given that Oconee was designed and built before most of the NRC-accepted guidance was developed. Documentation associated with the NRC's review and approval of the Oconee design is relatively lacking in detail due to the plant's vintage; however, because Oconee was built to Duke Power Company fleet design specifications that were also employed for the design and construction of the newer McGuire and Catawba nuclear power stations, consideration of the NRC's review of the design of these other Duke plants can inform a review of the Oconee design. As documented above, the NRC reviewed the cable design for McGuire and accepted the use of armored cable as a means of providing protection against fault propagation and damage to adjacent cabling.

The concern for a MV power cable fault propagating to control cabling, resulting in consequential failure(s) of DC systems is beyond the plant's design and licensing basis and is not supported by operating experience (OE). Duke Energy conducted an extensive review of OE, which concluded that cable faults resulting in damage to adjacent equipment required failures in addition to the initiating cable failure (e.g., failure or disabling of circuit protective equipment) in order to cause the collateral damage. The consideration of multiple failures is outside of the ONS single failure design criteria. In addition to active circuit protective equipment, passive design features exist to protect against the propagation of a cable fault to DC systems. As discussed previously, the ONS design employs the use of grounded cable supports and grounded shielded cables that effectively provide a series of intervening grounded barriers to protect against fault propagation. These barriers would also have to fail in order for a fault to propagate to the point of damaging DC circuits.

In conclusion, Duke Energy believes the configuration of cables in Trench 3 and the PSW ductbank is safe and in accordance with design and licensing requirements for cable routing and cable separation at Oconee that have been reviewed and accepted by the NRC.