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TENNESSEE VALLEY AUTHORITY
Division of Nuclear Engineering

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QA Record

BROWNS FERRY NUCLEAR PLANT

EVALUATION OF BROWNS FERRY NUCLEAR PLANT CABLE INSTALLATION CONCERNS

SUMMARY REPORT

(REVISION 1)

MARCH 1989

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EVALUATION OF BROWNS FERRY NUCLEAR PLANT
CABLE INSTALLATION CONCERNS

SUMMARY REPORT

PREPARED FOR

TENNESSEE VALLEY AUTHORITY
DIVISION OF NUCLEAR ENGINEERING

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1.0 INTRODUCTION

1.1 Background

During the summer of 1986, the U.S. Nuclear Regulatory Commission (NRC) began a review of concerns relating to the adequacy of construction practices at the Tennessee Valley Authority's (TVA) Watts Bar Nuclear Plant (WBN). The review identified that many of the concerns centered on potential damage to electrical cables due to alleged improper or inadequate cable installation practices. Accordingly, the NRC performed a comprehensive review to determine if significant damage had occurred to cables during their installation at WBN. Since TVA's Sequoyah (SQN) and WBN plants are based on the same overall design, the NRC extended the evaluation of the cable installation concerns to the SQN plant. The Technical Evaluation Report (TER) describing the NRC evaluation, conclusions, and recommendations regarding the concerns relating to potential abuse of electrical cable from installation practices at SQN was provided to TVA via reference 1.

TVA performed an extensive and comprehensive evaluation of those SQN issues for which the TER determined implementation was required prior to startup of that plant (reference 2). These issues were successfully resolved at SQN and its cable installation practices in these areas were demonstrated to have resulted in adequate cable installation (reference 3).

As a result of generic reviews of the Condition Adverse to Quality Reports (CAQRs) issued to document the potential conditions at SQN, these same cable installation concerns have been identified at Browns Ferry Nuclear Plant (BFN).

In order to evaluate the extent to which these concerns applied to BFN and to determine whether significant damage had occurred to cables during their installation, TVA implemented an individual indepth review on BFN. This report provides the evaluations, conclusions, and recommendations from this review for resolution of the BFN specific cable installation concerns.

1.2 Purpose

The BFN evaluation was performed to determine if significant cable abuse had occurred during installation. The plan was specifically intended to address the following:

- Determine if significant differences existed between the cable installation practices and procedures utilized in the construction of BFN and those utilized in the industry during the time period of BFN's construction.

- Perform plant walkdowns to review specific installation practices and assess the overall quality of the cable installation.

° Determine the extent to which the installed cables at BFN are enveloped by the SQN cable issue resolution program.

° Establish, as necessary, a BFN corrective action program for resolution of the cable installation concerns.

1.3 Approach

The issues of pullbys, jamming, and vertical cable supports were resolved at SQN by performing direct current high potential tests on a selected number of installed cables. During this testing, several insulation breakdowns occurred at high voltages ranging from 7.5 to 10.8 kV dc. Subsequent testing at the University of Connecticut's Electrical Insulation Research Center (Reference 20) and Wyle Laboratories (References 20 and 21) demonstrated that cables with insulation defects similar to those discovered in the failed cables were in fact in a serviceable condition and could perform their intended function during the design basis accident. This raised serious questions regarding the validity of high potential tests on installed cables. Futhermore, the NRC Advisory Committee on Reactor Safeguards, following its review of the SQN test program, stated ". . . we recommend against the continued use of high-voltage testing of installed low-voltage cables" (reference 4).

Accordingly, TVA determined that the approach for resolution of the BFN cable installation concerns should be initially based upon inspection and analysis. Forming an integral element in this program would be the extensive calculations, field inspections, and results of tests performed at SQN. In order to determine the extent to which the BFN installation is enveloped by the SQN test program, TVA performed the following:

° A walkdown of the TVA cable installation requirements which existed during the construction of BFN for comparison against the requirements which existed in the industry during that time period as well as at SQN during its cable installation (reference 5).

° A review of the cable materials and constructions utilized in safety-related applications at BFN. Special consideration was given to the cables durability or susceptibility with respect to the types of damage postulated in the TER. This review includes a comparison of the BFN cables with SQN cables, and their associated properties. The purpose of this review was to determine whether the BFN cables were more, less, or equally susceptible to installation damage when compared with the SQN cables, which were demonstrated to not have incurred installation damage (reference 6).

° A review of selected representative cable installations to examine whether any damage had occurred and to assess the relative difficulty which the conduit configuration presented to the cable installation (Reference 7). This walkdown was also intended to provide a basis for comparison of the as-installed cable configuration at BFN with that previously analyzed and/or tested at SQN.

The results of the above reviews formed the basis for the conclusions on the BFN cable installation issues and established the corrective action plan, as necessary, for resolution of each issue.

1.4 Report Format

The report addresses the individual cable installation issues which included:

Cable sidewall pressure
Cable pullbys
Cable jamming
Vertical cable supports
Cable bend radius
Pulling cable around 90-degree condulets and through mid-run flexible conduit
Use of condulets as pull points for large 600V cables R1

Sections 2.0, 3.0, and 4.0 provide an overview of the results of the examinations of installation practices, cable materials, and installation conditions, respectively. Section 5.0 provides an individual evaluation of each of the above issues; conclusions and recommendations are provided within the discussion on each issue. An overall assessment and summary of the BFN cable installation issue resolution program is provided in section 6.0. The references identified in the report are listed in section 7.0.

2.0 CABLE INSTALLATION REQUIREMENTS

The review of cable installation requirements (reference 5) concentrated on the period from issuance of the BFN construction permit in May 1967 to the time that the three BFN units were brought on line in 1973, 1974, and 1976, respectively. This report recognized that for the cable installation issues of concern, the BFN installation procedures were generally silent. The sole exception was sidewall pressure for which a limitation of 100 lb/ft was stated in January 1973. However, this requirement would have had little impact on BFN, as cable installation was virtually complete on units 1 and 2 by that time. In the area of cable pull tension, the industry recognized limit of .008 lb/cir mil was identified in TVA requirements documents prior to the beginning of BFN construction. Monitoring of pull tension became mandatory in 1973; however, this was subsequent to the majority of BFN units 1 and 2 cable pulling. Although cable pull tension is not a specific area of concern, adherence to this requirement could help alleviate concerns such as pullby, sidewall pressure, and jamming damage.

This review has identified what today might be considered a lack of proper requirements. The purpose, however, was to compare BFN against the requirements which existed at the time of its construction. To accomplish this a detailed review of industry standards and manufacturers installation recommendations was performed.

One of the earliest sources of guidance on cable installation is the Underground Systems Reference Book (reference 8) which was originally published in 1931, with the first (and last) revision in 1957. As indicated in the title, the scope of this publication focused on the installation of underground cables including buried cables, cables installed in ducts, pipe-type cables and submarine cables. The discussions on installation of cables in ducts and pipe-type cables include the considerations of cable sidewall pressure, cable jam ratio and cable bend radius. These parameters appear to have been developed specifically for the installation of paper-lead cables in underground ducts and pipes. This conclusion is supported by the numerous cautions, contained in the installation sections, regarding possible distortion or scoring of the lead sheath or distorting the oil or gas channel in low-pressure oil- or gas-filled cables. It is interesting to note that the text states "Usually, no attempts are made to measure the pulling tensions imposed on low-voltage cables."

A technical paper of the same era, "Pipe-Line Design for Pipe-Type Feeders" (reference 9) addresses the concerns of sidewall pressure and jam ratios. However these considerations are again applied specifically to pipe-type cables, which operate at very high electrical stresses and relatively high pressure with either oil or gas as the pressure medium.

The Simplex Manual (reference 10), issued in 1959, represents one of the earliest cable manufacturer handbooks. This manual, which addresses the installation of cable in ducts and conduits, provides guidance for cable sidewall pressure and bend radius. It is silent on the other cable installation issues and particular notice is taken of the lack of consideration of cable jamming.

In the late 1960s a working group was formed on Wire and Cable Systems in the Station Design Subcommittee of the Power Generation Committee of the IEEE Power Engineering Society. The work of this group would eventually be published as IEEE Standard 422-1977, "IEEE Guide for the Design and Installation of Cable Systems in Power Generating Stations." A draft version of that document was made available in November 1970 and subsequently presented at the 1971 IEEE Winter Power Meeting (reference 11). While again relating the industry recognized concerns on cable pull tension and sidewall pressure, with minor discussions on raceway bend radii, it contains no mention of or guidance for the remaining BFN installation concerns. This is especially noteworthy as it is in the time period of the major cable pulling activities at BFN.

In 1971, IEEE Standard 336 was issued. Although it's title is "Installation, Inspection, and Testing Requirements for Instrumentation and Electric Equipment During Construction of Nuclear Power Generating Plants," it contained no specific recommendations or requirements for cable installation.

The mid-1970s began to see the formal preparation and issuance of cable manufacturer installation handbooks. In 1974 Essex issued its Control Cable Engineering Handbook (reference 18) as a successor to their Underground Cable Engineering Handbook. This manual, which as indicated by its title is directed toward control cables, addresses only the requirements for cable pull tension, sidewall pressure and bend radius. The Raychem Installation Guide (reference 12) in 1976 also provides recommendations for cable pull tension, sidewall pressure and bend radius, but is silent in the other areas of concern. The Anaconda Cable Installation Manual (reference 13), first published in 1976, addresses these same considerations and provides the first reference found which applied the concern of jam ratio to all cables including low voltage. It does refine the scope, however, in its statement "For one or two conductors or for a multiconductor with an overall jacket, jamming is not applicable."

IEEE Standard 422 was issued in 1977. It still contained the recommendations, previously discussed in its 1970 draft, for cable pull tension and sidewall pressure, had expanded the discussion of the bend radius of raceways and its relationship to cable radius, and provided the first industry consensus on vertical cable supports. It did not contain any recommendations or discussion on cable pullbys, jamming or pulling around 90 degree condulets or through flexible conduit.

The Okonite Company published their first bulletin (EHB-78) in 1978 (reference 14) which addressed the installation of cable systems. This manual discusses cable pull tension, sidewall pressure and bend radius and provides specific recommendations on vertical cable support. It does not address the remaining BFN issues.

The 1979 Kerite Installation data (reference 16) reflects the changing industry philosophy and provides recommendations for cable pull tension, sidewall pressure, jamming, bend radius and vertical cable supports. No guidance or cautions are provided for cable pullbys or pulls around condulets or through flexible conduits.

The publications issued in the early 1980s reflect the state-of-the-art in cable installation today. This includes considerations of cable pull tension, sidewall pressure, jamming, vertical cable supports and bend radius. It is evidenced in the 1982 Eaton Cable Installation Guide (reference 17) and the 1984 initial issue of IEEE 690 "IEEE Standard for the Design and Installation of Cable Systems for Class 1E Circuits in Nuclear Power Generating Stations." It is noted, however, that while IEEE 690 represents the first industry consensus standard to address cable jamming, it does so only in its appendix which is not actually part of the standard itself. The Okonite "Installation Practices for Cable Raceway Systems" (reference 15) issued in 1982 contains the most comprehensive review of installation practices found in this review. In addition to the concerns addressed in the two guides discussed in this paragraph, it includes specific prohibitions on cable pullbys and pulling around 90 degree condulets. It represents, however, the recommendations of a single manufacturer and not on industry consensus.

The above constitutes a review of all known and readily available cable installation guides and standards. It is intended to show the origin and evolution of cable installation practices and requirements. In particular, it is utilized to determine those aspects of cable installation practice which would have clearly been agreed upon by a majority of cable installation experts at the time of BFN construction.

From this review it can be seen that when BFN was constructed, there did exist general industry guidance concerning cable pull tension and bend radius. The issue of cable sidewall pressure had been addressed, but there was little specific guidance. Cable jamming and vertical cable supports had not been identified as concerns for generating station cables and no requirements or recommendations existed concerning cable pullbys or pulling cable around 90-degree condulets and through mid-run flexible conduit. Specific guidance in these areas did not appear until the late 1970s, years after BFN commercial operation, and many of the issues still lack specific guidance and/or industry consensus support. It is believed that these issues were adequately addressed, as was the case at BFN, by the use of a trained and experienced workforce.

This review could find no basis for considering many of the cable installation concerns to have been industry practice around 1970, the time of major activity in BFN cable pulling. Nor was any basis found for concluding that the later requirements were determined by the industry to require backfit on previous plants. Nevertheless, each of these issues and their relationship to BFN, has been individually addressed in section 5.0 of this report.

The secondary purpose of the review of cable installation requirements was to determine the similarity of procedures utilized in the construction of BFN and SQN. The results (reference 5) indicate that cables at both BFN and SQN were installed with the same requirements with the exception of sidewall pressure. However, the SQN cable issue resolution program was performed without any credit taken for this requirement. Accordingly, from the aspect of cable installation requirements, the results of the cable resolution program at SQN are directly applicable to BFN.

3.0 CABLE MATERIAL EVALUATION

A study was performed of the cable materials and design practices utilized at BFN in comparison with those at SQN (reference 6). The purpose of this study was to determine the type of cable insulation and jacket materials installed at BFN and their relative durability with respect to the specific installation concerns. In addition, the design practices utilized in selecting cable for a particular application were to be reviewed. The information from each of these reviews would then be compared to the results of similar examinations on SQN to determine whether the BFN materials compared favorably with respect to application and ability to withstand the rigors of installation. The results of the BFN and SQN comparison would determine whether the recently completed cable resolution programs at SQN were representative, from a material and application standpoint, of those at BFN.

The results of these reviews indicate that BFN compares favorably with SQN. Perhaps of greatest significance is the fact that BFN does not utilize silicone rubber insulated cables as part of the general design practice. These cables were of the most concern at SQN. At BFN they are used strictly in pigtail extension applications where they would be relatively short lengths.

The reviews indicate that most cable contracts were shared by BFN and SQN. This would generally be expected to provide for a random selection of cable types and manufacturers for each installation, at either plant. In addition, all cables of a particular insulation material were procured to the same specification requirements, ensuring a consistent minimum level of physical properties. The installed cables at BFN are therefore considered to be equally resistive to installation damage as those at SQN. Accordingly, from the aspect of cable material and application, the results of the cable resolution program at SQN are directly applicable to BFN.

During this review, it was noted that while both plants utilize the same type of cables, BFN, due to the timeframe in which it was constructed, utilizes a greater quantity of polyethylene insulated cables. These thermoplastic cables are considered to be more susceptible to creep over time at elevated temperatures than the other widely utilized materials, which are thermosetting. This was considered in the evaluation of the individual issues in section 5.0 of this report.

4.0 CABLE INSTALLATION EVALUATION

A walkdown team was formed to perform field inspections of the BFN cable installation. The purpose was to determine if significant cable abuse occurred during installation as would be evidenced by the existing conduit configuration and inspections on selected representative conduits and cables. In addition, the walkdown was intended to provide a basis for comparison of the as-installed cable configuration at BFN with that of other nuclear plants of its vintage as well as that recently analyzed and/or tested at SQN. The results of this comparison would determine whether the recently completed cable resolution programs at SQN were representative, from an installation configuration standpoint, of those at BFN.

The results of the walkdown were very favorable (reference 7). Good craftmanship was generally exhibited, particularly in the use of cable pulling lubricant. There appeared to be a good knowledge of cable installation practices, especially with respect to the installation and routing of conduits. The compact nature of the plant, the limited number of buildings containing safety-related electrical equipment, and the close proximity of much of the interconnected equipment contributed in reducing the difficulty of the individual pulls. The installed cable configuration at BFN compared favorably with that of SQN and is similar to other plants of its vintage. Accordingly, from the aspect of installed cable and conduit configuration, the results of the cable resolution program at SQN are directly applicable to BFN.

The probability of accidents related to common mode failures from cable installation problems as postulated in the SQN TER (reference 1) is significantly reduced by the BFN cable routing practices inside the primary containment (drywell). In this area, Division I cables were generally installed in trays except where they drop from the tray to their end devices, or where a direct conduit route to the end device is shorter than the distance required to access the tray. Therefore, although Division II cables are installed only in conduit inside primary containment, it is not expected that cables of both divisions could be subjected to the same installation deficiencies.

In addition, all cables located in the three worst case harsh environment areas (drywell, steam tunnel, and heat exchanger rooms) and required for the mitigation of a design basis event that creates a harsh environment are being replaced prior to restart (see reference 7, sections 5.2.2 and 5.4.2). These replacements will be made in accordance with all presently applicable standards and specifications.

The walkdowns were performed in accordance with the issued procedure which identified specific attributes for inspection. These included conduit and cable data, accessibility of pull points, use of lubricant, conduit configuration, and the existence of any cable damage. The walkdown, however, was not restricted to only those conduits, attributes, or issues in the original procedure. Rather the walkdown team scanned the installation as a whole in all plant areas inspected, which resulted in the addition of conduits into the review for concerns such as excess bends between pull points, condulet sizing, and 4-kV cable bend radius. The walkdown results, therefore, represent an inspection even more comprehensive than originally outlined.

Subsequent to the issuance of revision 0 of this report, insulation damage was noted on cable 2ES320-I which was not observed during the initial walkdowns. Analysis of the damage and the raceway configuration led to the determination that the cuts were the result of using condulets as pull points in circuits with large, stiff, 600V single conductors. Their inflexibility, especially when coupled with a high conduit fill, resulted in a very difficult installation at the condulets. Walkdowns were performed to confirm the validity of the postulated mechanism and to confirm that the issue was bounded. A joint TVA/NRC inspection was made of cable 2ES320-I after it was removed from its conduit to further validate the mechanism. Recurrence controls have been identified. Cable 2ES320-I and its raceway, along with seven other circuits and their raceways with similar configurations will be reworked prior to unit 2 restart. R1

5.0 SPECIFIC ISSUES

5.1 Sidewall Pressure

5.1.1 Issue Description

The issue of cable sidewall pressure (SWP) is concerned with possible damage to cable shielding or insulation due to excessive radial force exerted on the insulation and jacket of a cable at a bend point, during pulling operations. A detailed description of sidewall pressure requirements, contributing factors and failure mechanisms is provided in paragraph 5.1.1 of the Cable Issues Walkdown Report (Reference 7).

This issue has been addressed at BFN, primarily by the walkdown effort which observed conduit and cable installations. The effort determined the extent or possibility of cable damage due to sidewall pressure. In addition, a comparison of installation requirements and cable insulation and jacket materials, between BFN and SQN plants, was performed to assess the applicability of SQN calculation results to BFN. The calculations performed at SQN indicated that no damage due to SWP occurred during the cable installation.

5.1.2 Conclusions

As discussed in paragraph 5.1.1 of the Cable Issues Walkdown Report (Reference 7), acceptable limits for sidewall pressure have changed with time and vary significantly between various cable types and constructions. Earlier limits for sidewall pressure, established by cable manufacturers and the industry, have been significantly increased. TVA has performed independent tests to determine sidewall pressure limits for the types of cables used in their Nuclear Program. These results are documented in TVA QA Record "Cable Sidewall Bearing Pressure Tests" (Reference 22). The TVA tests have verified relatively high limits are acceptable for cables used at BFN.

The results of the Cable Issues Walkdown Report indicate that the possibility of damage to cables installed at BFN due to excessive sidewall pressure is not of concern. The walkdown evidence indicates good workmanship as reflected in the use of an adequate number and location of pullpoints and also that the pullpoints were utilized during cable installation. The installed conduit configurations were similar in severity to those analyzed in the SQN SWP calculations. Calculations performed on the worst-case observed conduits at BFN indicated that allowable SWP was not exceeded.

Cable materials analyzed for potential damage due to SWP at SQN are similar to those used at BFN and have similar durability with respect to SWP damage. This is demonstrated by the Materials Evaluation Report (Reference 6).

Overall conclusions drawn from the above is that the possibility of damage to cables due to sidewall pressure is not of concern based on SQN calculation results, their applicability to BFN, and the BFN walkdown conclusions.

5.1.3 Recommendations

No further corrective action is required for the issue of cable sidewall pressure.

5.2 Pullbys

5.2.1 Issue Description

A pullby is the pulling of one or more new cables past previously installed cables in a conduit. A pullback is the removal of one or more (but not necessarily all) cables previously installed in a conduit. Depending upon the conduit conditions and nature of the pull (removal), it could be possible for the pulled (removed) cables to "saw through" the insulation of the previously installed cables. For the purposes of this report, the term pullby refers to the concerns for pullbys and pullbacks. A detailed description of the pullby issue, contributing factors, and failure mechanisms is provided in Paragraph 5.2.1 of the Cable Issues Walkdown Report (Reference 7).

The issue of pullbys has been addressed at BFN by the performance of inspection walkdowns and by comparison of BFN installation requirements/practices and cable materials to those utilized at SQN to determine applicability of SQN test results.

5.2.2 Conclusions

The SQN TER (Reference 1) raises specific concerns regarding the pulling of abrasive manila, or braided synthetic pull lines, and thermosetting jacketed cables over previously installed thermoplastic insulated/jacketed cables. BFN walkdown observations found no evidence of braided pullropes being used for pullbys. This was supported by the high incidence of left-in-place insulated pull wires. Although the authors of this report do not condone use of pull wires/ropes that were installed with previous cables, it was observed that the BFN practice of using No. 10 AWG insulated wire as pull wire is preferrable to other more abrasive options.

Due to the time frame of TVA's revision to cable procurement specifications (i.e., transition from polyethylene type cables to cross-linked cables in 1975), it is obvious that the majority of post commercial operation maintenance/modification pullbys would result in thermosetting cables being pulled over thermoplastic cables.

The authors of this report agree with conclusions drawn in the SQN TER that the most important consideration in preventing pullby damage is adequate use of lubrication. The Cable Issues Walkdown Report identified cable lubricant in more abundance at pullby inspection points than in non-pullby condulets. This indicates that BFN craftsmen understood the need to provide abundant lubrication when performing pullbys.

In addition, the Cable Issues Walkdown Report found no evidence of pullby damage. Conduit installation practices utilized limited distances and number of bends between pull points, which is a favorable factor in preventing pullby damage. All walkdown evidence indicated that installed pull points were utilized. In addition, the Cable Issues Walkdown Report indicates that pullbys were limited to control cable installations.

SQN pullby test results addressed a wide range of cable types/materials including thermoplastic insulation/jacket materials (See Reference 19). Based upon review of the SQN test results, the installed configurations and the Materials Evaluation Report (Reference 6), it was concluded that the SQN pullby tests encompassed the pullby situations at BFN.

It should also be noted that all cables located in the three worst case harsh environment areas (Drywell, steam tunnel and heat exchanger rooms) and required for the mitigation of a design basis event that creates a harsh environment shall be placed prior to restart in conformance with presently applicable standards and specifications. (See References 23-26.)

5.2.3 Recommendations

Based on the conclusions stated above recommendations regarding the pullby issue are as follows:

° TVA should ensure that specifications and site procedures achieve the following:

1. Provide direction to not use previously installed pull wires or cables as pull lines. Pull lines should be non-abrasive.

2. Length of pullby cable should be limited.

3. A high quality, flowable, pull lubricant such as "Polywater J" should be utilized for pullbys.

TVA has, in place, a program to identify any adverse trend of cable failures that could result from pullby cable damage. This program should be continued with appropriate actions to be initiated in the event of cable failures resulting from pullby damage.

5.3 Jamming

5.3.1 Issue Description

When the ratio of the inside diameter of a conduit to the cable diameter is close to 3.0, one of the cables in a pull of three cables of equal diameter could slip between the two others and cause them to wedge in the conduit. By definition this results in a sudden large increase in tension and the pull would be stopped. If not, the tension would increase to the point where either the pulling line breaks or the insulation is crushed or deformed, thereby releasing the tension and rendering the cable useless.

A more detailed discussion on jamming may be found in Paragraph 5.3.1 of the Cable Issues Walkdown Report (Reference 7).

5.3.2 Conclusions

The results of the Cable Issues Walkdown Report show that the possibility of damage to cables at BFN due to jamming is not of concern. The two companion reports indicate that the cables at SQN and BFN were installed under similar specifications and the materials are similar in durability with respect to jamming damage. In addition, 45 conductors of the same kind were HVDC tested at SQN without any failures.

5.3.3 Recommendations

No further corrective action is required for the issue of cable jamming at BFN.

5.4 Vertical Cable Supports

5.4.1 Issue Description

The issue of vertical cable supports addresses concerns regarding cable damage due to excessive strain resulting from improperly supported cables in a vertical section of conduit. Of special concern are instances where a conduit fitting, box, or termination device is located at the top of a vertical section of a conduit which can result in damage to cable jacket and insulation due to the cable being forced to conform to sharp changes in direction at edges of the fittings. A detailed description of the vertical cable supports issue is presented in the Cable Issues Walkdown Report (Reference 7) paragraph 5.4.1.

The issue of vertical cable supports at BFNP has been addressed by performance of inspection walkdowns and by comparison of BFN installation requirements and practices and cable materials to those utilized at SQN to determine applicability of SQN cable testing.

5.4.2 Conclusions

Analysis of the SQN cable tests for the vertical cable supports issue and the Materials Evaluation Report reveals that the SQN tests are not applicable to BFN due to differences in cable insulation materials.

The Cable Installation Requirements Report (Reference 5) shows the requirements for vertical cable supports were not in effect at either BFN or SQN until after commercial operation of both plants, therefore the cables were installed under similar conditions.

The Cable Issues Walkdown Report identified a potential for cable damage due to this issue. Also the walkdown sample did not include medium voltage cables.

5.4.3 Recommendations

Based on the walkdown results for the inspected cable, it is recommended that all conduit containing medium voltage (5 kV and above) Class 1E cables be walked down to verify that vertical sections are properly supported to the current TVA General Construction Specification G-38 criteria. Vertical sections of cable not properly supported should be HVDC tested at the maintenance voltage levels specified in IEEE Standard 400 and supports added if the cable passes the test. This recommendation is based on the increased potential for electrical fault in these cables due to the higher voltage stresses that could occur at jacket/insulation deformations. This is a pre-restart recommendation.

With respect to low-voltage power and control circuits, it is recommended that the original walkdown effort described in the Cable Issues Walkdown Report (Reference 7, paragraph 5.4.2) be continued. This will identify situations with cable deformations or substantial strain on cables in a condulet or similar fitting. These cables should be tested by insulation resistance testing in accordance with IEEE Standard 690 (see Paragraph 1.3, "Approach" for the reservations about high-voltage dc testing) and supported if the cable passes the test. This recommendation is post-restart. However, it is felt by the authors of this report that TVA management should pursue resolution of this matter within a reasonable time frame of two years. The authors of this report feel that the recommendation for post-restart completion of the walkdown of low-voltage power and control cables in vertical runs is justified for the following reasons:

- No damage that would result in immediate concern was observed.
- Low-voltage power and control cables generally operate at or below temperature ratings, below voltage ratings, and with low-voltage stress.
- Multi-conductor control cables have the protection of sheaths and the added protection of binders.
- The major area of concern is the effect of a DBE on thermoplastic insulation in vertical run situations, with condulets at the top and located in containment and steam tunnel areas. All cables located in the three worst case harsh environment areas (Drywell, steam tunnel and heat exchanger rooms) and required for the mitigation of a design basis event that creates a harsh environment shall be replaced prior to restart in conformance with presently applicable standards and specifications. (See References 23-26.)
- TVA has in place a program that would identify an adverse trend of cable failures that could result from insulation damage due to inadequately supported cables in vertical conduit.

5.5 Cable Bend Radii

5.5.1 Issue Description

The Cable Bend Radii issue addresses the concern regarding bending of cables beyond a specified limit. Cable manufacturers have assigned minimum bend radius values to preclude any possibility of damage to the cable. The effects of exceeding the bend radius are different for medium (5 kV and above) than for low voltage power, control and instrumentation cables. This is discussed further in the Cable Issues Walkdown Report (Reference 7, paragraph 5.5.1).

5.5.2 Conclusions

The Cable Issues Walkdown Report revealed cases of cable bend radius violations. Violations were found in instrumentation, control, and power cables. In gen.ral, any degradation of instrument cables due to bend radius deficiencies will be detected as a result of routine instrument calibration and maintenance. Therefore, no corrective action for these cables is necessary.

Low voltage power and control, as well as instrumentation cables, which exceed manufacturer's recommended bend radius are not likely to experience failures other than of a random nature since they generally operate below temperature ratings, voltage ratings, and with low voltage stress. Medium voltage cables which exceed bend radius limits are of concern due to the possibility of corona discharge initiated failure.

5.5.3 Recommendations

Based on the results of the Cable Issues Walkdown Report (Reference 7, paragraph 5.5.3), the comparison of materials in the Materials Evaluation Report (Reference 6) and the Cable Installation Requirements Report (Reference 5) the recommended action for closure of the cable bend radius issue is the performance of a walkdown of Class 1E medium voltage cables. This walkdown should inspect these medium voltage cables using G-38 requirements as acceptance criteria. Any cables which do not meet this criteria will be technically justified or replaced to ensure compliance with G-38 requirements. This is a pre-restart recommendation.

5.6 Pulling Through 90 Degree Condulets and Mid-Run Flexible Conduit

5.6.1 Issue Description

According to the SQN TER (Reference 1), cable being pulled through flexible conduit is subjected to additional sidewall pressures due to the reduced internal surface area caused by the convolute structure of the flexible conduit. The TER also states that a cable that stops moving during a pull will tend to have its surface locked into the corrugations of the flex conduit, causing additional stress on the cable when the pull is resumed. The TER further states that sidewall pressure is substantially increased when a cable is "pulled under tension around the inside edge of a 90 degree condulet".

5.6.2 Conclusions

The results of the walkdown (Cable Issues Walkdown Report, Reference 7, paragraph 5.6.3) indicates minimal use of mid-run flexible conduit at BFN. Where flexible conduit was used, it was observed at locations adjacent to a pull point that would have allowed the flexible conduit to be installed over the cable for the initial pull. No indications of cable damage from pulls around condulets were observed. Discussion with BFN electricians verified that condulets were being used as pullpoints.

5.6.3 Recommendations

Based on the walkdown results, no further corrective action is required for this issue.

5.7 Use of Condulets as Pull Points for Large 600V Cables

5.7.1 Issue Description

During the initial walkdown, (February 1988) cable 2ES320-I was inspected for the issues of jamming and sidewall pressure. Three small cuts (approximately one-half inch long) in the jacket were observed. The cuts were located inside one of two back-to-back three-inch LBs directly above the 480V Reactor MOV Board 2A, Panel 5. The cuts were judged to be insignificant in nature and not indicative of either jamming or excess sidewall pressure. No insulation damage was noted at that time.

In November 1988, in response to a request from the NRC staff for additional detail regarding these cuts, a supplemental inspection was made. At this time tape was noted on one conductor in the LB containing the cuts. This tape had not been noted in the first walkdown as a result of the dust ithin the fitting. Taping of inidividual conductors is sometimes used by electricians to provide temporary identification of a particular phase during installation. However, since it is also an approved jacket repair procedure in a mild environment, a maintenance request was prepared and the tape removed. This revealed a radial cut in the jacket which exposed an oblong area of insulation with a major axis of 1" and a minor axis of 3/8". A small piece of insulation was missing (approximately 1/8" in diameter and estimated to be 10 mils deep) and a cut was visible. The jacket partially covered the area of the cut; therefore, complete inspection was impossible. R1

In order to determine if the damage was isolated to this one circuit or a widespread condition the balance of those unit 2 safety related cables having the same raceway and cable configuration (i.e. those others in the jam ratio) were inspected. The condition of cables at every raceway access point as well as at the termination points was evaluated. Jacket damage was noted on three other cables, however no further instances of insulation damage were observed. It was noted that each raceway where damage occured contained a standard format condulet.

From this it was postulated that the cause of the damage was the use of standard format condulets in circuits containing large, stiff cables of single conductor construction. Furthermore, it was believed that as conduit fill levels increased the resulting congestion at the condulet opening made the installation even more difficult.

In order to verify the proposed mechanism and to bound the problem, safety related cables in conduit were identified to ascertain if there were any which were;

1. larger in size and therefore potentially more severe,

2. equal in size and potentially equivalent,

3. and smaller. This latter group being more flexible would provide evidence of whether or not the lower bounds had been identified. R1

The subject identification process yielded a family of circuits which could be ranked for severity according to their fill percentage. No 500 MCM safety related cables in conduit were identified. Of the remaining 400 and 300 MCM cables, some had a higher fill than 2ES320-I and some had a lower fill.

Further walkdowns were conducted which revealed no additional damage. The circuits with a higher fill percentage utilized pull boxes rather than condulets and so did not have the congestion problem. These with lower fill percentages appear to have had a combination of adequate space and flexibility so as to preclude damage at the condulets.

5.7.2 Conclusions

The Cable Issues Walkdown Report shows that the use of standard format condulets in circuits containing large, stiff, single-conductor 600V cable has resulted in several cases of jacket damage and one case of insulation damage.

Subsequent analysis and inspections have identified the damage mechanism and provided assurance that the suspect family has been identified.

5.7.3 Recommendations

All eight circuits identified in the walkdown report as 3-400MCM cables installed in three inch conduit and utilizing standard format condulets as pull points should be replaced prior to unit 2 restart. In addition, the raceways for these circuits should be reworked to eliminate the use of condulets and to avoid being in the critical jam ratio range. R1

6.0 SUMMARY

The cable installation concerns at BFN arose from a review of concerns at other TVA facilities. An examination of the evolution of the requirements which form the basis for the concerns indicates that many were not in effect, and would not have clearly been agreed upon by a majority of cable installation experts, at the time of BFN construction. Furthermore, no basis was found for concluding that the later requirements were determined by the industry to require backfit on previous plants. This appears to be justified by the excellent operating history of electrical cables with respect to installation concerns. This is true not only in the nuclear industry as a whole but also specifically at BFN, which in its decade of operation has a reported random failure rate for control and low voltage power cables near zero. NUREG/CR4257, Appendix B (Reference 27) "Representative Failure Modes and Causes for Cables Screened from LER Data Base" does not show any failures caused by the type of cable installation deficiencies listed in the TER.

The above information notwithstanding, TVA implemented an extensive and comprehensive review of each of the concerns as it applied to BFN. Mindful of the concerns and cautious of many senior members of the cable industry and the NRC Advisory Committee on Reactor Safeguards, the BFN program was structured to provide a firm basis for its conclusions without resorting to the type of high potential testing performed at SQN. However, it was recognized that the SQN program represented one of the most indepth evaluations of installed cables performed in the nuclear industry.

The BFN cable resolution program was therefore designed to utilize the knowledge and results gained in the SQN experience. This information was applied to BFN, however, only when technically justified from an individual review on each issue. This review included an examination of the installation practices and procedures utilized at each plant during construction as well as the properties of the cable materials with respect to susceptibility to installation damage. In addition, an extensive walkdown was performed to gather BFN specific installation information and to provide a basis for determining the comparableness between BFN and SQN.

The results of the BFN program represent an effort equal to the SQN program in the depth and breadth of physical and literature examination and technical support. The walkdown effort alone far exceeded that on which the original SQN TER concerns were based, both in the extent of the attributes, and the scope of the installations, examined.

This report has demonstrated the integrity of cables installed at BFN. Implementation of the recommendations contained herein, along with the separate upgraded installation procedures recently issued, will ensure that this integrity is maintained.

The damage to cable 2ES320-I was identified subsequent to the issuance of revision 0 of this report. That damage was determined to have not been attributable to any of the six issues which this effort was undertaken to resolve. This new issue has been scoped and bounded and all cables sharing common significant attributes have been targetd for a total rework of both cable raceways pior to unit 2 restart. As a result, this issue is considered closed and the conclusions of the initial issue of this report are revalidated. R1

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ENCLOSURE 2

BROWNS FERRY NUCLEAR PLANT
CABLE ISSUES WALKDOWN REPORT