FLORIDA POWER AND LIGHT COMPANY
TURKEY POINT UNITS 3 AND 4
OUTSIDE CONTAINMENT LIMITORQUE WIRE REPORT

JPE-PTPO-87-350

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1.0 INTRODUCTION

Limitorque operators within the scope of 10CFR50.49 at Turkey Point Units 3.& 4 were inspected in response to I.E.N. 86-03 to insure that they contained qualified wires. As a result of that inspection, several wires were found in outside containment operators which were either not of a type qualified by Limitorque or were not identifiable.

In all cases where wires were found which were not of a type identified as qualified for use at Turkey Point, the wires were replaced with a qualified type. Wires which are considered to be qualified are:

1) Teledyne Thermatics, Tefzel 280, Doc Pac 36.0
2) Rockbestos, Firewall SIS, Doc Pac 23.0
3) Raychem, Flamtrol, Doc Pac 21.2
4) General Electric, SI57279, Doc Pac 13.0

Five types of wire were identified for which nuclear type test documentation was not supplied. However such insulation did have a (UL) label linking it to industry tests and manufacturing procedures. Each of these types is insulated with either PVC or with X-linked polyethylene.

Manufacturer and type of wire could not be identified for some wires. This was because the wires were typically short and bore either no marking, incomplete marking, or unidentifiable marking.

A visual inspection was performed on each wire removed. There were no signs of aging or cracking evident in any of the insulation. All wires appeared to be in good condition and were functional when they were replaced with their fully qualified counterparts.

This report is an investigation of the types of wire found and of the operability of the Limitorque operators containing these wires.

2.0 REQUIRED ENVIRONMENTAL PARAMETERS

Normal operating temperatures

Doc Pac 17.2 for Limitorque operators provides that the normal ambient temperature for all outside containment Limitorque operators is 40°C. Assuming a 5°C temperature rise inside the switch compartment cover to account for occasional short duration operation of the valves, 45°C is the assumed normal ambient temperature inside the switch compartment cover. Since the wires are all in low current control service, self heating of the wires is negligible. Therefore the assumed normal operating temperature of the wires is 45°C.

Accident conditions

The Limitorque operators outside containment on the 50.49 list can be subjected to either of two distinct types of harsh environments. None of the operators could be exposed to both types of accidents.

The first group consists of the following tag numbers:
MOV-3/4-350, 843A, 843B, 860A, 860B, 863A,863B, 869, 872, 880A, 880B
MOV-878A, 878B.

Limitorque doc pac 17.2 Rev.0 provides that these operators could be exposed to radiation but not to excessive temperature. These operators are located in the auxiliary building. The highest dose expected in this area is 2.0×10^{6} rads at the outside of the switch compartment cover. This is the total integrated dose over 40 years of normal operation followed by the worst-case design basis accident. The longest required operating time is 31 days post accident.

The second group consists of the following tag numbers:
MOV-3/4-1403, 1404, 1405.

Limitorque doc pacs 17.2 and 17.3 provide that these operators could be exposed to steam but not to excessive radiation. These are located near high energy secondary coolant lines. A line rupture could result in short term temperature of 212°F at the outside of the switch compartment cover. The longest required operating time for any of these operators is 30 minutes post accident.

Furthermore, Reference 4) documents a high energy line break experiment performed by Research Dynamics Inc. under supervision of Florida Power & Light Co. During the test a Limitorque operator was subjected to an environment more severe than the Turkey Point required temperature profile for an outside containment high energy line break.

The test data demonstrates that the temperature inside the limit switch compartment will not exceed 179°F (82°C) where the wires are located. The test temperature profile exceeded the required profile for conservatism. Self heating of the wires is negligible since they are in low current control service. During the test the wires were energized and the valve was cycled periodically.

Assuming a 5°C temperature rise inside the switch compartment cover to account for occasional short duration operation of the valves, 87°C is the assumed accident ambient temperature inside the switch compartment cover. Since the wires are all in low current control service, self heating of the wires is negligible. Therefore the assumed accident operating temperature of the wires is 87°C.

3.0 OPERABILITY OF VULKENE SIS VW-1

Vulkene SIS VW-1 was identified as follows:

DESCRIPTION - 12 AWG stranded CU
MARKINGS - 12 AWG 600V E-7088-L VULKENE SIS (UL) VW-1
MANUFACTURER - General Electric
UL RATING - SIS
INSULATION TYPE - Cross-Linked Polyethylene

As was stated in the introduction, all removed wires were inspected and no age related degradation of the insulation was found. The following demonstrates that no age related degradation (cracking or difficulty of bending) would be expected.

This type is insulated with cross-linked polyethylene. It is qualified in accordance with IEEE 323-1983 as documented in reference 6). It can withstand all required environments as given in section 2.0 with margin as demonstrated below.

Reference 6) documents that the test samples were subjected to 1×10^5 rads to simulate radiation received during normal plant operation. The samples then received 1×10^8 rads to simulate accident conditions inside containment.

Section 2.0 provides that the maximum exposure of this wire is 2.0×10^6 rad. The tested dose exceeds the requirement of 2.0×10^6 rad with ample margin.

Reference 6) also provides that the test samples were then subjected to the following high temperature environment:

1) 150°C for 100 hours in circulating air for thermal aging.

The samples were then subjected to the following steam environment to simulate a LOCA.

2) 296°F for 1.1 hours
3) ramp from 296°F to 190°F in 1.1 hours
4) ramp from 190°F to 120°F in 17 days

Reference 6) documents that the test samples passed the above exposure in accordance with IEEE 323-1983.

Qualified life

It is now demonstrated that the period 1) exposure envelopes the 20 year installed life at assumed normal operating temperature. This is done by calculating equivalent life at 45°C using Arrhenius methodology. See section 2.0 for derivation of assumed normal operating temperature.

Doc Pac 1001 Rev.0 Appendix D provides that the activation energy for X-linked polyethylene is 1.13 eV.

Reference 2) (EQN.4-16) provides:

$$\ln(t2/t1) = A/K\ (1/T2 - 1/T1)$$

where
- t2 is the life at temperature T2
- t1 is the life at temperature T1
- T2 is temperature in degrees Kelvin
- T1 is temperature in degrees Kelvin
- A is the activation energy (eV)
- K is Boltzmans constant = 8.617E-5

Rearranging the equation and substituting data from test period (1) above:

$$t2 = (t1)\, e^{[A/K\ (1/T2 - 1/T1)]}$$

where
- T2 = 45 + 273.15 = 318.15 degrees Kelvin
- A = 1.13 eV
- t1 = 100 hours
- T1 = 150 + 273.15 = 423.15 degrees Kelvin

$$t2 = 100\, e^{[\ 1.13\ /\ 8.617E\text{-}05\ (\ 1/\ 318.15\ -\ 1/\ 423.15\ )]}$$

t2 = 2766363 hours

$$2{,}766{,}363 \text{ hours} \times \frac{1 \text{ year}}{8760 \text{ hours}} = 315.79 \text{ years}$$

Based on the period 1) test exposure of 150°C for 100 hours, the qualified life of Vulkene SIS VW-1 wire for Turkey Point installed in outside containment Limitorque operators is greater than the 40 year design life of the plant. This exceeds the 20 year installed life of these wires.

<u>Performance under accident conditions at the end of installed life</u>

It is now demonstrated that the period (2) exposure envelopes the required temperature profile for a main steam line break outside containment at the end of installed life.

Section 2 provides that these wires will not exceed 87°C during accident conditions. The following calculation does not take credit for the thermal lag of the Limitorque operator. The full 100°C steam exposure is used for conservatism. Assuming a 5°C temperature rise to account for occasional short duration operation of the valves, 105°C is the assumed highest accident temperature of these wires.

The period 2) test exposure was 296°F (146°C) for 1.1 hours. This envelopes the required main steam line break temperature profile of 30 minutes at 105°C with ample margin.

This material is therefore acceptable as an electrical insulator after being subjected to the worst case postulated radiation or temperature exposure inside a Limitorque operator outside containment at the end of its installed life.

Based on the foregoing it has been demonstrated that Limitorque operators containing Vulkene SIS VW-1 wire located outside containment at Turkey Point would have performed their safety function had they been called upon to do so.

Additional testing covering Vulkene SIS VW-1 type wire is contained in Turkey Point Doc Pac 13.0.

4.0 OPERABILITY OF (UL) IDENTIFIED WIRES

Table 1 lists identified wire types found in the outside containment Limitorque valve operators. These wires are all insulated with either PVC or X-linked polyethylene.

Section 4.1 demonstrates that the insulation has a useful life longer than the installed life and could then withstand a design basis accident.

Section 4.2 contains a discussion of the radiation resistance of PVC and X-linked polyethylene. It is demonstrated that the insulation would have remained useful if it had been called upon to withstand a design basis radiation exposure.

Section 4.3 contains a discussion of operability during and following harsh temperature exposure. It is demonstrated that the insulation would have remained useful if it had been called upon to withstand a design basis temperature exposure.

4.1 USEFUL LIFE OF PVC AND POLYETHYLENE INSULATION

As was stated in the introduction, all removed wires were inspected and no age related degradation of the insulation was found. The following demonstrates that no age related degradation (cracking or difficulty of bending) would be expected.

The maximum installed life of any of these wires has been approximately 20 years. This is the time between original installation during construction of the power plant and the time when the wires were removed.

Doc Pac 17.2 for Limitorque operators provides that the normal ambient temperature for all outside containment operators is 40°C. Assuming a 5°C temperature rise to account for occasional short duration operation of the valves, 45°C is the assumed normal ambient temperature of these wires since the wires are all in low current control service.

The lowest (UL) temperature rating of any of these wires was 60°C. Section 2) provides that the assumed normal operating temperature of the wires is 45°C. Therefore all of these wires are well within their temperature ratings during normal operation.

Section 2.0 of this report provides that these wires will not exceed 87°C during accident conditions. The following calculation does not take credit for the thermal lag of the Limitorque operator. The full 100°C steam exposure is used for conservatism. Assuming a 5°C temperature rise to account for occasional short duration operation of the valves, 105°C is the assumed highest accident temperature of these wires.

Doc Pac 1001 Rev. 0 Appendix D provides that:

(1) $\log_{10}(\text{life in hours}) = \dfrac{\text{slope of curve}}{\text{ambient temp (°K)}} + \text{intercept of curve}$

(2)	PVC	X-linked polyethylene
slope=	5000	5676
intercept=	-10	-10.77
act. energy=	.99	1.13

Reference 2) (EQN.4-16) provides:

(3) $\ln(t2/t1) = A/K\ (1/T2 - 1/T1)$

where
t2 is the life at temperature T2
t1 is the life at temperature T1
T2 is temperature in degrees Kelvin
T1 is temperature in degrees Kelvin
A is the activation energy (eV)
K is Boltzmans constant = 8.617E-5

Useful life of PVC:

Substituting data (2) for PVC into equation (1) above:

$$\log_{10}(\text{life in hours}) = \frac{5000}{45°C + 273} - 10 = 5.72$$

life in hours = $10^{5.72}$ hours = 524,807 hours at 45°C

Section 4.3 of this report provides that PVC has been tested at 121°C for 1 hour in a circulating air oven per (UL) standards. Therefore no chemical reactions or phase changes occur at or below 105°C. It is therefore acceptable to use arrhenius methodology to calculate equivalent life as follows.

The equivalent life at 45°C representing the 30 minute accident duration at 105°C is calculated:

Rearranging equation (3) and substituting data (2):

$$t2 = (t1)\, e^{[A/K\,(1/T2 - 1/T1)]}$$

where

T2 = 45 + 273.15 = 318.15 degrees Kelvin
A = .99 eV
t1 = .5 hours
T1 = 105 + 273.15 = 378.15 degrees Kelvin

$$t2 = .5\, e^{[\,.99\,/\,8.617E{-}05\,(\,1/\,318.15 - 1/\,378.15\,)]}$$

t2 = 154 hours

Subtracting the equivalent life at 45°C representing the 30 minute accident duration at 105°C from the total useful life at 45°C:

524,807 hours - 154 hours = 524,653 hours

$$524{,}653 \text{ hours} \times \frac{1 \text{ year}}{8760 \text{ hours}} = 59.9 \text{ years}$$

The useful life of PVC insulation is 59.9 years at 45°C plus 30 minutes at 105°C. This exceeds the 20 year installed life of the wires.

useful life of X-linked polyethylene:

Substituting data (2) for X-linked polyethylene into equation (1) above:

$$\log_{10}(\text{life in hours}) = \frac{5676}{45°C + 273} - 10.77 = 7.079$$

life in hours = $10^{7.079}$ hours = 11,996,556 hours at 45°C

Section 4.3 of this report provides that X-linked polyethylene has been tested at 121°C for 1 hour in a circulating air oven per (UL) standards. Therefore no chemical reactions or phase changes occur at or below 105°C. It is therefore acceptable to use arrhenius methodology to calculate equivalent life as follows.

The equivalent life at 45°C representing the 30 minute accident duration at 105°C is calculated:

Rearranging equation (3) and substituting data (2):

$$t2 = (t1)\, e^{[A/K\,(1/T2 - 1/T1)]}$$

where

T2 = 45 + 273.15 = 318.15 degrees Kelvin
A = 1.13 eV
t1 = .5 hours
T1 = 105 + 273.15 = 378.15 degrees Kelvin

$$t2 = .5\, e^{[\,1.13 / 8.617E\text{-}05\,(\,1/318.15 - 1/378.15\,)]}$$

t2 = 346 hours

Subtracting the equivalent life at 45°C representing the 30 minute accident duration at 105°C from the total useful life at 45°C:

11,996,556 hours - 346 hours = 11,996,210 hours

$$11{,}996{,}210 \text{ hours} \times \frac{1 \text{ year}}{8760 \text{ hours}} = 1369 \text{ years}$$

The useful life of X-linked polyethylene insulation is 1369 years at 45°C plus 30 minutes at 105°C. This exceeds the 20 year installed life of the wires.

4.2 RADIATION RESISTANCE OF PVC AND X-LINKED POLYETHYLENE

Section 2.0 of this report provides that maximum normal operating exposure plus accident exposure for Limitorque operators outside containment is 2.0×10^6 rad.

Wire types 1, 3 and 4 are insulated with PVC. Reference table 1 of this report for wire types.

Reference 1) page 3-11 discusses radiation test results of various formulations and configurations of PVC. The conclusions are that no serious damage occurs below 5×10^6 rads. One sample lost less than 20% tensile strength at 1×10^8 rads.

Reference 2) page C4 shows PVC as being generally satisfactory as an insulating material at exposures exceeding 1×10^7 rads. This is 5 times the expected worst case dose.

This material is therefore acceptable as an electrical insulator after being subjected to the worst case postulated exposure of 2×10^6 rads.

Wire types 2 and 5 are insulated with X-linked polyethylene. Reference table 1 of this report for wire types.

Reference 1) page 3-16 discusses radiation test results of X-linked polyethylene. The conclusion is that no serious damage occurs below 4.4×10^6 rads. Service limits of 1×10^8 are recommended.

Reference 2) page C4 shows polyethylene as incurring only incipient to mild damage at exposures exceeding 1×10^7 rads. This is 5 times the expected worst case dose.

This material is therefore acceptable as an electrical insulator after being subjected to the worst case postulated exposure of 2×10^6 rads.

4.3 OPERABILITY DURING AND FOLLOWING HARSH TEMPERATURE EXPOSURE

Underwriters Laboratories requires all wires bearing the (UL) label to undergo certain tests as outlined in various UL standards. This is a discussion of the tests required for each UL listed type identified in table 1 of this report and of their ability to withstand the worst-case postulated temperature exposure.

TW

Types 1 and 4 are UL rated TW wires.

Reference 8, paragraph 37.1 provides that UL rated TW wire undergo a heat-shock test. The wires must be subjected to 121°C for 1 hour in a circulating air oven. The wires shall not show any cracks either on the surface or internally after completing the test.

Section 2.0 of this report provides data that the accident operating temperature of these wires is 87°C for 30 minutes. If the thermal lag is not considered, using the full 100°C steam exposure for conservatism, and assuming a 5°C temperature rise to account for occasional short duration operation of the valves, 105°C is then the highest accident temperature of these wires.

The (UL) test of 121°C for 1 hour envelopes the conservative accident profile of 105°C for 30 minutes with margin.

This insulation type is therefore acceptable as an electrical insulator after being subjected to the worst case postulated temperature exposure.

Based on the foregoing it has been demonstrated that Limitorque operators containing UL type TW wires located outside containment at Turkey Point would have performed their safety function had they been called upon to do so.

SIS

Types 2 and 5 are UL rated SIS wires.

Reference 11, Table 50.231 provides that UL rated SIS wire undergo an aging test. The wires must be subjected to 121°C for 1 hour in a circulating air oven. The wires must retain at least 70% of their original elongation after completing the test.

Section 2.0 of this report provides data that the accident operating temperature of these wires is 87°C for 30 minutes. If the thermal lag is not considered, using the full 100°C steam exposure for conservatism, and assuming a 5°C temperature rise to account for occasional short duration operation of the valves, 105°C is then the highest accident temperature of these wires.

The (UL) test of 121°C for 1 hour envelopes the conservative accident profile of 105°C for 30 minutes with margin.

This insulation type is therefore acceptable as an electrical

insulator after being subjected to the worst case postulated temperature exposure.

Based on the foregoing it has been demonstrated that Limitorque operators containing UL type SIS wires located outside containment at Turkey Point would have performed their safety function had they been called upon to do so.

TFN

Type 3 is UL rated TFN wire.

Reference 10, paragraphs 54.1 and 54.2 provide that UL rated TFN wire undergo a heat-shock test. The wires must be subjected to 121°C for 1 hour in a circulating air oven. The wires shall not show any cracks either on the surface or internally after completing the test.

Section 2.0 of this report provides data that the accident operating temperature of these wires is 87°C for 30 minutes. If the thermal lag is not considered, using the full 100°C steam exposure for conservatism, and assuming a 5°C temperature rise to account for occasional short duration operation of the valves, 105°C is then the highest accident temperature of these wires.

The (UL) test of 121°C for 1 hour envelopes the conservative accident profile of 105°C for 30 minutes with margin.

This insulation type is therefore acceptable as an electrical insulator after being subjected to the worst case postulated temperature exposure.

Based on the foregoing it has been demonstrated that Limitorque operators containing UL type TFN wires located outside containment at Turkey Point would have performed their safety function had they been called upon to do so.

5.0 OPERABILITY OF UNIDENTIFIED WIRES

Manufacturer and type of wire could not be identified for some wires. This was because the wires were typically short and bore either no marking or incomplete marking. These wires typically resembled the wires described in the previous two groups. It is likely that they were insulated with one of the same materials. No further testing has been performed to demonstrate this, however these wires are considered acceptable for the following reasons.

As was stated in the introduction, all removed wires were visually inspected and no age related degradation (cracking or difficulty of bending) of the insulation was found. The following demonstrates that no age related degradation would be expected.

It is believed that the insulating materials found are PVC and X-linked polyethylene. These materials are shown to be acceptable for use in section 4.0 thru 4.3. They have been evaluated for useful life, temperature withstanding and radiation resistance. They have been demonstrated as satisfactory for use in outside containment Limitorque operators at Turkey Point.

Reference 5) article 310 and article 402 give temperature ratings of (UL) listed cables. The lowest temperature rating listed is 60°C. Insulation with this temperature rating is typically thermoplastic. Therefore all commonly used insulation is operated within its temperature rating during normal operation based on the assumed normal operating temperature of 45°C from section 2.0 of this report.

Reference 2) figure C-1 gives radiation resistance of commonly used thermoplastic insulation. This figure shows that all commonly used insulations, with the exception of Teflon, are capable of withstanding the maximum required dose of $2x10^6$ rad.

Reference 2) appendix B provides activation energies of commonly used organic materials. The materials commonly used as electrical insulation typically have activation energies greater than the .99 eV of PVC. Insulation other than PVC would therefore have a longer useful life than PVC. Section 4.1 provides that PVC has a useful life of 59.9 years at the assumed normal operating temperature plus 30 minutes at the assumed accident temperature. This is greater than the 20 year installed life. Therefore other commonly used insulations would have useful lives exceeding the 20 year installed life.

As in section 4.3 of this report, (UL) testing typically requires a 121°C circulating air test which is one hour in duration. These tests envelope the 87°C for 30 minute required accident profile from section 2.0 of this report. Therefore all commonly used (UL) listed wire can withstand a steam line break accident inside a Limitorque operator outside containment at Turkey Point.

The discussion to this point in section 5.0 has been based on assumptions of insulation types used in unidentified wires. These assumptions are believed to be true but can not be proven for the case of unlabeled wire. Therefore FPL has conducted the testing program outlined below.

Reference 4) documents a high energy line break experiment performed by Research Dynamics Inc. under supervision of Florida Power & Light Co. During the test a Limitorque operator was subjected to an environment more severe than the Turkey Point required temperature profile for an outside containment high energy line break.

The following are paraphrased excerpts from that report.

One objective of the experiment was to demonstrate that any wire, no matter what type or how it got to end-of-life condition, would be adequate. That is, the additional environmental stress put on the valve actuator during a steam line break accident will not cause either operator or indication misaction.

The steam line break was chosen over the radiation environment because radiation at levels less than 10^7 *rads will have little effect other than to crack the insulation while condensation from the steam could provide a conductive path causing misoperation. In addition, deliberate flaws (cuts in insulation and stripped wires) will mechanically simulate thermal and radiation aging.*

The limitorque actuator was tested in two different configurations without using qualified wiring and with many deliberate flaws in the wiring. All of the indicators and switches worked as required. No shorting occurred.

The steam test enveloped the maximum pressure and temperature profiles which are required at Turkey Point. Additional margin was induced by the long warm up times using steam.

The above objective was achieved indicating that the wire insulation is not required for proper operation of the valve during adverse environmental conditions in outside containment applications.

Therefore the wire type is not important for use in Limitorque operators.

6.0 CONCLUSIONS

Based on the foregoing it has been demonstrated that the wires removed from the Turkey Point outside containment Limitorque operators would have performed their safety function had they been called upon to do so.

REFERENCES

1) EPRI NP-2129, Project 1707-3, Final Report, November 1981, Radiation Effects on Organic Materials in Nuclear Plants.
2) EPRI NP-1558, Project 890-1, Final Report, September 1980, A Review of Equipment Aging Theory and Technology.
3) Shapiro, J., Radiation Protection, second edition, Harvard University Press (1981)
4) Research Dynamics Inc. (Nov. 8,1986), Experimental Testing of Wiring for Limitorque Valve Actuator for Florida Power & Light Company
5) Schram, Peter J., The National Electrical Code Handbook, McGraw-Hill Book Company (1984)
6) Elam, Gary J., Patel Engineers, Final Test Report for Anaconda/Continental SIS Cross-Linked Polyolefin and G. E. Vulkene SIS Cross-Linked Polyethylene Cables used in the Calvert Cliffs Nuclear Power Plant. Report No. PEI-TR-860500-02, issued Jan. 23, 1986.
7) IPCEA Pub. No. S-61-402(Third Edition) NEMA Pub. No. WC 5-1973 Revision 2-September 1977, IPCEA-NEMA Standards Publication Thermoplastic-insulated Wire and Cable for the Transmission and Distribution of Electrical Energy
8) UL Standard 83-1986, Thermoplastic insulated wires and cables.
9) UL Standard 44-1983, Rubber insulated wires and cables.
10) UL Standard 62-1983, Flexible cord and fixture wire.
11) UL Standard 1581-1986. Reference standard for electrical wires, cables, and flexible cords.