ELECTRIC POWER RESEARCH INSTITUTE

Evaluation of Medium-Voltage Cable Joints

New and Modified Single-Phase Cold Shrink and Separable Connector Cable Joints

Technical Report

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New and Modified Single-Phase Cold Shrink and Separable Connector Cable Joints

1014439

Final Report, September 2006

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NOTE

CITATIONS

This report was prepared by

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This report describes research sponsored by the Electric Power Research Institute (EPRI).

The report is a corporate document that should be cited in the literature in the following manner:

Evaluation of Medium-Voltage Cable Joints: New and Modified Single-Phase Cold Shrink and Separable Connector Cable Joints. EPRI, Palo Alto, CA: 2006. 1014439.

REPORT SUMMARY

This research is a continuation of work evaluating performance of state-of-the-art joints. Three single-phase cold shrink joints and three “I”-type premolded separable connector joints were evaluated. Two of the separable connectors were rated 600 A and one was rated 900 A; both were installed on ethylene propylene rubber (EPR) 15-kV cables.

Results & Findings
The report describes test results for six selected joints in terms of joint assembly/fabrication and ac voltage breakdown. Results are given for three 15-kV single-phase cold shrink joints and three “I” type separable connector joints, rated 600-900 A. The joints’ overall electrical test performance also was evaluated.

Challenges & Objective(s)
This project facilitates selection and application of technically superior, cost-effective 15-kV cold shrink joints and separable connectors whose designs are among the least complex.

Applications, Values & Use
The project's data and observations provide insights into the strengths and weaknesses of the joints tested. They also suggest precautions and improvements that can be made when preparing cables and assembling joints for improved performance.

EPRI Perspective
Cable joint installation methodology has not received as much prior consideration as cable installation. Proper installation is necessary for reliable operation. Recent information on failure statistics indicates that accessory failures represent a significant issue for cable system reliability. Unlike cable constructions that vary only in conductor size, shape, and wall thickness of the various polymeric layers, joints vary considerably from each other in design and installation methodology. While joint types evaluated in this project meet standard requirements, their installation can still be problematic for utilities. Among concerns are installation costs that involve labor-intensive issues, complexity of installation, ability to work in confined spaces, and characteristics that influence trouble-free operation. This project addresses these issues.

Approach

Joints were subjected to extensive technical evaluations and observation of installation parameters. These state-of-the-art joints are all commercially available. The work performed was intended to facilitate selection and application of technically superior medium-voltage cold shrink and separable connector joints, which are the least complex and easiest to assemble with the greatest margin for error.

Joint kits and jointing materials were provided by manufacturers and participating utilities. Cable preparation and joint assembly/fabrication were performed by skilled splicers according to joint manufacturers' instructions.

Keywords

Joints
Cable installers
Comparative evaluation
Performance evaluation
Distribution cables
Cold shrink
Separable connector

ABSTRACT

In the continuation of work to evaluate the performance of state-of-the-art joints three single-phase cold shrink joints and three “I”-type premolded separable connector joints, two of them rated 600 A and one 900 A, installed on ethylene propylene rubber (EPR) 15 kV cable were subjected to extensive technical evaluations and observation of installation parameters. These state-of-the-art joints are commercially available. The work performed was intended to facilitate the selection and application of technically superior, relatively least complex, ease of assembly and with less margin for error medium voltage cold shrink and separable connector joints.

Joint kits and jointing materials were provided by manufacturers and participating utilities. Cable preparation and joint assembly/fabrication were performed by skilled splicers in accordance with the joint manufacturers’ instructions.

Cable preparation, joint assembly/fabrication and electrical tests were performed at Cable Technology Laboratories, Inc., in New Brunswick, NJ.

ACKNOWLEDGMENTS

Cable Technology Laboratories and the Electric Power Research Institute express their thanks to Baltimore Gas and Electric Co., Consolidated Edison Co. of New York, Exelon, KeySpan Energy and Public Service Electric and Gas Co., who contributed generously with funds, cables, joint kits, made skilled splicers available for the execution of the project and participated in the Industry Advisory Group meetings, contributing thereby to the success of the present project.

EXECUTIVE SUMMARY

This is a continuation of ongoing work on the evaluation of state-of-the-art joints. This report provides a technical evaluation of three single phase cold shrink joints and three "I"-type premolded separable connector joints installed on ethylene propylene rubber (EPR) 15 kV cable. The report includes installation parameters such as time required, design complexity, skill and space needed in assembly/fabrication of the joints. The six state-of-the-art joints are commercially available.

Approach

The following joints were included in the project. Cable preparation and joint assembly was performed by experienced utility splicers at Cable Technology Laboratories, Inc., in accordance with the joint manufacturers' instructions:

15 kV New and Modified Single-Phase Cold Shrink Joints

- Tyco (New) – CAS-15M-2
- Pirelli (Modified) – Elaspeed
- 3M (Modified) – QS-III Type 5417A

15 kV "I"-Type Separable Connector Joints

- Elastimold – K656I, Al Connector, Rated 600 A
- Richards – P625JI2, Al Connector, Rated 600 A
- Richards – P925JI2, Cu Connector, Rated 900 A

Determinations and electrical tests, as follows, were performed at Cable Technology Laboratories in New Brunswick, New Jersey:

- Analysis of Joint Assembly/Fabrication
  - Time required to complete joint
  - Complexity of making the joint
  - Skill required
  - Space required

- Electrical Tests of Completed Joints:
  - AC voltage withstand test prior to heat cycling
  - Partial discharge measurements prior to heat cycling
  - Heat cycling for 30 days at 130°C conductor temperature
  - Partial discharge measurements after heat cycling
  - Impulse voltage withstand test at 130°C conductor temperature
  - Partial discharge measurements after impulse voltage withstand test
  - AC voltage time test to breakdown

In addition, a gas-pressure venting test was performed on cold shrink joints before and after heat cycling.

Summary of Test Results

A comparison of assembly/fabrication and test results for all similar joints tested follows and can serve to facilitate the selection and application of the most effective, least complex, technically superior joint design. The summary includes results for some of the joints that were evaluated earlier using the same test procedure. The results of those tests were published in EPRI Report 1000045, entitled "Evaluation of Premolded and Field Assembled Joints for Extruded Dielectric Medium Voltage Cables", dated June 2000.

15 kV Single Phase Cold and Heat Shrink Joints – Analysis of Assembly/Fabrication – Table No. 1

15 kV Single Phase Cold and Heat Shrink Joints – Interface Gas Pressure Venting Test – Table No. 2

15 kV Single Phase Cold and Heat Shrink Joints – AC Voltage Breakdown Test – Table No. 3

15 kV Single Phase Cold and Heat Shrink Joints – Evaluation of Overall Electrical Test Performance – Table No. 4

15 kV Separable Connector Cable Joints – Analysis of Assembly/Fabrication – Table No. 5

15 kV Separable Connector Cable Joints – AC Voltage Breakdown Test – Table No. 6

15 kV Separable Connector Cable Joints – Evaluation of Overall Electrical Test Performance – Table No. 7

Details of individual results on the newly tested joints, dissection of the breakdown sides and photographs of the failures are provided in Appendices A through F.

Table ES-1
15 kV Single Phase Cold and Heat Shrink Joints – Analysis of Assembly/Fabrication

Joint Kit Manufacturer	Joint Type	Time to Complete min*	Design Complexity 0-10**	Skill Required 0-10**	Longitudinal Space Req. inches	Width of Space Req. inches
New and Modified Joints						
Tyco (New)	Cold Shrink	80	3	3	72	48
Pirelli (Modified)	Cold Shrink	85	4	4	72	48
3M (Modified)	Cold Shrink	75	3	3	72	48
Joints Previously Evaluated						
Raychem	Heat Shrink	120	5	7	80	48
Pirelli	Cold Shrink	95	4	5	72	48
3M	Cold Shrink	85	3	4	72	48

*One Splicer.

**Subjective rating; 10 denotes most difficult.

Table ES-2
15 kV Single Phase Cold and Heat Shrink Joints – Interface Gas Pressure Venting Test

Joint Kit Manufacturer	Joint Type	Gas Venting Pressure - psi	
		Prior to Heat Cycling	After Heat Cycling
New and Modified Joints			
Tyco (New)	Cold Shrink	35*	35*
Pirelli (Modified)	Cold Shrink	35*	35*
3M (Modified)	Cold Shrink	25**	30***
Joints Previously Evaluated			
Raychem	Heat Shrink	35*	35*
Pirelli	Cold Shrink	35*	35*
3M	Cold Shrink	30**	30**

*Pressure increased in 5 psig increments each 5 min. Test stopped at this level without gas leaking.

**Leaked at start of gas application at indicated pressure level.

***Leaked between one and four minutes of gas application at indicated pressure level.

Table ES-3
15 kV Single Phase Cold and Heat Shrink Joints – AC Voltage Breakdown Test

Joint Kit Manufacturer	Joint Type	Average Breakdown Voltage – kV	
		Heat Cycled in Air	Heat Cycled in Water
New and Modified Joints			
Tyco (New)	Cold Shrink	91*	114
Pirelli (Modified)**	Cold Shrink	76*	78
3M (Modified)	Cold Shrink	86	68
Joints Previously Evaluated			
Raychem	Heat Shrink	86	63
Pirelli	Cold Shrink	93	98
3M	Cold Shrink	83	84

*Average of three results only (all others are average of four results). One failure (with low breakdown level) originated from cut in cable insulation; therefore this breakdown is not taken into account.

**Kit used for joint assembly was marginally suitable (loosely fitting) for the cable used in the project.

Table ES-4
15 kV Single Phase Cold and Heat Shrink Joints – Evaluation of Overall Electric Test Performance

Joint Kit Manufacturer	Joint Type	Overall Performance Rating*
New and Modified Joints		
Tyco (New)	Cold Shrink	10
Pirelli (Modified)	Cold Shrink	7
3M (Modified)	Cold Shrink	6
Joints Previously Evaluated**		
Raychem	Heat Shrink	7
Pirelli	Cold Shrink	10
3M	Cold Shrink	9

*Subjective rating; 10 is the best.

**Evaluated by a different group of participants.

Table ES-5
15 kV Separable Connector Cable Joints – Analysis of Assembly/Fabrication

Joint Kit Manufacturer	Joint Type	Time to Complete min*	Design Complexity 0-10**	Skill Required 0-10**	Longitudinal Space Req. inches	Width of Space Req. inches
Elastimold, 600 A	Premolded	75	5	6	72	48
Richards, 600 A	Premolded	75	5	6	72	48
Richards, 900 A	Premolded	75	5	6	72	48

*One Splicer.

**Subjective rating; 10 denotes most difficult.

Table ES-6
15 kV Separable Connector Cable Joints – AC Voltage Breakdown Test

Joint Kit Manufacturer	Joint Type	Average Breakdown Voltage – kV	
		Heat Cycled in Air	Heat Cycled in Water
Elastimold, 600 A	Premolded	122	76
Richards, 600 A	Premolded	76	86
Richards, 900 A	Premolded	96	83

Table ES-7
15 kV Separable Connector Cable Joints – AC Voltage Breakdown Test

Joint Kit Manufacturer	Joint Type	Average Breakdown Voltage – kV	
		Joints with Retaining Ring	Joints with EPR Tape Bumper Instead of Retaining Ring
Elastimold, 600 A	Premolded	103 (4*)	76 (4*)
Richards, 600 A	Premolded	---	81 (8*)
Richards, 900 A	Premolded	---	90 (8*)

*Number of joints tested.

Table ES-8
15 kV Separable Connector Cable Joints – Evaluation of Overall Electric Test Performance

Joint Kit Manufacturer	Joint Type	Overall Performance Rating*
Elastimold, 600 A	Premolded	8
Richards, 600 A	Premolded	8
Richards, 900 A	Premolded	8

*Subjective rating; 10 is the best.

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1
INTRODUCTION

This report was prepared by Cable Technology Laboratories, the principal investigator for EPRI Project EP-P13120/C6530, “Evaluation of New and Modified Single Phase Cold Shrink and Separable Connector Cable Joints”. The report incorporates test results, experiences and knowledge gained in the performance of the project which comprised the preparation of the extruded dielectric cable, assembly and testing of three single phase cold shrink and three “I”-type separable connector joints.

This project was preceded by two other EPRI projects entitled, “Evaluation of Premolded and Field Assembled Joints for Extruded Dielectric Medium Voltage Cables,” (EPRI Product ID 1000045 – May 2000) and “Evaluation of Single and Three Conductor Transition Joints for Extruded/PILC Medium Voltage Cables,” (PID 1008447 - May 2003).

The following is a list of individuals who provided guidance and assistance in the performance of this project and preparation of the final report.

Industry Advisors:	John Spence – BG&E
	Frank Doherty – Con Edison
	Thomas Hui – Con Edison
	George Murray – Con Edison
	William Smith – Con Edison
	Daniel Zoladz – Exelon
	Steven W. Bruckner – KeySpan Energy
	John Haines – KeySpan Energy
	Lucio Rivera – KeySpan Energy
	Anthony J. Vota – KeySpan Energy
	Timothy McLaughlin – PSE&G
Project Manager	Robert J. Keefe – EPRI
Investigators:	Michael Gokhberg – CTL
	Carlos Katz – CTL

2
PURPOSE

The purpose of this project was to provide a technical evaluation of three single phase cold shrink joints and three “I”-type separable connector joints for extruded dielectric 15 kV cables. All six joints are commercially available. The project included a technical evaluation and determination of complexity of assembly, selection and application of the most effective, least complex, from the standpoint of time and skill required, technically superior joint design.

3
JOINTS

The following joints were evaluated in the project:

- 15 kV New and Modified Design Single-Phase Cold Shrink Joints
  - Tyco (New) – CAS-15M-2
  - Pirelli (Modified) – Elaspeed
  - 3M (Modified) – QS-III Type 5417A
- 15 kV Separable Connector Joints
  - Elastimold – K656I, Al Connector, Rated 600 A
  - Richards – P625JI2, Al Connector, Rated 600 A
  - Richards – P925JI2, Cu Connector, Rated 900 A

It should be noted that the term "modified design joint" refers to joints previously available in the market, where the manufacturer modified one or more of the components in order to make it more suitable for its intended application.

Joint kits were acquired through participating utilities. Cable preparation and assembly of joints were performed by experienced splicers, provided by participating utilities with the assistance of CTL technicians, in accordance with the manufacturers' instructions. Cable preparation, joint assembly and performance of electrical tests were conducted at Cable Technology Laboratories in New Brunswick, New Jersey.

Joint assemblies are described in details in Section 5.

4
CABLE

The cable employed with all six joints had the following design:

1/C, 750 kcmil compact copper conductor, 15 mils extruded semiconducting conductor shield, 165 mils EPR insulation, 30 mils extruded semiconducting insulation shield, 20 copper flat straps (25 by 175 mils), 50 mils embedded polypropylene jacket.

The cable, of the reduced insulation thickness type, was manufactured by BICC (a division of General Cable Corp.) for Consolidated Edison Company of New York in accordance with applicable industry standards and was contributed to the project by Consolidated Edison.

5
DESCRIPTION OF JOINT ASSEMBLIES

5.1 Tyco Cold Shrink – CAS-15M-2 15 kV Class Straight Joint

This is a new cold shrink joint. It was assembled in accordance with Tyco Product Installation Instructions PII – 55217, Rev. AF dated 03/28/2003.

Components of the Tyco cold shrink joint are shown in Figure 5-1.

Figure 5-1
Components of Tyco Cold Shrink Joint

The joint kit contains the following materials:

- Field control mastic (FCM)
- Two-layer patch
- Cold shrink joint body incorporating conductor shield, EPDM insulation, insulation shield, metallic shield (braid), outer non-conductive sleeve, mounted on two support plastic tubes
- Copper shielding mesh
- Spring clamps
- Silicone lubricating compound
- Gel/wrap corrugated jacket
- Installation tool

The order in which the joint is assembled is as follows:

Sections of cable are cut back to expose the conductor, insulation, insulation shield and neutrals in accordance with Tyco's instructions.

The neutrals are laid back along the cable and secured with vinyl tape supplied in the kit.

The insulation is abraded and cleaned. Before parking the joint body, the outside of the cable jacket is cleaned on one end for 30 inches and covered with a plastic bag supplied in the kit.

The joint body, which has an identification label on the same end as a shorter support tube side, is carefully placed over the cable with the label toward the connector.

The exposed cable conductors are inserted in the connector and the connector is crimped and deburred. The insulation and the connector are cleaned with a solvent supplied in the kit.

Several turns of a marking tape are installed on the insulation shield of the cable end, away from the joint body, at 1½ inches from the insulation shield cut back.

Field control mastic (FCM) strip is applied onto the end of each cable insulation extending onto the connector ends. The two-layer patch provided is installed around the connector in the following order: the protective paper is removed from the front side of the patch, the patch is centered over the connector by making sure that it extends equally over the FCM at the insulation cutbacks. Next, the remaining backing protective paper is removed and the patch is wrapped with a light tension around the connector.

An FCM strip is wrapped around the cable insulation shield cutback on each end. Silicone lubricating compound is applied as a film over the cable insulation shield, insulation, FCM mastic strips and the outside of the two-layer patch.

The joint body is carefully moved until the labeled shorter support tube is 1 inch from the jacket cutback. This tube is removed by pulling it using the installation tool provided with the kit. The partially collapsed joint body is positioned using the red marking tape. The longer support tube is removed from the other end of the joint body. The centering of the joint body, between the jacket cutbacks, is verified by having equal dimensions on both sides. The joint body must cover the FCM at the insulation shield cutbacks.

The copper shielding mesh is connected to the cable neutrals with a spring clamp, installed at 1 inch from the jacket cutback, on each side. A few layers of PVC tape are applied over the spring clamps covering the ends of the copper mesh on both sides.

The gel/wrap corrugated jacket is lubricated in the area between the PowerGel sealant strips, attached to its inner surface, centered over the splice and closed by snapping the closure, starting at its center. Two tie-wraps are snuggly tight at each end.

The joint is completed.

5.2 Pirelli Cold Shrink Elaspeed Straight Joint

This is a modified joint. It was assembled in accordance with Pirelli Assembly Instructions dated 07/24/2003

A cross-sectional diagram of the Pirelli cold shrink joint is shown in Figure 5-2.

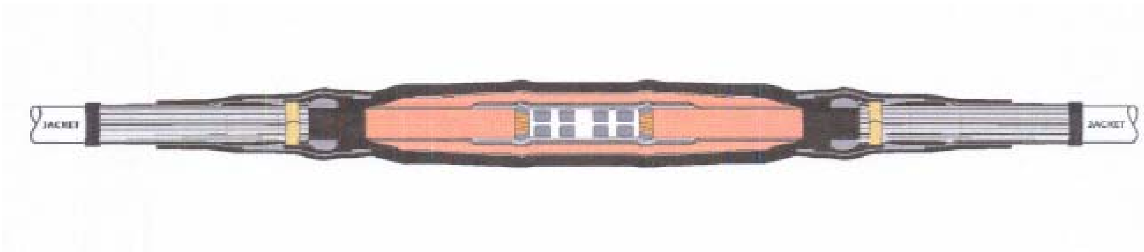

Figure 5-2
Pirelli Cold Shrink Joint

The joint kit contains the following materials:

- Splice housing assembly (mounted on two bonded plastic carrier tubes) comprising a three-layer joint body, semiconducting sleeve over the joint body, stress control grease, copper shielding mesh, outer jacket and plastic protection film.
- High permittivity mastic compounds
- Silicone oil lubricant
- Sealing mastic strips (black)
- Sealing mastic pad
- Constant force springs
- Rubber tape
- Twisting wrenches

The order in which the joint is assembled is as follows:

The cable jacket is removed for 12.25 inches distance on each end. From the cut back, the adjacent part of the jacket is abraded for 4 inches. One half lapped layer of black sealing mastic is stretched to 0.5 inch thickness and applied on the 2-inch center section of the abraded areas. The neutrals on each end are held down with binding wire at 1 inch from the jacket cut back, laid back along the cable and temporarily secured with vinyl tape.

The insulation shield, insulation and conductor shield of the cables are cut back to the specified dimensions.

The joint housing assembly is parked on one of the cables with the blue straps towards the length of the cable.

The exposed cable conductors are inserted in the connector. The connector is crimped and deburred. The exposed insulation is abraded and cleaned with a solvent supplied in the kit.

The indents and gaps at the connector area are filled with high permittivity mastic strips. The high permittivity mastic pad is centered and wrapped around the connector, overlapping equally the cable insulation of both cables.

The joint housing assembly is centered over the mastic pad after removing the plastic protection film.

The bond between the two carrier tubes that support the housing is broken by two wrenches turned in opposite direction. The short section of the carrier tube is expelled first and part of the joint sleeve is collapsed over the exposed cable. The distance of 1 inch between the edge of the sleeve and the cable jacket cutback is verified. As the blue straps are cut, the second (longer) section of the carrier tube is released and the joint sleeve is collapsed on the other end.

Using a hammer, longitudinal half sections of the carrier tube are separated and removed from the cable.

Excess grease (white) is removed from the ends.

Two half lapped layers of rubber insulating tape are tightly applied on both sides (ends) to ensure a good contact between the outer semiconducting layer that extends over the joint body and the cable insulation (specially where they first come in contact).

Two half lapped layers of black sealing mastic are applied for 1.5 inches the overlapping outer semiconducting layer of the joint and the cable neutrals.

The copper shielding mesh is unfolded from the joint body and extended over the cable neutrals. Constant force springs are applied over the copper braid shield and neutrals at each end.

Sealing mastic pads are aligned with the black sealing mastic strips previously applied on each cable jacket and tightly wrapped around each joint end.

The jacket is lubricated with silicone oil and unfolded from both sides of the joint body onto the underlying cable structure by pulling on the straps provided.

The joint is completed.

5.3 3M Cold Shrink – QS-III Straight Joint

This is a modified joint. It was assembled in accordance with 3M Instruction Sheet 78-8124-5933-3-C.

A cross-sectional diagram of the 3M cold shrink joint is shown in Figure 5-3.

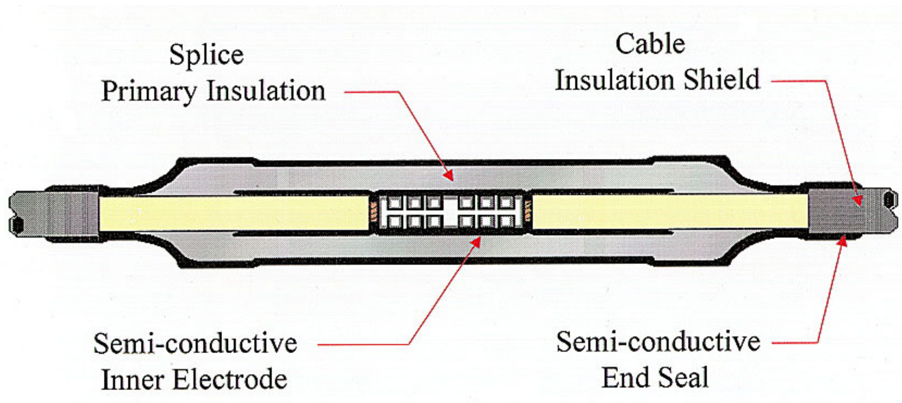

Figure 5-3
3M Cold Shrink Joint

The joint kit contains the following materials:

- Cold shrink 5417A silicone rubber joint body
- Cold shrink jacketing tube
- Cold shrink adapter tube
- Tubes 3M P 55/R compound (red)
- Scotch 2230 mastic sealing strips
- Scotch 2228 rubber mastic tape roll
- Neutral pad
- 3M cable cleaning pads
- Cable preparation template

The order in which the joint is assembled is as follows:

The cable ends are cut back to expose the conductor, insulation, and insulation shield to the specified dimensions shown in the instructions and in the cable preparation template. Additional length is required on one cable for the metallic shield connection. The insulation is removed from the conductor for ½ connector length plus (if aluminum connector used) an allowance in connector length due to crimping (specified in the instructions). Insulation removal length from each cable shall not exceed 3.75 inches.

The neutrals are laid back along the cable and secured with vinyl tape. The cable jacket and insulation are cleaned.

The cold shrink joint is positioned over the connector area, aligning its end at the center of a previously applied marker tape and installed by unwinding the loose core end. The joint body ends must overlap onto the insulation shield of each cable by at least 0.5 inches.

The neutral pad is positioned on the joint body. The neutrals are routed over the neutral pad and connected using a suitable compression connector. Two layers of vinyl tape are applied around each end of the neutral pad and over the connector.

Short sections of the cable jacket (removed during the cable preparation) are placed under the neutral assembly to protect the exposed cable insulation shield. These sections should not touch the joint body.

Rubber mastic tape is applied around each jacket end.

The cold shrink jacketing tube is installed (completely covering the rubber mastic) starting on one end by slowly pulling and unwinding the inner core counterclockwise toward the joint body. The outer core should remain relatively stationary while unwinding the inner core. The jacketing tube is installed in final position, over the rubber mastic on the other end. This portion of cold shrink tube installs differently in that as the tube shrinks, the end rolls under.

The joint is completed.

5.4 Elastimold K656I ("I"-Type) 600 A Separable Connector Joint

This joint was assembled in accordance with Elastimold Installation Instructions IS-0868 of May 2001 and IS-0868 of August 2000 (for installation of sealing components).

A cross-sectional diagram of the Elastimold separable connector joint is shown in Figure 5-4.

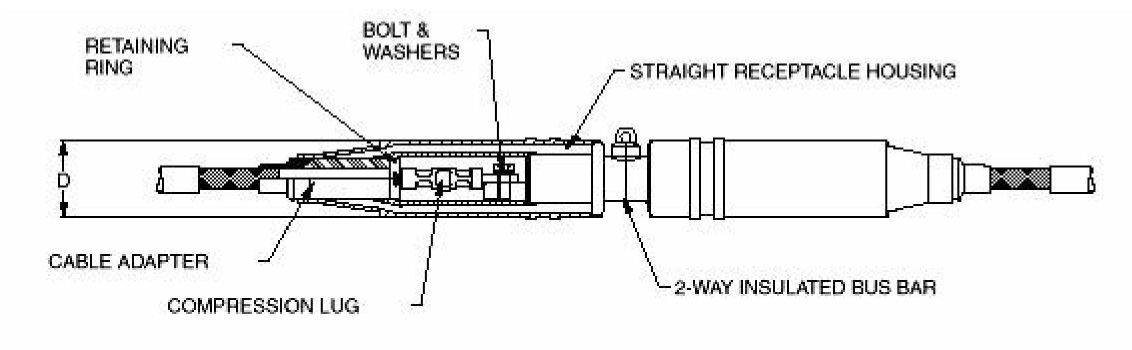

Figure 5-4
Elastimold "I"-Type Separable Connector Joint

The joint kit contains the following materials:

- Two receptacle housings (sleeves)
- One insulated bus bar (yoke)
- Two aluminum holding collars (retaining rings)
- Two lug connectors

- Two cable adapters
- Two hex-head bolts
- Belleville and flat washers (two of each)
- Nylon venting rod
- Silicone lubricant
- Hex wrench

In addition, cold shrink tubes and mastic strips are recommended to seal the joint ends. They are included in a separate kit.

Note: With one exception the joints were assembled following Elastimold installation instructions. The exception related to the fact that in half of the joints (4) Con Edison splicers, following their normal practice, used EPR tape bumpers instead of retaining rings.

The order in which the joint is assembled is as follows:

The cable jacket is removed from both ends for a distance of 2.5 inches more than the cutback length needed for the insulation shield. The first sealing mastic strip is wrapped around the cable jacket starting no more than 0.25 inch from the jacket cutback. The neutrals are folded over the mastic, along the jacket, and pressed into the mastic in such a way as to not touch each other. The second sealing mastic strip is wrapped over the neutrals, above the previously applied mastic. Two layers of vinyl tape are tightly applied over the mastic to prevent the cold shrink sealing tube core from sticking onto the mastic.

Sections of cable are cut back to expose the conductor, insulation, and insulation shield in accordance with instructions. The ends of the cable insulation are slightly penciled.

Cold shrink sealing tubes and receptacle housings are placed over both cable ends. The cable ends are cleaned.

A cable adapter is lubricated and carefully slid over the cable insulation overlapping the insulation shield for 1 inch. The procedure is repeated at the second cable end.

A retaining ring (or EPR tape bumper) is installed in front of each cable adapter and tightened with a wrench. This retaining ring keeps the cable adapter in place when the receptacle housing is pulled forwards, over it.

A lug connector is slid on the exposed conductor on each end. Prior to crimping the distance from the connector end to the front of the retaining ring is verified. It should not exceed 7.125 inches.

The lug connectors are crimped on the conductors of the cables. The distance between the connector end and the front of the retaining ring should not be more than 6.75 inches.

The bus bar (yoke) is connected to the lug connectors using hex bolts, Belleville and flat washers. Hex bolts are tightened with 50-60 ft. lbs. of torque.

Lubricating compound is applied to the outside of the cable adapters and bus bar.

The receptacle housing (with a venting rod inserted) is slid towards the bus bar on each end. A 600 RRT assembly tool is used to install the housing into its final position. The venting rod prevents air pressure build up inside the joint; it is removed after the housing is in its final position.

The third sealing mastic strip is applied following the two layers of vinyl tape around the cable insulation shield, next to the receptacle housing ends. The cold shrinkable sealing tubes are installed at the ends by pulling and unwinding the loose core in clockwise direction. The tube must overlap the joint end at least 1 inch for a proper seal.

The receptacle housings and cable metallic shield are connected to ground through the eyelets.

The joint is completed.

5.5 Richards P625JI2 (“I”-Type) 600 A Separable Connector Joint

This joint was assembled in accordance with Richards Installation Instructions RP-II-JI, JY, JH, JU-11D dated 10/23/2003.

A detail of Richards separable connector joint is shown in Figure 5-5.

The joint kit contains the following materials:

- Two receptacle housings (sleeves)
- One insulated aluminum bus bar (current-carrying component)
- Two aluminum retaining rings
- Two aluminum lug connectors
- Two cable adapters
- Two polymeric assembly aids
- Two hex-head bolts
- Belleville and flat washers (two of each)
- Nylon venting rod
- Silicone lubricant

In addition, the instructions recommend having on hand shrinkable tubes and mastic to seal the joint ends. They are not included in the kit.

Note: With one exception the joints were assembled following Richards installation instructions. The exception related to the fact that in all eight joints Con Edison splicers, following their normal practice, used EPR tape bumpers instead of retaining rings.

Figure 5-5
Richards "I"-Type Separable Connector Joint

The order in which the joint was assembled is as follows:

The cold or heat shrinkable sealing tubes and receptacle housings are placed over both cable ends.

The sections of cable are cut back to expose the conductor, insulation, insulation shield and metallic shield in accordance with the instructions.

The cable ends are cleaned to prevent contamination to the inside of the housing.

A marking tape is installed on the insulation shield of each cable, 1 inch from its cut back.

A cable adapter is lubricated and installed over the cable insulation on each end with the help of the assembly aid (polymeric cone shape plug). The cable adapter should flush with the tape marker.

The assembly aid is removed. An EPR tape bumper (replacement for the retaining ring) is installed in front of the cable adapter on each end.

A lug connector is installed and crimped on the exposed conductor of each cable.

The bus bar (yoke) is connected on both sides to the lug connectors using hex bolts, Belleville and flat washers. Hex bolts are tightened with 50-60 ft. lbs. of torque.

The receptacle housing (with a venting rod inserted) is slid towards the bus bar on each end. A P6AT1 assembly tool is used to install the housing into its final position. The venting rod prevents air pressure build up inside the joint; it is removed after the housing is in its final position.

Mastic sealing material is applied on the cable jacket at the joint ends. Heat or cold shrinkable sealing tubes are installed at the ends.

The receptacle housing, bus bar and cable metallic shield are connected to ground through the eyelets.

The joint is completed.

5.6 Richards P925JI2 ("I"-Type) 900 A Separable Connector Joint

This joint was assembled in accordance with Richards Installation Instructions RP-II-JI, JY, JH, JU-11D dated 10/23/2003.

A crosscut of Richards separable connector joint is shown in Figure 5-5 (Section 5.5).

The joint kit contains the following materials:

- Two receptacle housings (sleeves)
- One insulated copper bus bar (current-carrying component)
- Two aluminum retaining rings
- Two copper lug connectors
- Two cable adapters
- Two polymeric assembly aids
- Two hex-head bolts
- Belleville and flat washers (two of each)
- Nylon venting rod
- Silicone lubricant

In addition, the instructions recommend having on hand shrinkable tubes and mastic to seal the joint ends. They are not included in the joint kit.

Note: With one exception the joints were assembled following Richards installation instructions. The exception related to the fact that in all eight joints Con Edison splicers, following their normal practice, used EPR tape bumpers instead of retaining rings.

The order in which the joint was assembled is as follows:

The cold or heat shrinkable sealing tubes and receptacle housings are placed over both cable ends.

The sections of cable are cut back to expose the conductor, insulation, insulation shield and metallic shield in accordance with instructions.

The cable ends are cleaned to prevent contamination to the inside of the housing.

A marking tape is installed on the insulation shield of each cable, 1 inch from its cut back.

A cable adapter is lubricated and installed over the cable insulation on each end with the help of the assembly aid (polymeric cone shape plug). The cable adapter should flush with the tape marker.

The assembly aid is removed. A retaining ring is installed in front of the cable adapter and tightened with a wrench. This retaining ring keeps the cable adapter in place when the receptacle housing is pulled forward, over it.

A lug connector is installed and crimped on the exposed conductor of each cable.

The bus bar (yoke) is connected on both sides to the lug connectors using hex bolts, Belleville and flat washers. Hex bolts are tightened with 50-60 ft. lbs. of torque.

The receptacle housing (with a venting rod inserted) is slid towards the bus bar on each end. A P6AT1 assembly tool is used to install the housing into its final position. The venting rod prevents air pressure build up inside the joint; it is removed after the housing is in its final position.

Mastic sealing material is applied on the cable jacket at the joint ends. Heat or cold shrinkable sealing tubes are installed at the ends.

The receptacle housing, bus bar and cable metallic shield are connected to ground through the eyelets.

The joint is completed.

6
TEST PROGRAM

6.1 Tests on Completed Joints

The project encompassed the following determinations and electrical tests performed on joint assemblies:

- Analysis of Joint Assembly/Fabrication
  - Time required to complete joint
  - Complexity of making the joint
  - Skill required
  - Space required
- Breakdown of time required for preparation of cables and assembly/fabrication of joints.
- AC voltage withstand test prior to heat cycling
- Partial discharge measurements prior to heat cycling
- Heat cycling for 30 days to a conductor temperature of 130°C in air and in water
- Partial discharge measurements after heat cycling
- Impulse voltage withstand test at 130°C conductor temperature
- Partial discharge measurements after impulse voltage withstand test
- AC voltage time test to breakdown

For each type of joint, two assemblies were setup (one in air and one in water) for heat cycling with a bend in the cables immediately adjacent to the joints.

In addition, a gas-pressure venting test was performed on cold shrink joints before and after heat cycling.

The joints were dissected and photographed after completing the ac voltage breakdown tests.

6.2 AC Voltage Withstand Test Prior to Heat Cycling

An ac voltage withstand test was performed shortly after completing assembly of the joints to assure they can withstand voltages applied during further testing. A voltage of 35 kV to ground (4 U_o) was applied for 5 minutes to each joint assembly.

6.3 Interface Gas Pressure Venting Test

An interface gas pressure test was performed as shown in Figure 6-1 on cold shrink joints to determine the ability of the joints to withstand internal pressure without venting. If the joint vents at relatively low pressures, environmental water and contaminants could gain ingress to the cable/joint interface resulting in electrical failure. This test was performed initially and after heat cycling tests.

Procedure

1. Seal far end of cable.
2. Immerse cable with joint in water.
3. Apply gas pressure in 5 psig increments up to 35 psig. At each increment hold pressure for five minutes.
4. Observe joint ends for gas leakage.

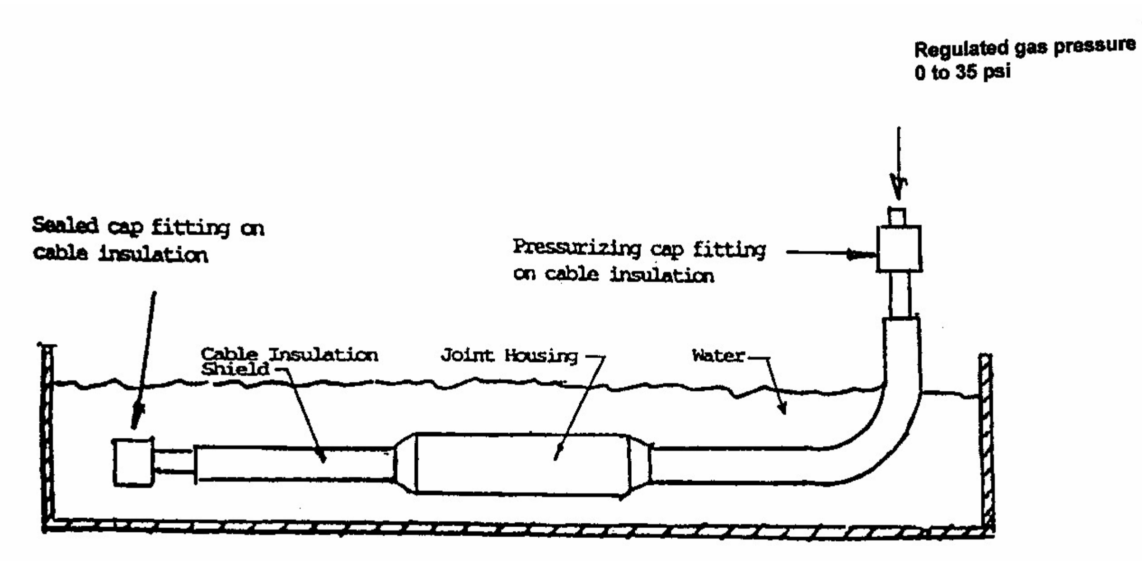

Figure 6-1
Interface Gas Pressure Venting Test

6.4 Partial Discharge Test

The partial discharge tests were performed prior and after initial interface gas pressure venting test (prior to heat cycling), after heat cycling following the interface gas pressure venting test and after hot impulse test. The purpose of the partial discharge test was to determine whether the gas pressure venting test, cyclic heating for 30 days at the emergency operating conductor temperature of 130ºC and impulse withstand test at 130ºC had adversely affected the structural integrity of the joints. The partial discharge measurements were performed at ambient temperature at voltages up to 26 kV (3 U_o).

6.5 Heat Cycling Test

The eight joints and corresponding cables were set-up for heat cycling, as shown in Figures 6-2 and 6-3. They were divided into two groups, each constituting a separate heating circuit. Each circuit consisted of four joints and corresponding cables, two in air and two in water. In one of the circuits, one joint in air and one in water were installed misaligned to create a condition simulating displacement of the cable from the horizontal position of the joints. The four joints to be tested in water were installed in individual six inch diameter PVC pipes, having at the ends 90 degree elbows joined to the straight section with rubber reducers. They were submerged to a depth of one meter of water, measured from the top surface of the joint.

A voltage of 26 kV (3.0 U_o) was continuously applied to the conductors at the terminals. The temperature at the conductor was automatically controlled to 130 ± 5°C employing a third circuit in air. This circuit is referred to as the "control cable". It is not under voltage and permits direct measurement of the conductor/connector temperatures. Figure 6-2 illustrates the loop connection for circulating the same current through the conductors in each circuit. A tabulation of thermocouple locations for each of the setups is included in the Appendices to this report. Recording of temperatures was performed two or three times a day. Special emphasis was placed in recording maximum temperatures during each heat cycle.

Figure 6-3 is a photograph of the laboratory set-up for the heat cycling test.

6.6 Impulse Voltage Withstand Test

The impulse voltage withstand test was performed with the conductor at 130°C, the emergency temperature for extruded cable. This test was performed to verify that the joint subsequent to heat cycling could withstand voltage surges, simulating lightning strokes at the BIL of the voltage class. IEEE recommended practices for impulse testing were followed.

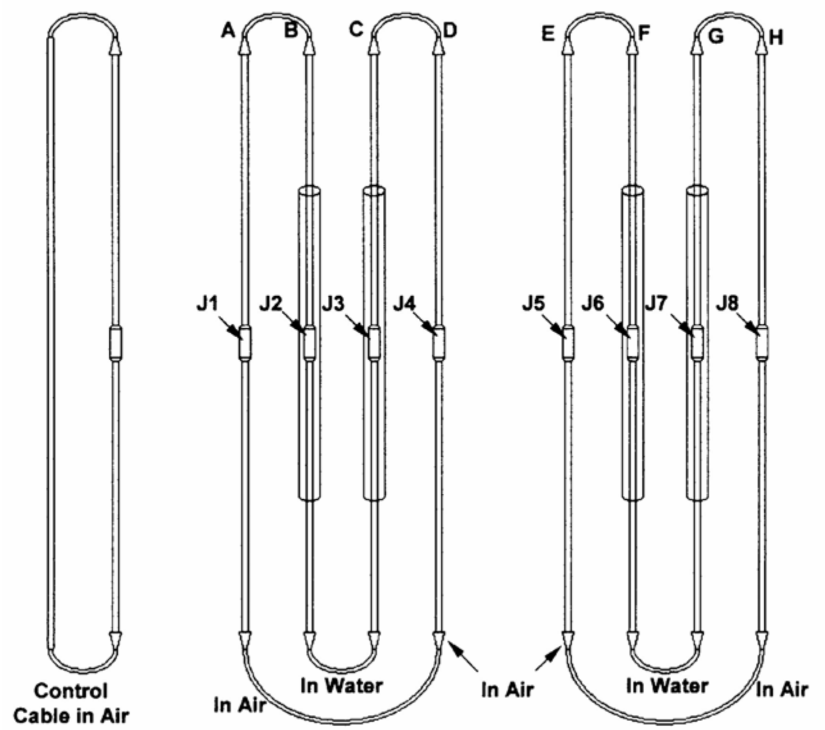

Figure 6-2
Heat Cycle – Conductor Connection for Circulating the Same Current Through all Joints.

Figure 6-3
Laboratory Setup for Heat Cycling Tests.

6.7 AC Voltage Breakdown Test

An ac voltage breakdown test was the final test performed and served to determine the dielectric strength of each joint as a measure of the electrical degradation to which the joint had been subjected by the previously mentioned tests and as an indication of the ability of the joint to perform satisfactorily in service.

6.8 Failed Joint Dissection

Following the heretofore described test program, the failed joints were dissected and the location and cause of failure were ascertained and reported. Photographs of the joint failures were taken and are included in the report.

7
TEST RESULTS

The test results for each of the six joints are included as Appendices A-F of the report.

8
DISCUSSION OF TEST RESULTS

8.1 Tyco Cold Shrink Joint

Test data for this joint are presented in Section 7, Appendix A of this report.

8.1.1 Analysis of Joint Assembly/Fabrication

Table A-1 lists the various parameters of significance for the assembly/fabrication of this joint. It will be noted that the time required for one splicer to assemble/fabricate the joint was approximately 80 minutes. This is similar to other cold shrink joints tested. The complexity and skill required are in the low end of the subjective rating of 0-10 where 10 denotes the poorest rating. The longitudinal distance and width of space required to assemble/fabricate the joint are comparable to both 3M and Pirelli joints.

8.1.2 Time to Complete Joint

Table A-2 provides a breakdown of the time required for one splicer to prepare cable ends and install the complete joint.

8.1.3 AC Voltage Withstand Test Prior to Heat Cycling

An ac voltage withstand test was performed on all joint assemblies prior to heat cycling. Each of the eight joints withstood the applied voltage of 35 kV (4.0 U_o) for five minutes (Table A-3).

8.1.4 Partial Discharge Test Prior to Heat Cycling

Table A-4 provides partial discharge test results for all joints prior to heat cycling. No partial discharge above 3 pC was detected at voltages up to 26 kV.

8.1.5 Interface Gas Pressure Venting Test Prior to Heat Cycling

This test was performed on one joint to be aged in air and one in water. The results are presented in Table A-5. There was no venting of pressure up to 35 psi in any of the two joints tested. The test was discontinued.

8.1.6 Partial Discharge Test After Interface Gas Pressure Venting Test

The two joints subjected to gas venting pressure tests were thereafter subjected to partial discharge tests with results similar to those obtained prior to the venting tests (Table A-6).

8.1.7 Heat Cycling

Table A-7 lists the thermocouple locations at various points on the control cable and cable loops.

Table A-8 provides daily records of temperature for the indicated locations, after seven hours of heating for the 30-day heat cycle test (8 hours current on, 16 hours off). The initial records show that the temperature of the connector in the control cable was approximately 15°C higher than that of the corresponding cable conductor. It is suspected that the high temperature could be attributed to the thickness of the joint jacket, which may not dissipate the heat well. After three initial heat cycles, where high temperatures were recorded, it was decided to continue the test without modifying the current. The temperature of the conductor, as measured on the control cable, ranged from 126 to 129°C. The joint assemblies in water ran cooler due to dissipation of heat into the water. Even though the connector ran at higher temperatures than the conductor, no negative incidents occurred during the 30 days of heat cycling.

8.1.8 Partial Discharge Test After Heat Cycling

Table A-9 shows the results of partial discharge measurements after completing 30 heat cycles for the eight joint assemblies. There were no detectable discharges at voltages up to 26 kV for all joints.

8.1.9 Interface Gas Pressure Venting Test After Heat Cycling

Interface gas pressure venting tests were repeated after heat cycling on one joint in air and one in water. The results are shown in Table A-10. No leaks were recorded when increasing the pressure up to 35 psi.

8.1.10 Partial Discharge Test After Interface Gas Pressure Venting Test

The two joints subjected to gas venting pressure tests were thereafter subjected to partial discharge tests with results similar to those obtained prior to the venting tests (Table A-11).

8.1.11 Impulse Voltage Withstand Test at 130°C Conductor Temperature

Table A-12 shows that each of the joint assemblies in air and in water withstood ten impulses at negative and ten impulses at positive polarity at the BIL of 110 kV using an impulse having a 1.2/50 μs shape. The conductor temperature during this test was about 130°C.

8.1.12 Partial Discharge Test After Hot Impulse Voltage Withstand Test

To establish if the application of the impulse voltage at elevated temperature affected the integrity of the joints, partial discharge measurements were made on the eight joints. The results are presented in Table A-13. No partial discharges above 3 pC were detected at voltages up to 26 kV.

8.1.13 AC Voltage Time Step Test to Breakdown

Each of the eight joints was subjected to an ac voltage breakdown test. The results are presented in Table No. A-14. Tests were performed by first applying 16.5 kV to each assembly and increasing the voltage in five-minute steps equivalent to 40 V/mil of the cable nominal insulation wall thickness, until achieving breakdown. The results indicate that the joints heat cycled in water broke down on the average at a 20% higher voltage level than those aged in air (114 vs. 91 kV). It should be noted that the breakdown voltage for Joint T8, which failed prematurely at 56 kV was not taken into account when calculating the average value.

8.1.14 Dissection After AC Voltage Breakdown

Table A-15 provides the results of dissection of the eight joints after tests. The four joints that had been aged in air broke down radially starting at or very close to the cutback insulation shield. In Joint T8, which failed at 56 kV, the failure originated from a cut into the insulation. Of the four joints aged in water one also failed radially, next to the edge of the insulation shield, while the other three broke down longitudinally at the interface between the cable insulation and the inner layer of the joint body.

In several of the joints the field control mastic, applied at the end of the insulation shield and in the gaps at the connector (under the two-layer patch), had spread over the cable insulation surface. Apparently the high temperature, during heat cycling, softens the mastic causing its re-distribution under the high radial hoop stresses generated in the insulation of the cold shrink sleeves. No negative effect of this redistribution was noted.

It was also found that in two of the joints heat cycled in air the outer non-conductive sleeve (over the metallic shield) had split longitudinally, apparently during heat cycling. When assembling the joints, a thermocouple attached to a thin copper plate (with sharp edges) was placed on the outside of this sleeve, on each joint. Taking into account the thermal expansion of the joint body under the elevated temperature conditions, it is possible that these sharp edges could have cut the sleeve. The joints aged in water had a better cooling and did not show the sleeve splitting.

Refer to Figures A-1 through A-4 included in Appendix A.

8.1.15 Test Experiences and Observations

Table No. A-16 provides a summary of experiences and observations while testing the joints. Except for the one joint that failed at a relatively low voltage due to a cut into the insulation, the Tyco joints showed excellent overall performance during testing.

8.2 Pirelli Cold Shrink Joint

Test data for this joint are presented in Section 7, Appendix B of this report.

8.2.1 Analysis of Joint Assembly/Fabrication

Table B-1 lists the various parameters of significance for the assembly/fabrication of the joint. The time required for one splicer to assemble/fabricate the joint was approximately 85 minutes. This is similar to other cold shrink joints tested. The complexity and skill required are in the mid to low end of the subjective rating 0-10 where 10 denotes the poorest rating. The longitudinal distance and width of space required to assemble/fabricate the joint are comparable to that required for the Tyco and the 3M joints.

8.2.2 Time to Complete Joint

Table B-2 provides a breakdown of the time required for one splicer to prepare cable ends and install the complete joint.

8.2.3 AC Voltage Withstand Test Prior to Heat Cycling

An ac voltage withstand test was performed on all joint assemblies prior to heat cycling. Each of the eight joints withstood the applied voltage of 35 kV (4.0 U_o) for five minutes (Table B-3).

8.2.4 Partial Discharge Test Prior to Heat Cycling

Table B-4 provides partial discharge test results for the eight joints prior to heat cycling. No partial discharge above 3 pC was detected at voltages up to 26 kV.

8.2.5 Interface Gas Pressure Venting Test Prior to Heat Cycling

This test was performed on one joint to be aged in air and one in water. The results are presented in Table B-5. There was no venting of pressure up to 35 psi in the two joints. The test was discontinued at this pressure level.

8.2.6 Partial Discharge Test After Interface Gas Pressure Venting Test

The two joints subjected to gas venting pressure tests were thereafter subjected to partial discharge tests with results similar to those obtained prior to the venting tests (Table B-6).

8.2.7 Heat Cycling

Table B-7 lists the thermocouple locations at various points on the control cable and cable loops.

Table B-8 provides daily records of temperature for the indicated locations, after seven hours of heating for the 30-day heat cycling test (8 hours current on, 16 hours off) with 26 kV (~3 U_o) applied continuously to the cables. The temperature at the conductor, as measured on the control cable, ranged from 126 to 129°C, approaching the emergency operating temperature of the cable. The joint assemblies in water ran cooler due to dissipation of heat into the water. No negative incidents occurred during the 30 days of heat cycling.

8.2.8 Partial Discharge Test After Heat Cycling

Table B-9 shows the results of partial discharge measurements after completion of 30 heat cycles for the eight joint assemblies. Heat cycling did not induce partial discharges in the joints.

8.2.9 Interface Gas Pressure Venting Test After Heat Cycling

Interface gas pressure venting tests were repeated on the same two previously tested joints after heat cycling. One of these joints had been aged in air and the other one in water. The results are shown in Table B-10. No leaks were recorded when increasing the pressure up to 35 psi.

8.2.10 Partial Discharge Test After Interface Gas Pressure Venting Test

The two joints subjected to gas venting pressure tests were thereafter subjected to partial discharge tests with results similar to those obtained prior to the venting tests (Table B-11).

8.2.11 Impulse Voltage Withstand Test at 130°C Conductor Temperature

As shown in Table B-12 each of the joint assemblies withstood ten impulses at negative and ten impulses at positive polarity at the BIL of 110 kV using an impulse wave of 1.2/50 µs shape. The conductor temperature during this test was about 130°C.

8.2.12 Partial Discharge Test After Hot Impulse Voltage Withstand Test

To establish if the application of the impulse voltage at elevated temperature affected the integrity of the joints, partial discharge measurements were made on the eight joints. The results are presented in Table B-13. No partial discharges above 3 pC were detected at voltages up to 26 kV.

8.2.13 AC Voltage Time Step Test to Breakdown

Each of the eight joints was subjected to an ac voltage breakdown test. The results are presented in Table B-14. Tests were performed by first applying 16.5 kV to each assembly and increasing the voltage in five-minute steps equivalent to 40 V/mil of the cable nominal insulation wall thickness, until achieving breakdown. The results show similar average breakdown levels for joints heat cycled in air and in water (76 vs. 78 kV). It should be noted that because of findings during dissection of Joint P4 the breakdown voltage of this joint (36 kV) was not taken into account when calculating the average breakdown value.

8.2.14 Dissection After AC Voltage Breakdown

Table B-15 provides the results of dissection of the eight joints after tests. All failures consisted of radial breakdowns occurring very much in the same area, where the outer semiconducting sleeve bridges over the cable extruded insulation shield. Of the four joints aged in air three (Joints P1, P5 and P8) failed at or very close to the cutback insulation shield. In Joint P4, which failed at 36 kV, the failure originated from a cut into the insulation that, most likely, was made during cable preparation. In Joints P2, P6 and P7 (aged in water) breakdown took place between the edge of the inner high permittivity layer and the insulation shield cut back. Figures B-1 through B-3 illustrate the breakdown of these three joints.

During dissection it was established that several joint bodies had been installed off center (Figure B-4). In this particular joint (B-4) the distance between the inner high permittivity layer of the joint body and the insulation shield cut back on the cable was measured 1.5 inches on one end and 0.02 inch on the other end of the joint.

8.2.15 Test Experiences and Observations

Table B-16 provides a summary of experiences and observations while testing the joints. It was learned from the manufacturer (after completion of the tests) that the kit used for joint assembly (model No. 35SIJC-V2) may not have been the most suitable for the cable used in the project. Kit model No. 15SIPJC-V2 having smaller diameter of the joint body would have fit the cable better. This, plus the relatively high effort to pull the joint jacket into place may have contributed to the displacement of the joint body, thereby reducing dielectric strength of the joints.

Comparative tests performed during a separate evaluation on four different size joints showed that the smaller joints, better fitting, had significantly higher ac voltage breakdown levels.

8.3 3M Cold Shrink Joint

Test data for this joint are presented in Section 7, Appendix C of this report.

8.3.1 Analysis of Joint Assembly/Fabrication

Table C-1 lists the various parameters of significance for the assembly/fabrication of the joint. It will be noted that the time required for one man to assemble/fabricate the joint was approximately 75 minutes, which is slightly less than the time required for the Tyco and Pirelli joints. The complexity and skill required are in the low end of the subjective rating 0-10 where 10 denotes the poorest rating. The longitudinal distance and width of space required to assemble/fabricate the joint are comparable to the Tyco and Pirelli joints.

8.3.2 Time to Complete Joint

Table C-2 provides a breakdown of the time required for one splicer to prepare cable ends and install the complete joint.

8.3.3 AC Voltage Withstand Test Prior to Heat Cycling

An ac voltage withstand test was performed on all joint assemblies prior to heat cycling. Each of the eight joints withstood the applied voltage of 35 kV (4.0 U_o) for five minutes (Table C-3).

8.3.4 Partial Discharge Test Prior to Heat Cycling

Table C-4 provides partial discharge test results for the eight joints prior to heat cycling. No partial discharge above 3 pC was detected at voltages up to 26 kV.

8.3.5 Interface Gas Pressure Venting Test Prior to Heat Cycling

This test was performed on one joint to be aged in air and one in water. The results are presented in Table C-5. Venting of pressure in the two joints occurred at 25 psi. The test was discontinued at this pressure level.

8.3.6 Partial Discharge Test After Interface Gas Pressure Venting Test

The two joints subjected to gas venting pressure tests were thereafter subjected to partial discharge tests with results similar to those obtained prior to the venting tests (Table C-6).

8.3.7 Heat Cycling

Table C-7 lists the thermocouple locations at various points on the control cable and cable loops.

Table C-8 provides daily records of temperature for the indicated locations, after seven hours of heating for the 30-day heat cycle test (8 hours current on, 16 hours off) with 26 kV (~3 U_o) applied continuously to the cables. The temperature of the conductor, as measured on the control cable, ranged from 127 to 129°C, approaching the emergency operating temperature of the cable.

The joint assemblies in water ran cooler due to dissipation of heat. No negative incidents occurred during the 30 days of heat cycling.

8.3.8 Partial Discharge Test After Heat Cycling

Table C-9 shows the results of partial discharge measurements after completion of 30 heat cycles for the eight joint assemblies. There was no partial discharge at voltages up to 26 kV for all joints.

8.3.9 Interface Gas Pressure Venting Test After Heat Cycling

Interface gas pressure venting tests were repeated on the same two previously tested joints after heat cycling. One of these joints had been aged in air and the other one in water. The results are shown in Table C-10. Venting of pressure in both joints occurred at 30 psi, one step higher than prior to heat cycling.

8.3.10 Partial Discharge Test After Interface Gas Pressure Venting Test

The two joints subjected to gas venting pressure tests were thereafter subjected to partial discharge tests with results similar to those obtained prior to the venting tests (Table C-11).

8.3.11 Impulse Voltage Withstand Test at 130°C Conductor Temperature

As shown in Table C-12, each of the joint assemblies in air and in water withstood ten impulses at negative and ten impulses at positive polarity at the BIL of 110 kV using an impulse wave of 1.2/50 μs shape. The conductor temperature during this test was about 130°C.

8.3.12 Partial Discharge Test After Hot Impulse Voltage Withstand Test

To establish if the application of the impulse voltage at elevated temperature affected the integrity of the joints, partial discharge measurements were made on the eight joints. The results are presented in Table B-13. One of the joints (3M6) exhibited 350 pC at 15.6 kV, approximately 2 times rated voltage to ground. No partial discharges above 3 pC, at voltages up to 26 kV, were detected on the other joints.

8.3.13 AC Voltage Time Step Test to Breakdown

Each of the eight joints was subjected to an ac voltage breakdown test. The results are presented in Table C-14. Tests were performed by first applying 16.5 kV to each assembly and increasing the voltage in five-minute steps equivalent to 40 V/mil of the cable nominal insulation wall thickness, until achieving breakdown. The results indicate that the joints heat cycled in air broke down on the average at a 13% higher voltage level than those aged in water (86 vs. 68 kV). The lowest voltage breakdown levels were recorded on Joints 3M6 and 3M7 (both heat cycled in water), 50 and 43 kV, respectively.

8.3.14 Dissection After AC Voltage Breakdown

Table C-15 provides the results of dissection of the eight joints after completion of the other tests.

It should be noted that water was found under the jacket in Joints 3M3 and 3M6 (Figure C-6).

It was established that of the four joints aged in air one (3M1) failed longitudinally, at the interface between the joint and the cable. Two (3M5 and 3M8) failed at or very close to the cutback insulation shield. In Joint 3M4 the failure occurred at the center of the connector. Of the joints aged in water one breakdown took place at the middle of the connector (Joint 3M2), one at about 0.5 inches from the insulation shield cut back (Joint 3M3). In Joints 3M6 and 3M7 failures occurred next to the edge of the connector. Illustrations of some of these failures are provided in Figures C-1 through C-4.

8.3.15 Test Experiences and Observations

Table C-16 provides a summary of experiences and observations while testing the joints.

As previously mentioned Joints 3M6 and 3M7 had the lowest voltage breakdown levels. Slices containing the breakdown paths were examined with the aid of a microscope. During this examination voids were found in the insulation of both joints. The size of the largest voids ranged between 10 and 15 mils in the greatest dimension. Figure C-5 shows one of these voids. In addition, more voids were found away from the failure location.

The presence of water under the jacket appears to have been related to the jacket application. During installation part of the jacket unfolds leaving a powder residue inside one end. Because of this powder, the inner jacket surface does not appear to have fully adhered to the sealing mastic material, allowing for water to enter under the jacket.

The results of interface gas pressure venting tests indicate that in the case gas would be generated, it will leak at a lower pressure than for the Tyco and Pirelli joints. Venting of pressure in 3M joints occurred prior to and after heat cycling (at 25 and 30 psi, respectively).

8.4 Elastimold 600 A Separable Connector Joint

Test data for the joint are presented in Section 7, Appendix D of this report.

8.4.1 Analysis of Joint Assembly/Fabrication

Table D-1 lists the various parameters of significance for the assembly/fabrication of the joint. The time required for one man to assemble/fabricate the joint was approximately 75 minutes and comparable to the other separable connector joints (600 and 900 A made by Richards). The complexity and skill required are in the mid range of the subjective rating 0-10 where 10 denotes the poorest rating. The longitudinal distance and width of space required to assemble/fabricate the joint are comparable to the other separable connector joints.

8.4.2 Time to Complete Joint

Table D-2 provides a breakdown of the time required for one splicer to prepare cable ends and install the complete joint.

8.4.3 AC Voltage Withstand Test Prior to Heat Cycling

An ac voltage withstand test was performed on all joint assemblies prior to heat cycling. Each of the eight joints withstood the applied voltage of 35 kV (4.0 U_o) for five minutes (Table D-3).

8.4.4 Partial Discharge Test Prior to Heat Cycling

Table D-4 provides partial discharge test results for the eight joints prior to heat cycling. Partial discharge levels above the maximum allowed (3 pC) were experienced on three joints. The partial discharge levels were 600 pC (Joint E1), 400 pC (Joint E4) and 800 pC (Joint E6). Discharge inception voltage ranged from 11 to 20 kV.

8.4.5 Heat Cycling

Table D-5 lists the thermocouple locations at various points on the control cable and cable loops.

Table D-6 provides daily records of temperature for the indicated locations, after seven hours of heating for the 30-day heat cycle test (8 hours current on, 16 hours off) with 26 kV (~3 U_o) applied continuously to the cables. The records show that during heat cycling the temperature of the connectors in the control cable were 15-20°C higher than that of the corresponding cable conductors. Further dissection and examination of the joints after completing all tests confirmed that some of the connectors had been overheated.

According to IEEE Std 404 “the current and temperature ratings of the cable joint shall be equal to or greater than those of the cable for which it is designed”. Therefore, the heat cycling procedure for all joints tested within this project was designed to have a cable conductor temperature of 130°C at the end of the current-on period. As shown in Table D-6, when testing the Elastimold separable joints, currents of 1300 A were required. Considering that these joints are rated for 600 A, such currents could result in overheating of the connectors.

After three initial heat cycles, where high temperatures were noted, it was decided to continue heat cycling under the same conditions. The temperature of the conductor as measured on the control cable ranged from 126 to 130°C. The joint assemblies in water ran cooler due to dissipation of heat into the water.

8.4.6 Partial Discharge Test After Heat Cycling

Table D-7 shows the results of partial discharge measurements after completing 30 heat cycles for the eight joint assemblies. There was no partial discharge above 3 pC up to 26 kV for all joints, including the three that showed high level of partial discharge prior to heat cycling. It is believed that during the cyclic aging the joint components improved their accommodation to the cable and thereby the partial discharge diminished to insignificant levels.

8.4.7 Impulse Voltage Withstand Test at 130°C Conductor Temperature

As shown in Table D-8, each of the joint assemblies in air and in water withstood ten impulses at negative and ten impulses at positive polarity at the BIL of 110 kV using an impulse wave of 1.2/50 μs shape. The conductor temperature during these tests was about 130°C.

8.4.8 Partial Discharge Test After Hot Impulse Voltage Withstand Test

A partial discharge test was performed on each of the eight joints. No change was noted in their performance as shown in Table D-9.

8.4.9 AC Voltage Time Step Test to Breakdown

Next each of the eight joints was subjected to an ac voltage breakdown test. Tests were performed by first applying 16.5 kV to each of the assemblies and increasing the voltage each five-minutes in steps, equivalent to 40 V/mil of the cable nominal insulation wall thickness, until achieving breakdown. The results are presented in Tables D-10 and D-11. Table D-10 compares the results of ac breakdown tests for joints heat cycled in air vs. in water. The results show about similar average breakdown levels (91 vs. 88 kV). Table D-11compares the ac breakdown levels for joints employing retaining rings (first group) vs. those prepared with EPR tape bumpers (second group). The results indicate that the joints employing the EPR tape broke down (on the average) at a 26% lower voltage level than those incorporating the rings (76 vs. 103 kV).

8.4.10 Dissection After AC Voltage Breakdown

Table D-12 provides the results of dissection of the eight joints after tests.

Of the four joints aged in air one (E5) failed longitudinally, at the interface between the insulating layers of the bus bar and the receptacle housing. Two joints (E1 and E8) failed at or close to the inner semi-conducting layer of the cable adapter. In Joint E4 the failure occurred at the cut back of the insulation shield. Of the joints aged in water three breakdowns (E2, E6 and E7) took place at the cable insulation shield cut back. One failure occurred at the location of the step in the semiconducting layer of the cable adapter (Joint E3).

Figures D-1 through D-5 are illustrations of some of the joint failures described above.

8.4.11 Test Experiences and Observations

Test experiences and observations during testing of the Elastimold separable connector joints are listed in Table D-13.

As previously mentioned, joints employing retaining rings exhibited significantly higher voltage breakdown levels than those incorporating EPR tape bumpers. It is suspected that employing the EPR bumper allows shifting of the cable adapter from its initial position resulting in cavity formation at the location of the step in the semiconducting layer of the cable adapter (refer to Figure D-5).

Overall, the Elastimold separable connector joints showed a very good performance during testing.

8.5 Richards 600 A Separable Connector Joint

Test data for this joint are presented in Section 7, Appendix E of this report. During the 30-day heat cycling test one of the joints in air failed. Another joint (also cycled in air) was found to be overheated. In investigating it was determined that these conditions were related to two problems – one was looseness of the hex-head bolts, which connect the connector and the bus bar; the second was that the compression tool used by the splicers, while crimping the connectors, apparently had not been properly adjusted. The lack of full compression was conducive to overheating of the connectors. It was decided to take a new group of eight joints and repeat the evaluation. Based on recommendations from Richards and Consolidated Edison, it was decided to use aluminum connectors with 330 or 180 mils wall thickness (one type for each four joint assemblies) for the installation of the new joints. Connectors with 330 mils wall thickness had been used with the first group of joints.

The test results in this report are for the eight replacement joints.

8.5.1 Analysis of Joint Assembly/Fabrication

Table E-1 lists the various parameters of significance for the assembly/fabrication of the joint. The time required for one splicer to assemble/fabricate the joint was approximately 75 minutes and was comparable to the other separable connector joints. The complexity and skill required are in the mid range of the subjective rating 0-10 where 10 denotes the poorest rating in each classification. The longitudinal distance and width of space required to assemble/fabricate the joint are comparable to the other separable connector joints.

8.5.2 Time to Complete Joint

Table E-2 provides a breakdown of the time required for one splicer to prepare cable ends and install the complete joint.

8.5.3 AC Voltage Withstand Test Prior to Heat Cycling

An ac voltage withstand test was performed on all joint assemblies prior to heat cycling. Each of the eight joints withstood the applied voltage of 35 kV (4.0 U_o) for five minutes (Table E-3).

8.5.4 Partial Discharge Test Prior to Heat Cycling

Table E-4 provides partial discharge test results for the eight joints prior to heat cycling. No partial discharge (above 3 pC) was detected at voltages up to 26 kV.

8.5.5 Heat Cycling

Table E-5 lists the thermocouple locations at various points on the control cable and cable loops.

Table E-6 provides daily records of temperature for the indicated locations, after seven hours of heating for the 30-day heat cycle test (8 hours current on, 16 hours off) with 26 kV (~3 U_o) applied continuously to the cables. The temperature of the conductor, as measured on the control cable, ranged from 126 to 130°C. The temperature of the connectors in the control cable was 10-15°C higher than that of the corresponding cable conductors. Connectors with a thicker wall run 5-6°C cooler than those with a thinner wall. No negative incidents occurred during the 30 days of heat cycling tests.

8.5.6 Partial Discharge Test After Heat Cycling

Table E-7 shows the results of partial discharge measurements after completing 30 heat cycles for the eight joint assemblies. There was no partial discharge above 3 pC at voltages up to 26 kV for all joints.

8.5.7 Impulse Voltage Withstand Test at 130°C Conductor Temperature

As shown in Table E-8, each of the joint assemblies in air and in water withstood ten impulses at negative and ten impulses at positive polarity at the BIL of 110 kV using an impulse wave of 1.2/50 μs shape. The cable conductor temperature during these tests was about 130°C.

8.5.8 Partial Discharge Test After Hot Impulse Voltage Withstand Test

A partial discharge test was performed on each of the eight joints. No change was noted in their performance as shown in Table E-9.

8.5.9 AC Voltage Time Step Test to Breakdown

Each of the eight joints was subjected to an ac voltage breakdown test with results as outlined in Table E-10. Tests were performed by first applying 16.5 kV to each of the assemblies and increasing the voltage each five-minutes in steps equivalent to 40 V/mil of the cable nominal insulation wall thickness, until achieving breakdown. The results indicate that, on the average, joints heat cycled in water broke down at a 13% higher voltage level than those aged in air (86 vs. 76 kV).

8.5.10 Dissection After AC Voltage Breakdown

After completing the ac voltage breakdown tests, each of the eight joints were dissected and examined. Results of the dissection are provided in Table D-11. All four joints aged in air (R1, R4, R5 and R8) broke down at the location of the step in the semi-conducting layer of the cable adapter. Of the four joints aged in water one (R2) failed longitudinally, at the interface between the insulation of the cable adapter and the receptacle housing. Two joints (R3 and R6) failed at the location of the step in the cable adapter. In one joint (R7) the failure path was a combination of radial (through the cable insulation) and longitudinal (at the interface between the insulation of the cable and the adapter).

Figures E-1 through E-4 are illustrations of some of the joint failures described above.

During dissection it was noted that in several joints the inner semiconducting layer of the receptacle housing exhibited signs of partial melting and pitting in the area corresponding to the location of the hex bolt (Figures E-5 and E-6).

8.5.11 Test Experiences and Observations

Test experiences and observations during testing of the Richards 600 A separable connector joints are listed in Table E-12.

Most of the breakdowns (six) occurred in the area where the step in the inner semiconducting layer of the cable adapter was not flush with the edge of the cable insulation shield, creating a cavity at the interface between the cable insulation and the inner layer of the cable adapter. It appears that employing an EPR tape bumper instead of the retaining ring results in shifting of the cable adapter during installation of the receptacle housing and the creation of a gap at the interface between the cable insulation and the inner semiconducting layer of the cable adapter.

The erosion on the inner semiconducting layer surface of the receptacle housing (Figures E-5 and E-6) apparently was caused by impulse voltages to which the assemblies were subjected. The test impulses had a standard shape of 1.2 x 50 µs. At this fast transient the semiconducting material can acquire a substantially different potential than the cable conductor (connector) depending on volume resistivity of the semiconducting component[1]. This difference in potential

[1] S. A. Boggs, "500 Ω-m – Low Enough Resistivity for a Cable Ground Shield Semicon?" IEEE Electrical Insulation Magazine, Vol. 17, No. 4, 2001.

could result in sparking through the air gap between the exposed sharp edge of the hex bolt and the semi-conducting layer causing the observed damage.

The performance of the Richards 600 A separable connector joint is considered to be satisfactory.

8.6 Richards 900 A Separable Connector Joint

Test data for this joint are presented in Section 7, Appendix F of this report.

8.6.1 Analysis of Joint Assembly/Fabrication

Table F-1 lists the various parameters of significance for the assembly/fabrication of the joint. The time required for one splicer to assemble/fabricate the joint was approximately 75 minutes and was comparable to the other separable connector joints. The complexity and skill required are in the mid range of the subjective rating 0-10 where 10 denotes the poorest rating in each classification. The longitudinal distance and width of space required to assemble/fabricate the joint are comparable to the other separable connector joints.

8.6.2 Time to Complete Joint

Table F-2 provides a breakdown of the time required for one splicer to prepare cable ends and install the complete joint.

8.6.3 AC Voltage Withstand Test Prior to Heat Cycling

An ac voltage withstand test was performed on all joint assemblies prior to heat cycling. Each of the eight joints withstood the applied voltage of 35 kV (4.0 U_o) for five minutes (Table F-3).

8.6.4 Partial Discharge Test Prior to Heat Cycling

Table F-4 provides partial discharge test results for the eight joints prior to heat cycling. No partial discharge (above 3 pC) was detected at voltages up to 26 kV.

8.6.5 Heat Cycling

Table F-5 lists the thermocouple locations at various points on the control cable and cable loops.

Table F-6 provides daily records of temperature for the indicated locations, after seven hours of heating for the 30-day heat cycle test (8 hours current on, 16 hours off) with 26 kV (~3 U_o) applied continuously to the cables. The temperature of the conductor, as measured on the control cable, ranged from 126 to 129°C. The temperature of the copper connectors in the control cable were 11-13°C lower than that of the corresponding cable conductors because of the larger cross-section of the copper current-carrying components. The joint assemblies in water ran cooler due to dissipation of heat into the water. No negative incidents occurred during the 30 days of heat cycling tests.

8.6.6 Partial Discharge Tests After Heat Cycling

Table F-7 shows the results of partial discharge measurements after completion of 30 heat cycles for the eight joint assemblies. There was no partial discharge above 3 pC at voltages up to 26 kV for all joints.

8.6.7 Impulse Voltage Withstand Test at 130°C Conductor Temperature

Table F-8 shows that each of the joint assemblies in air and in water withstood ten impulses at negative and ten impulses at positive polarity at the BIL of 110 kV using an impulse wave of 1.2/50 μs shape. The conductor temperature during these tests was about 130°C.

8.6.8 Partial Discharge Test After Hot Impulse Voltage Withstand Test

A partial discharge test was performed on each of the eight joints. No change was noted in their performance as shown in Table F-9.

8.6.9 AC Voltage Time Step Test to Breakdown

Each of the eight joints was subjected to an ac voltage breakdown test with results as outlined in Table F-10. Tests were performed by first applying 16.5 kV to each of the assemblies and increasing the voltage in steps, equivalent to 40 V/mil of the cable nominal insulation wall thickness, each 5 minutes, until achieving breakdown. The results indicate that joints heat cycled in air broke down, on the average, at a 12% higher voltage level than those aged in water (96 vs. 83 kV).

8.6.10 Dissection After AC Voltage Breakdown

Table F-11 lists the findings on dissections of the joints after ac voltage breakdown tests. Two joints (R4 and R7) failed longitudinally at the interface between the insulation of the bus bar and the receptacle housing. Two joints (R1 and R8) failed at or close to the cut back of the insulation shield. In Joint R3 the failure progressed radially through the cable insulation and then propagated longitudinally at the interface between the insulation of the cable and the cable adapter. Three failures occurred at the location of the step in the semiconducting layer of the cable adapter (Joints R2, R5 and R6).

Figures F-1 through F-5 are illustrations of some of the joint failures described above.

8.6.11 Test Experiences and Observations

Test experiences and observations during the testing of the Richards 900 A separable connector joints are listed in Table F-12.

The lowest voltage breakdown values were obtained in Joints R2, R5 and R6, where failure took place in coincidence with the step in the semiconducting layer of the cable adapter. Employing an EPR tape bumper instead of the retaining ring resulted in shifting of the cable adapter during installation of the receptacle housing and the creation of a gap at the interface between the cable insulation and the inner semiconducting layer of the cable adapter. Similar observations were made in the other separable connector joints assembled with an EPR tape bumper.

In several joints, the inner semiconducting layer of the receptacle housing exhibited melting and pitting in the area of the hex-head bolt (Figure F-6). This erosion of the semiconducting material, as described earlier in Section 8.5.11, most likely took place during the impulse voltage tests, as a result of sparking between the semicoducting layer and the hex-head bolt due to a difference in potential between these two elements.

The performance of the Richards 900 A separable connector joint in the test program is considered to be satisfactory.

A

TYCO COLD SHRINK JOINT ON 750 KCMIL, 15 KV CABLE

Tyco Cold Shrink – CAS-15M-2 Series

- Analysis of joint assembly/fabrication – Table A-1
- Breakdown of time required for preparation of cables and assembly of joint – Table A-2
- Test results – Tables A-3 through A-15
- Test experiences and observations – Table A-16

Table A-1
Analysis of Joint Assembly/Fabrication

Assembly/Fabrication	Results
Time required to complete joint, (1 splicer)	80
Complexity of making the joint, (0 to 10)*	3
Skill required, (0 to 10)*	3
Longitudinal space required, in.	72
Length of complete joint, in.	30
Width of space required (minimum), in.	48
Other requirements: Installation area must be clean	

* Subjective rating, 10 denotes most difficult.

Table A-2
Time to Complete Joint

Preparation of Cables	**Time, min.**
Cable sections cut to length	5
Jackets removed, flat straps folded back	10
Insulation shield stripped	6
Insulation cut back	4
Installation of Joint Housing	
Joint body parked, connector crimped	7
Insulation cleaned, gaps and indents filled with mastic	8
Two-layer patch installed, mastic applied over insulation shield cut back, joint application surface greased	10
Joint positioned and installed by removing supports	7
Mastic seal applied, copper mesh connected to flat straps	15
Jacket positioned and installed	8
Total (1 splicer)	80

Table A-3
AC Withstand Voltage Test Prior to Heat Cycling

Joint No.	Joint Identification	To be Heat Cycled in	Applied Voltage kV	Time minutes	Result
1	T1	Air	35	5	Passed
2	T4	Air	35	5	Passed
3	T5	Air	35	5	Passed
4	T8	Air	35	5	Passed
5	T2	Water	35	5	Passed
6	T3	Water	35	5	Passed
7	T6	Water	35	5	Passed
8	T7	Water	35	5	Passed

Table A-4
Partial Discharge Test Prior to Heat Cycling

Joint No.	Joint ID	To be Heat Cycled in	Partial Discharge - pC			Inception Voltage kV	Extinction Voltage kV
			at 13 kV	at 15.6 kV	at 26 kV		
1	T1	Air	<3	<3	<3	>26	>26
2	T4	Air	<3	<3	<3	>26	>26
3	T5	Air	<3	<3	<3	>26	>26
4	T8	Air	<3	<3	<3	>26	>26
5	T2	Water	<3	<3	<3	>26	>26
6	T3	Water	<3	<3	<3	>26	>26
7	T6	Water	<3	<3	<3	>26	>26
8	T7	Water	<3	<3	<3	>26	>26

Table A-5
Interface Gas Pressure Venting Test Prior to Heat Cycling

Joint Identification	T1	T2
Gas Pressure, psi		
5	No leak	No leak
10	No leak	No leak
15	No leak	No leak
20	No leak	No leak
25	No leak	No leak
30	No leak	No leak
35*	No leak	No leak

* Test discontinued.

Table A-6
Partial Discharge Test After Interface Gas Pressure Venting Test

Joint No.	Joint ID	To be Heat Cycled in	Partial Discharge - pC			Inception Voltage kV	Extinction Voltage kV
			at 13 kV	at 15.6 kV	at 26 kV		
1	**T1***	**Air**	**<3**	**<3**	**<3**	**>26**	**>26**
2	T4	Air	<3	<3	<3	>26	>26
3	T5	Air	<3	<3	<3	>26	>26
4	T8	Air	<3	<3	<3	>26	>26
5	**T2***	**Water**	**<3**	**<3**	**<3**	**>26**	**>26**
6	T3	Water	<3	<3	<3	>26	>26
7	T6	Water	<3	<3	<3	>26	>26
8	T7	Water	<3	<3	<3	>26	>26

* Joint subjected to interface gas pressure venting test.

Table A-7
Thermocouple Location on Cables During Heat Cycling

Thermocouple No.	Cable Component	Location
	Control Cable	
Control	Conductor, Cable	6 ft. from center of joint
1	Conductor, Cable	1 ft. from control thermocouple
2	Conductor, Cable	5 ft. from center of joint (opposite side)
3	Connector	Outside wall of connector
4	Top of Cable Insulation Shield	6 ft. from center of joint
5	Top of Cable Insulation Shield	6 ft. from center of joint (opposite side)
6	Top of Cable Jacket	7 ft. from center of joint
7	Top of Joint Housing	Center of joint, under jacket
	A, B, C, D Cable Loop	**(A, D in Air – B, C in Water)**
8	Top of Insulation Shield (A)	4 ft. from center of joint T1
9	Top of Joint Housing (A)	Center of joint T1, under jacket
10	Top of Joint Housing (B)	Center of joint T2, under jacket
11	Top of Joint Housing (C)	Center of joint T3, under jacket
12	Top of Joint Housing (D)	Center of joint T4, under jacket
13	Water in Pipe (B)	3 ft. from center of joint T2
	E, F, G, H Cable Loop	**(E, H in Air – F, G in Water)**
14	Top of Insulation Shield (E)	4 ft. from center of joint T5
15	Top of Joint Housing (E)	Center of joint T5, under jacket
16	Top of Joint Housing (F)	Center of joint T6, under jacket
17	Top of Joint Housing (G)	Center of joint T7, under jacket
18	Top of Joint Housing (H)	Center of joint T8, under jacket
19	Water in Pipe (F)	3 ft. from center of joint T6
20	Ambient Air	Next to joint setup

Table A-8
Heat Cycle, Daily Records After Seven-Hour Heating

Day of the Week	Wed.	Thu.	Fri.	Sat.	Sun.	Mon.	Tue.	Wed.
Date	**08/06**	**08/07**	**08/08**	**08/09**	**08/10**	**08/11**	**08/12**	**08/13**
Cycle No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Thermoc., Location								
Control Cable	**Temperature, °C**							
Cond., Contr. Cable	128	129	128	128	129	128	128	129
Conductor, Cable	127	128	127	127	128	126	127	128
Conductor, Cable	126	128	126	126	127	126	126	127
Connector	140	142	141	141	142	140	141	143
Top of Cable Insulation Shield	105	106	105	105	106	105	106	107
Top of Cable Insulation Shield	104	105	104	105	104	104	104	105
Top of Cable Jacket	93	94	93	93	94	93	93	94
Top of Joint Housing	98	99	97	97	98	97	98	99
A, B, C, D Cable Loop	**(A, D in Air - B, C in Water)**							
Top of Insulation Shield (A)	97	98	98	97	97	96	96	97
Top of Joint Housing (A)	97	98	99	97	98	96	97	98
Top of Joint Housing (B)	61	62	62	61	62	61	61	62
Top of Joint Housing (C)	58	59	59	58	59	59	58	59
Top of Joint Housing (D)	97	99	99	98	98	97	98	100
Water in Pipe (B)	49	51	50	49	50	49	49	52
E, F, G, H Cable Loop	**(E, H in Air - F, G in Water)**							
Top of Insulation Shield (E)	98	99	99	98	99	98	98	100
Top of Joint Housing (E)	97	99	98	97	99	97	98	100
Top of Joint Housing (F)	58	61	60	60	60	58	59	61
Top of Joint Housing (G)	57	60	59	59	59	57	58	59
Top of Joint Housing (H)	97	98	98	97	97	97	97	98
Water in Pipe (F)	50	51	51	50	51	50	50	52
Ambient Air	36	34	30	32	31	35	35	40
Current - A	1250	1250	1250	1250	1250	1250	1250	1230

Table A-8 (continued)
Heat Cycle, Daily Records After Seven-Hour Heating

Day of the Week	**Thu.**	**Fri.**	**Sat.**	**Sun.**	**Mon.**	**Tue.**	**Wed.**	**Thu.**
Date	**08/14**	**08/15**	**08/16**	**08/17**	**08/18**	**08/19**	**08/20**	**08/21**
Cycle No.	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Thermoc., Location								
Control Cable	**Temperature, °C**							
Cond., Contr. Cable	128	127			128	128	127	128
Conductor, Cable	128	126			127	127	126	127
Conductor, Cable	127	126			126	126	126	127
Connector	142	141			139	140	139	1
Top of Cable Insulation Shield	107	106			106	105	105	105
Top of Cable Insulation Shield	105	103			104	104	103	105
Top of Cable Jacket	92	92			92	91	91	91
Top of Joint Housing	99	98			99	99	98	98
A, B, C, D Cable Loop	**(A, D in Air - B, C in Water)**							
Top of Insulation Shield (A)	96	97			96	96	98	98
Top of Joint Housing (A)	99	101			101	102	100	100
Top of Joint Housing (B)	61	61			61	61	60	61
Top of Joint Housing (C)	58	59			58	58	58	59
Top of Joint Housing (D)	103	104			103	105	104	103
Water in Pipe (B)	50	51			50	51	51	53
E, F, G, H Cable Loop	**(E, H in Air - F, G in Water)**							
Top of Insulation Shield (E)	102	103			102	103	102	102
Top of Joint Housing (E)	101	102			102	103	101	101
Top of Joint Housing (F)	59	61			60	60	60	61
Top of Joint Housing (G)	59	60			60	60	60	61
Top of Joint Housing (H)	98	100			101	101	100	99
Water in Pipe (F)	48	50			50	50	50	51
Ambient Air	37	40			39	39	41	41
Current - A	1230	1230	1230	1230	1230	1230	1230	1230

Table A-8 (continued)
Heat Cycle, Daily Records After Seven-Hour Heating

Day of the Week	Fri.	Sat.	Sun.	Mon.	Tue.	Wed.	Thu.	Fri.
Date	**08/22**	**08/23**	**08/24**	**08/25**	**08/26**	**08/27**	**08/28**	**08/29**
Cycle No.	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Thermoc., Location								
Control Cable	**Temperature, °C**							
Cond., Contr. Cable	129			128	127	128	127	127
Conductor, Cable	129			128	126	127	126	126
Conductor, Cable	128			127	126	126	125	126
Connector	143			141	139	141	139	140
Top of Cable Insulation Shield	107			106	105	106	105	105
Top of Cable Insulation Shield	106			106	105	106	105	105
Top of Cable Jacket	92			90	90	92	91	91
Top of Joint Housing	98			99	98	99	98	99
A, B, C, D Cable Loop	**(A, D in Air - B, C in Water)**							
Top of Insulation Shield (A)	99			101	101	101	101	102
Top of Joint Housing (A)	99			101	101	103	102	102
Top of Joint Housing (B)	62			63	62	63	62	63
Top of Joint Housing (C)	58			59	59	60	60	60
Top of Joint Housing (D)	104			105	103	105	103	103
Water in Pipe (B)	50			53	51	53	52	51
E, F, G, H Cable Loop	**(E, H in Air - F, G in Water)**							
Top of Insulation Shield (E)	103			105	104	105	103	103
Top of Joint Housing (E)	102			104	104	105	103	102
Top of Joint Housing (F)	60			61	60	61	60	61
Top of Joint Housing (G)	60			62	61	61	60	61
Top of Joint Housing (H)	100			101	100	101	100	101
Water in Pipe (F)	50			52	50	52	51	51
Ambient Air	40			40	40	41	40	41
Current - A	1230	1230	1230	1230	1230	1230	1230	1230

Table A-8 (continued)
Heat Cycle, Daily Records After Seven-Hour Heating

Day of the Week	Sat.	Sun.	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Date	**08/30**	**08/31**	**09/01**	**09/02**	**09/03**	**09/04**	**09/05**	**09/06**
Cycle No.	**25**	**26**	**27**	**28**	**29**	**30**		
Thermoc., Location								
Control Cable	**Temperature, ˚C**							
Cond., Contr. Cable				127	127	127		
Conductor, Cable				126	126	126		
Conductor, Cable				126	125	125		
Connector				139	139	138		
Top of Cable Insulation Shield				105	104	104		
Top of Cable Insulation Shield				105	104	103		
Top of Cable Jacket				90	91	90		
Top of Joint Housing				98	99	99		
A, B, C, D Cable Loop	**(A, D in Air - B, C in Water)**							
Top of Insulation Shield (A)				102	102	102		
Top of Joint Housing (A)				101	102	101		
Top of Joint Housing (B)				62	63	62		
Top of Joint Housing (C)				60	61	60		
Top of Joint Housing (D)				102	102	101		
Water in Pipe (B)				51	51	51		
E, F, G, H Cable Loop	**(E, H in Air - F, G in Water)**							
Top of Insulation Shield (E)				103	103	102		
Top of Joint Housing (E)				102	103	102		
Top of Joint Housing (F)				60	60	60		
Top of Joint Housing (G)				60	61	60		
Top of Joint Housing (H)				100	100	99		
Water in Pipe (F)				49	49	48		
Ambient Air				35	34	33		
Current - A	1230	1230	1230	1250	1250	1250		

Table A-9
Partial Discharge Test After Heat Cycling

Joint No.	Joint ID	Heat Cycled in	Partial Discharge - pC			Inception Voltage kV	Extinction Voltage kV
			at 13 kV	at 15.6 kV	at 26 kV		
1	T1	Air	<3	<3	<3	>26	>26
2	T4	Air	<3	<3	<3	>26	>26
3	T5	Air	<3	<3	<3	>26	>26
4	T8	Air	<3	<3	<3	>26	>26
5	T2	Water	<3	<3	<3	>26	>26
6	T3	Water	<3	<3	<3	>26	>26
7	T6	Water	<3	<3	<3	>26	>26
8	T7	Water	<3	<3	<3	>26	>26

Table A-10
Interface Gas Pressure Venting Test After Heat Cycling

Joint Identification	T1	T2
Gas Pressure, psi		
5	No leak	No leak
10	No leak	No leak
15	No leak	No leak
20	No leak	No leak
25	No leak	No leak
30	No leak	No leak
35*	No leak	No leak

* Test discontinued

Table A-11
Partial Discharge Test After Interface Gas Pressure Venting Test

Joint No.	Joint ID	Heat Cycled in	Partial Discharge - pC			Inception Voltage kV	Extinction Voltage kV
			at 13 kV	at 15.6 kV	at 26 kV		
1	**T1***	**Air**	**<3**	**<3**	**<3**	**>26**	**>26**
2	T4	Air	<3	<3	<3	>26	>26
3	T5	Air	<3	<3	<3	>26	>26
4	T8	Air	<3	<3	<3	>26	>26
5	**T2***	**Water**	**<3**	**<3**	**<3**	**>26**	**>26**
6	T3	Water	<3	<3	<3	>26	>26
7	T6	Water	<3	<3	<3	>26	>26
8	T7	Water	<3	<3	<3	>26	>26

* Joints subjected to interface gas pressure venting test.

Table A-12
Impulse Withstand Test at 130°C Conductor Temperature

Joint No.	Joint ID	Heat Cycled in	Bend Adjacent to Joint	Withstand Voltage kV	Polarity	Number of Impulses	Result
1	T1	Air	No	110 110	Positive Negative	10 10	Passed Passed
2	T4	Air	No	110 110	Positive Negative	10 10	Passed Passed
3	T5	Air	No	110 110	Positive Negative	10 10	Passed Passed
4	T8	Air	Yes	110 110	Positive Negative	10 10	Passed Passed
5	T2	Water	No	110 110	Positive Negative	10 10	Passed Passed
6	T3	Water	No	110 110	Positive Negative	10 10	Passed Passed
7	T6	Water	No	110 110	Positive Negative	10 10	Passed Passed
8	T7	Water	Yes	110 110	Positive Negative	10 10	Passed Passed

Table A-13
Partial Discharge Test After Hot Impulse Withstand Test

Joint No.	Joint ID	Heat Cycled in	Partial Discharge - pC			Inception Voltage kV	Extinction Voltage kV
			at 13 kV	at 15.6 kV	at 26 kV		
1	T1	Air	<3	<3	<3	>26	>26
2	T4	Air	<3	<3	<3	>26	>26
3	T5	Air	<3	<3	<3	>26	>26
4	T8	Air	<3	<3	<3	>26	>26
5	T2	Water	<3	<3	<3	>26	>26
6	T3	Water	<3	<3	<3	>26	>26
7	T6	Water	<3	<3	<3	>26	>26
8	T7	Water	<3	<3	<3	>26	>26

Table A-14
AC Voltage Time Step Test to Breakdown

Joint No.	Joint ID	Heat Cycled in	Bend Adjacent to Joint	Breakdown Voltage kV	Time at Max. Voltage min.
1	T1	Air	No	89	1.1
2	T4	Air	No	96	3.2
3	T5	Air	No	89	0.8
4	T8	Air	Yes	56* 91 kV avg.	4.3
5	T2	Water	No	122	4.3
6	T3	Water	No	109	4.2
7	T6	Water	No	109	4.0
8	T7	Water	Yes	116 114 kV avg.	0.3

* Failure originated from cut in the insulation. This breakdown was not taken into account when calculating the average value.

Table A-15
Dissection After AC Voltage Breakdown Test

Joint No.	Joint ID	Heat Cycled in	Breakdown Voltage kV	Result
1	T1*	Air	89	Radial failure next to the edge of cable insulation shield (Figure A-2)
2	T4	Air	96	Radial failure at the edge of cable insulation shield
3	T5	Air	89	Radial failure next to the edge of cable insulation shield
4	T8*	Air	56	Radial breakdown at the edge of cable insulation shield. Failure started at a small cut into the insulation
5	T2	Water	122	Longitudinal breakdown at the interface between cable insulation and inner layer of joint body
6	T3	Water	109	Radial failure next to the edge of cable insulation shield
7	T6	Water	109	Longitudinal breakdown at the interface between cable insulation and inner layer of joint body (Figure A-3)
8	T7	Water	116	Longitudinal breakdown at the interface between cable insulation and inner layer of joint body (Figure A-1)

* Outer tube of joint body (over copper mesh) was found split (Figure A-4).

Table A-16
Test Experiences and Observations

Short joint support tube is convenient for use in tight spots.
Joint body still can be centered when short support tube is removed.
Two-layer patch and electric field control mastic are convenient to use.
Jacket provides a good mechanical protection.
The breakdown voltage level of joint assemblies aged in water is considerably higher than those of joints aged in air.
During heat cycling temperature at the connector of joints aged in air were noticeably higher than the cable conductor temperatures.
The high temperature could be attributed to the thickness of the joint jacket, which may not dissipate the heat well.
Due to high temperatures and hoop stresses electric field control mastic is redistributed, in the areas of high electric stress.
The high temperature results in splitting the outer non-conductive sleeve of the joint body.

Figure A-1
Longitudinal Failure in Joint T7.

Figure A-2
Failure in Joint T4. Failure at the Edge of the Cable Insulation Shield.

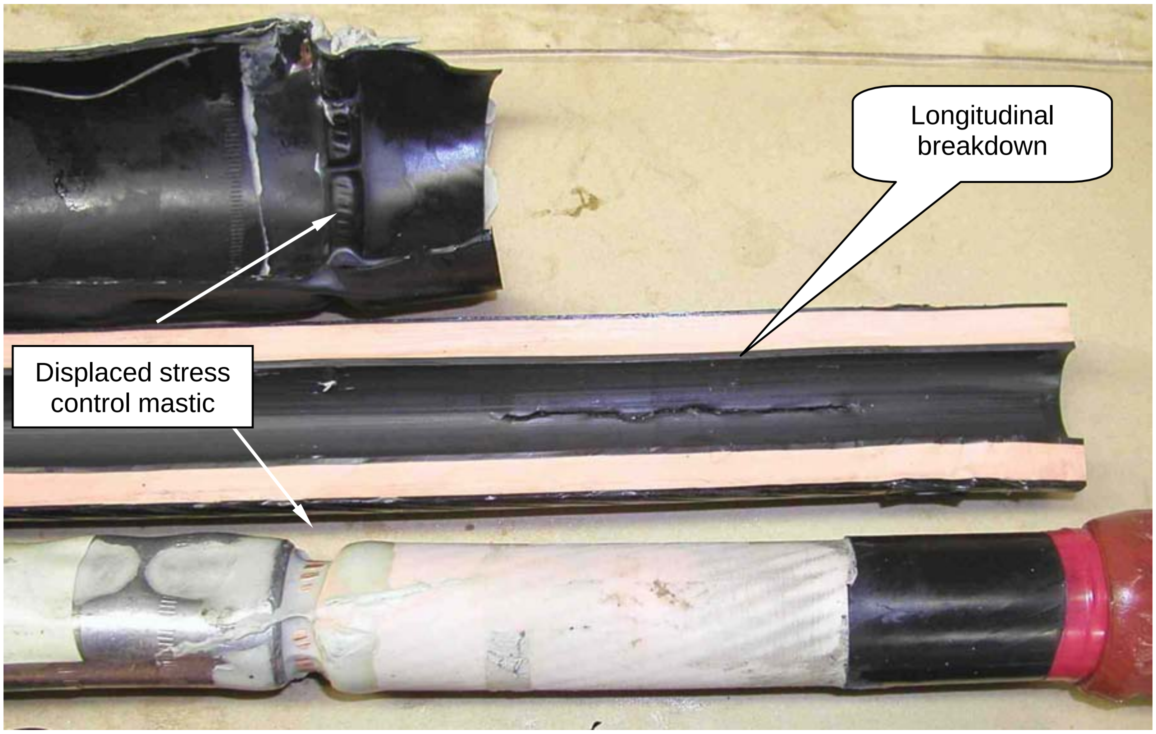

Figure A-3
Longitudinal Failure in Joint T6. Note Displaced Stress Control Mastic.

Figure A-4
Split Outer Sleeve of Splice Body in Joint T1 (Heat Cycled in Air).

B

PIRELLI COLD SHRINK JOINT ON 750 KCMIL, 15 KV CABLE

Pirelli Cold Shrink “Elaspeed“ Joint

- Analysis of joint assembly/fabrication – Table B-1
- Breakdown of time required for preparation of cables and assembly of joint – Table B-2
- Test results – Tables B-3 through B-15
- Test experiences and observations – Table B-16

Table B-1
Analysis of Joint Assembly/Fabrication

Assembly/Fabrication	Results
Time required to complete joint, (1 splicer)	85
Complexity of making the joint, (0 to 10)*	4
Skill required, (0 to 10)*	4
Longitudinal space required, in.	72
Length of complete joint, in.	33
Width of space required (minimum), in.	48
Other requirements: Installation area must be clean	

* Subjective rating, 10 denotes most difficult.

Table B-2
Time to Complete Joint

Preparation of Cables	**Time, min.**
Cable sections cut to length	5
Jackets removed, flat straps folded back	10
Insulation shield stripped	6
Insulation cut back	4
Installation of Joint Housing	
Joint body parked, connector crimped	7
Insulation cleaned, gaps and indents filled with mastic strips. High permitivity mastic pad installed over connector and insulation cut back	8
Cold shrink joint positioned and installed by removing carrier tubes	12
Excess grease cleaned, rubber tape wrapped over semiconducting sleeve of joint body	8
Mastic strips applied, copper mesh connected to metallic shield	12
Mastic pads installed, joint jacket lubricated and installed	10
Total (1 splicer)	80

Table B-3
AC Withstand Voltage Test Prior to Heat Cycling

Joint No.	Joint Identification	To be Heat Cycled in	Applied Voltage kV	Time minutes	Result
1	P1	Air	35	5	Passed
2	P4	Air	35	5	Passed
3	P5	Air	35	5	Passed
4	P8	Air	35	5	Passed
5	P2	Water	35	5	Passed
6	P3	Water	35	5	Passed
7	P6	Water	35	5	Passed
8	P7	Water	35	5	Passed

Table B-4
Partial Discharge Test Prior to Heat Cycling

Joint No.	Joint ID	To be Heat Cycled in	Partial Discharge - pC			Inception Voltage kV	Extinction Voltage kV
			at 13 kV	at 15.6 kV	at 26 kV		
1	**P1**	**Air**	**<3**	**<3**	**<3**	**>26**	**>26**
2	P4	Air	<3	<3	<3	>26	>26
3	P5	Air	<3	<3	<3	>26	>26
4	P8	Air	<3	<3	<3	>26	>26
5	P2	Water	<3	<3	<3	>26	>26
6	P3	Water	<3	<3	<3	>26	>26
7	P6	Water	<3	<3	<3	>26	>26
8	P7	Water	<3	<3	<3	>26	>26

Table B-5
Interface Gas Pressure Venting Test Prior to Heat Cycling

Joint Identification	P1	P2
Gas Pressure, psi		
5	No leak	No leak
10	No leak	No leak
15	No leak	No leak
20	No leak	No leak
25	No leak	No leak
30	No leak	No leak
35*	No leak	No leak

* Test discontinued

Table B-6
Partial Discharge Test After Interface Gas Pressure Venting Test

Joint No.	Joint ID	To be Heat Cycled in	Partial Discharge - pC			Inception Voltage kV	Extinction Voltage kV
			at 13 kV	at 15.6 kV	at 26 kV		
1	**P1***	**Air**	**<3**	**<3**	**<3**	**>26**	**>26**
2	P4	Air	<3	<3	<3	>26	>26
3	P5	Air	<3	<3	<3	>26	>26
4	P8	Air	<3	<3	<3	>26	>26
5	**P2***	**Water**	**<3**	**<3**	**<3**	**>26**	**>26**
6	P3	Water	<3	<3	<3	>26	>26
7	P6	Water	<3	<3	<3	>26	>26
8	P7	Water	<3	<3	<3	>26	>26

* Joint subjected to interface gas pressure venting test

Table B-7
Thermocouple Location on Cables During Heat Cycling

Thermocouple No.	Cable Component	Location
	Control Cable	
Control	Conductor., Cable	6 ft. from center of joint
1	Conductor, Cable	1 ft. from control thermocouple
2	Conductor, Cable	5 ft. from center of joint (opposite side)
3	Connector	Outside wall of connector
4	Top of Cable Insulation Shield	6 ft. from center of joint
5	Top of Cable Insulation Shield	6 ft. from center of joint (opposite side)
6	Top of Cable Jacket	7 ft. from center of joint
7	Top of Joint Housing	Center of joint, over jacket
	A, B, C, D Cable Loop	**(A, D in Air – B, C in Water)**
8	Top of Insulation Shield (A)	4 ft. from center of joint P1
9	Top of Joint Jacket (A)	Center of joint P1, over jacket
10	Top of Joint Jacket (B)	Center of joint P2, over jacket
11	Top of Joint Jacket (C)	Center of joint P3, over jacket
12	Top of Joint Jacket (D)	Center of joint P4, over jacket
13	Water in Pipe (B)	3 ft. from center of joint P2
	E, F, G, H Cable Loop	**(E, H in Air – F, G in Water)**
14	Top of Insulation Shield (E)	4 ft. from center of joint P5
15	Top of Joint Jacket (E)	Center of joint P5, over jacket
16	Top of Joint Jacket (F)	Center of joint P6, over jacket
17	Top of Joint Jacket (G)	Center of joint P7, over jacket
18	Top of Joint Jacket (H)	Center of joint P8, over jacket
19	Top of Insulation Shield (F)	5 ft. from center of joint P6
20	Water in Pipe (F)	3 ft. from center of joint P6
21	Ambient Air	Next to joint setup

Table B-8
Heat Cycle, Daily Records After Seven-Hour Heating

Day of the Week	Fri.	Sat.	Sun.	Mon.	Tue.	Wed.	Thu.	Fri.
Date	**11/14**	**11/15**	**11/16**	**11/17**	**11/18**	**11/19**	**11/20**	**11/21**
Cycle No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Thermoc., Location								
Control Cable	**Temperature, ˚C**							
Cond., Contr. Cable	126	127		128	128	127	127	128
Conductor, Cable	126	127		128	127	127	127	127
Conductor, Cable	128	128		128	128	129	128	128
Connector	129	129		129	130	130	130	131
Top of Cable Insulation Shield	104	104		104	105	105	105	105
Top of Cable Insulation Shield	103	103		103	105	104	104	105
Top of Cable Jacket	86	86		86	87	86	86	87
Top of Joint Jacket	66	67		67	69	69	68	68
A, B, C, D Cable Loop	**(A, D in Air - B, C in Water)**							
Top of Insulation Shield (A)	98	99		102	100	99	100	101
Top of Joint Jacket (A)	64	65		64	66	65	66	67
Top of Joint Jacket (B)	37	38		40	41	41	42	42
Top of Joint Jacket (C)	37	37		39	40	40	40	41
Top of Joint Jacket (D)	65	65		66	67	67	68	69
Water in Pipe (B)	37	36		36	37	37	38	39
E, F, G, H Cable Loop	**(E, H in Air - F, G in Water)**							
Top of Insulation Shield (E)	98	99		102	102	101	102	103
Top of Joint Jacket (E)	64	65		64	64	64	64	65
Top of Joint Jacket (F)	38	38		37	37	37	38	39
Top of Joint Jacket (G)	38	39		41	41	40	40	41
Top of Joint Jacket (H)	63	64		65	66	65	66	67
Top of Insulation Shield (F)	97	98		100	100	99	100	101
Water in Pipe (F)	37	36		37	38	39	40	40
Ambient Air	23	25		27	28	29	29	28
Current - A	1220	1220	1220	1220	1220	1220	1220	1220

Table B-8 (continued)
Heat Cycle, Daily Records After Seven-Hour Heating

Day of the Week	Sat.	Sun.	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Date	**11/22**	**11/23**	**11/24**	**11/25**	**11/26**	**11/27**	**11/28**	**11/29**
Cycle No.	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Thermoc., Location								
Control Cable	**Temperature, °C**							
Cond., Contr. Cable	128		128	129	129			
Conductor, Cable	127		127	129	129			
Conductor, Cable	128		128	130	130			
Connector	130		130	131	132			
Top of Cable Insulation Shield	106		106	107	107			
Top of Cable Insulation Shield	105		105	104	105			
Top of Cable Jacket	87		87	89	88			
Top of Joint Jacket	68		68	69	70			
A, B, C, D Cable Loop	**(A, D in Air - B, C in Water)**							
Top of Insulation Shield (A)	100		100	100	100			
Top of Joint Jacket (A)	67		67	66	67			
Top of Joint Jacket (B)	42		42	41	42			
Top of Joint Jacket (C)	41		41	41	41			
Top of Joint Jacket (D)	65		68	66	66			
Water in Pipe (B)	39		39	40	39			
E, F, G, H Cable Loop	**(E, H in Air - F, G in Water)**							
Top of Insulation Shield (E)	102		102	100	101			
Top of Joint Jacket (E)	65		65	67	67			
Top of Joint Jacket (F)	38		38	41	40			
Top of Joint Jacket (G)	40		40	42	41			
Top of Joint Jacket (H)	66		66	66	66			
Top of Insulation Shield (F)	100		99	100	99			
Water in Pipe (F)	39		39	39	40			
Ambient Air	24		24	27	28			
Current - A	1230	1230	1230	1220	1220	1220	1220	1220

Table B-8 (continued)
Heat Cycle, Daily Records After Seven-Hour Heating

Day of the Week	Sun.	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.	Sun.
Date	**11/30**	**12/01**	**12/02**	**12/03**	**12/04**	**12/05**	**12/06**	**12/07**
Cycle No.	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Thermoc., Location								
Control Cable	**Temperature, °C**							
Cond., Contr. Cable		128	128	127	128	128		
Conductor, Cable		128	127	127	128	128		
Conductor, Cable		130	129	128	130	130		
Connector		133	132	131	132	131		
Top of Cable Insulation Shield		107	106	105	106	106		
Top of Cable Insulation Shield		105	104	104	105	104		
Top of Cable Jacket		86	86	86	87	87		
Top of Joint Jacket		70	70	69	70	70		
A, B, C, D Cable Loop	**(A, D in Air - B, C in Water)**							
Top of Insulation Shield (A)		101	100	101	101	100		
Top of Joint Jacket (A)		67	67	67	67	67		
Top of Joint Jacket (B)		42	41	40	40	40		
Top of Joint Jacket (C)		41	40	40	39	40		
Top of Joint Jacket (D)		67	66	67	67	67		
Water in Pipe (B)		40	39	39	39	39		
E, F, G, H Cable Loop	**(E, H in Air - F, G in Water)**							
Top of Insulation Shield (E)		101	100	101	101	100		
Top of Joint Jacket (E)		67	67	67	67	67		
Top of Joint Jacket (F)		41	40	40	40	40		
Top of Joint Jacket (G)		41	40	39	39	40		
Top of Joint Jacket (H)		67	67	67	67	67		
Top of Insulation Shield (F)		99	98	99	98	98		
Water in Pipe (F)		40	40	40	40	40		
Ambient Air		26	25	24	22	23		
Current - A	1220	1220	1230	1230	1230	1230	1230	1230

Table B-8 (continued)
Heat Cycle, Daily Records After Seven-Hour Heating

Day of the Week	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.	Sun.	Mon.
Date	**12/08**	**12/09**	**12/10**	**12/11**	**12/12**	**12/13**	**12/14**	**12/15**
Cycle No.	**25**	**26**	**27**	**28**	**29**	**30**		
Thermoc., Location								
Control Cable	**Temperature, °C**							
Cond., Contr. Cable	128	128	127	127	128			
Conductor, Cable	128	128	127	126	128			
Conductor, Cable	130	131	129	128	130			
Connector	132	133	131	130	131			
Top of Cable Insulation Shield	106	106	105	105	106			
Top of Cable Insulation Shield	104	104	103	103	104			
Top of Cable Jacket	87	87	86	87	88			
Top of Joint Jacket	71	71	70	71	71			
A, B, C, D Cable Loop	**(A, D in Air - B, C in Water)**							
Top of Insulation Shield (A)	101	103	101	102	103			
Top of Joint Jacket (A)	67	67	66	67	67			
Top of Joint Jacket (B)	41	41	40	41	41			
Top of Joint Jacket (C)	40	41	40	41	41			
Top of Joint Jacket (D)	67	67	66	67	67			
Water in Pipe (B)	40	40	40	40	40			
E, F, G, H Cable Loop	**(E, H in Air - F, G in Water)**							
Top of Insulation Shield (E)	102	103	102	102	103			
Top of Joint Jacket (E)	67	67	66	67	67			
Top of Joint Jacket (F)	40	40	40	41	41			
Top of Joint Jacket (G)	40	40	40	40	41			
Top of Joint Jacket (H)	67	67	66	67	67			
Top of Insulation Shield (F)	99	100	98	99	100			
Water in Pipe (F)	40	40	40	41	40			
Ambient Air	24	25	25	27	27			
Current - A	1230	1230	1230	1220	1220	1220		

Table B-9
Partial Discharge Test After Heat Cycling

Joint No.	Joint ID	Heat Cycled in	Partial Discharge - pC			Inception Voltage kV	Extinction Voltage kV
			at 13 kV	at 15.6 kV	at 26 kV		
1	P1	Air	<3	<3	<3	>26	>26
2	P4	Air	<3	<3	<3	>26	>26
3	P5	Air	<3	<3	<3	>26	>26
4	P8	Air	<3	<3	<3	>26	>26
5	P2	Water	<3	<3	<3	>26	>26
6	P3	Water	<3	<3	<3	>26	>26
7	P6	Water	<3	<3	<3	>26	>26
8	P7	Water	<3	<3	<3	>26	>26

Table B-10
Interface Gas Pressure Venting Test After Heat Cycling

Joint Identification	P1	P2
Gas Pressure, psi		
5	No leak	No leak
10	No leak	No leak
15	No leak	No leak
20	No leak	No leak
25	No leak	No leak
30	No leak	No leak
35*	No leak	No leak

* Test discontinued.

Table B-11
Partial Discharge Test After Interface Gas Pressure Venting Test

Joint No.	Joint ID	Heat Cycled in	Partial Discharge - pC			Inception Voltage kV	Extinction Voltage kV
			at 13 kV	at 15.6 kV	at 26 kV		
1	**P1***	**Air**	**<3**	**<3**	**<3**	**>26**	**>26**
2	P4	Air	<3	<3	<3	>26	>26
3	P5	Air	<3	<3	<3	>26	>26
4	P8	Air	<3	<3	<3	>26	>26
5	**P2***	**Water**	**<3**	**<3**	**<3**	**>26**	**>26**
6	P3	Water	<3	<3	<3	>26	>26
7	P6	Water	<3	<3	<3	>26	>26
8	P7	Water	<3	<3	<3	>26	>26

* Joints subjected to interface gas pressure venting test

Table B-12
Impulse Withstand Test at 130°C Conductor Temperature

Joint No.	Joint ID	Heat Cycled in	Bend Adjacent to Joint	Withstand Voltage kV	Polarity	Number of Impulses	Result
1	P1	Air	No	110 110	Positive Negative	10 10	Passed Passed
2	P4	Air	No	110 110	Positive Negative	10 10	Passed Passed
3	P5	Air	No	110 110	Positive Negative	10 10	Passed Passed
4	P8	Air	Yes	110 110	Positive Negative	10 10	Passed Passed
5	P2	Water	No	110 110	Positive Negative	10 10	Passed Passed
6	P3	Water	No	110 110	Positive Negative	10 10	Passed Passed
7	P6	Water	No	110 110	Positive Negative	10 10	Passed Passed
8	P7	Water	Yes	110 110	Positive Negative	10 10	Passed Passed

Table B-13
Partial Discharge Test After Hot Impulse Withstand Test

Joint No.	Joint ID	Heat Cycled in	Partial Discharge - pC			Inception Voltage kV	Extinction Voltage kV
			at 13 kV	at 15.6 kV	at 26 kV		
1	P1	Air	<3	<3	<3	>26	>26
2	P4	Air	<3	<3	<3	>26	>26
3	P5	Air	<3	<3	<3	>26	>26
4	P8	Air	<3	<3	<3	>26	>26
5	P2	Water	<3	<3	<3	>26	>26
6	P3	Water	<3	<3	<3	>26	>26
7	P6	Water	<3	<3	<3	>26	>26
8	P7	Water	<3	<3	<3	>26	>26

Table B-14
AC Voltage Time Step Test to Breakdown

Joint No.	Joint ID	Heat Cycled in	Bend Adjacent to Joint	Breakdown Voltage kV	Time at Max. Voltage min.
1	P1	Air	No	69	1.2
2	P4	Air	No	36*	3.2
3	P5	Air	No	76	1.5
4	P8	Air	Yes	83 76 kV avg.	4.7
5	P2	Water	No	69	4.5
6	P3	Water	No	83**	2.3
7	P6	Water	No	69	1.6
8	P7	Water	Yes	89 78 kV avg.	0.5

*Failure originated from cut next to flat strap cut back. Breakdown voltage was not taken into account when calculating average value.

**Failure originated from nick in the cable insulation.

Table B-15
Dissection After AC Voltage Breakdown Test

Joint No.	Joint Id.	Heat Cycled in	Breakdown Voltage kV	Result
1	P1	Air	69	Radial failure next to the edge of cable insulation shield
2	P4	Air	36	Radial failure originated from cut next to flat strap cut back
3	P5	Air	76	Radial failure next to the edge of cable insulation shield (Figure B-1)
4	P8	Air	83	Radial breakdown at the edge of cable insulation shield
5	P2	Water	69	Radial breakdown about 150 mils from end of insulation shield (Figure B-2)
6	P3	Water	83	Radial failure originated from nick in the cable insulation
7	P6	Water	69	Radial breakdown about 300 mils from inner layer of joint body (Figure B-3)
8	P7	Water	89	Radial breakdown about 150 mils from inner layer of joint body

Table B-16
Test Experiences and Observations

Most of the joint components are incorporated in one package.
High permittivity mastic pad and mastic strips are convenient to use.
Special care is required to assure tight contact between the outer semiconducting sleeve, that extends over joint body and cable insulation. This is achieved by applying a rubber tape (supplied) over the joint ends.
Some effort is required to unfold the joint jacket.
AC breakdown levels for joints heat cycled in air and in water are similar.
Dissection of the joints after test completion indicated that some of the joint bodies had not been properly centered.
The joint kit used in the tested joints may not have been the most suitable for the cable used in the project. This plus the relatively high effort to pull the joint jacket into place may have contributed to the displacement of the joint body.

Figure B-1
Joint P5. Radial Failure next to the End Step in Insulation Shield.

Figure B-2
Joint P2. Radial Failure at 150 Mils from End of Insulation Shield.

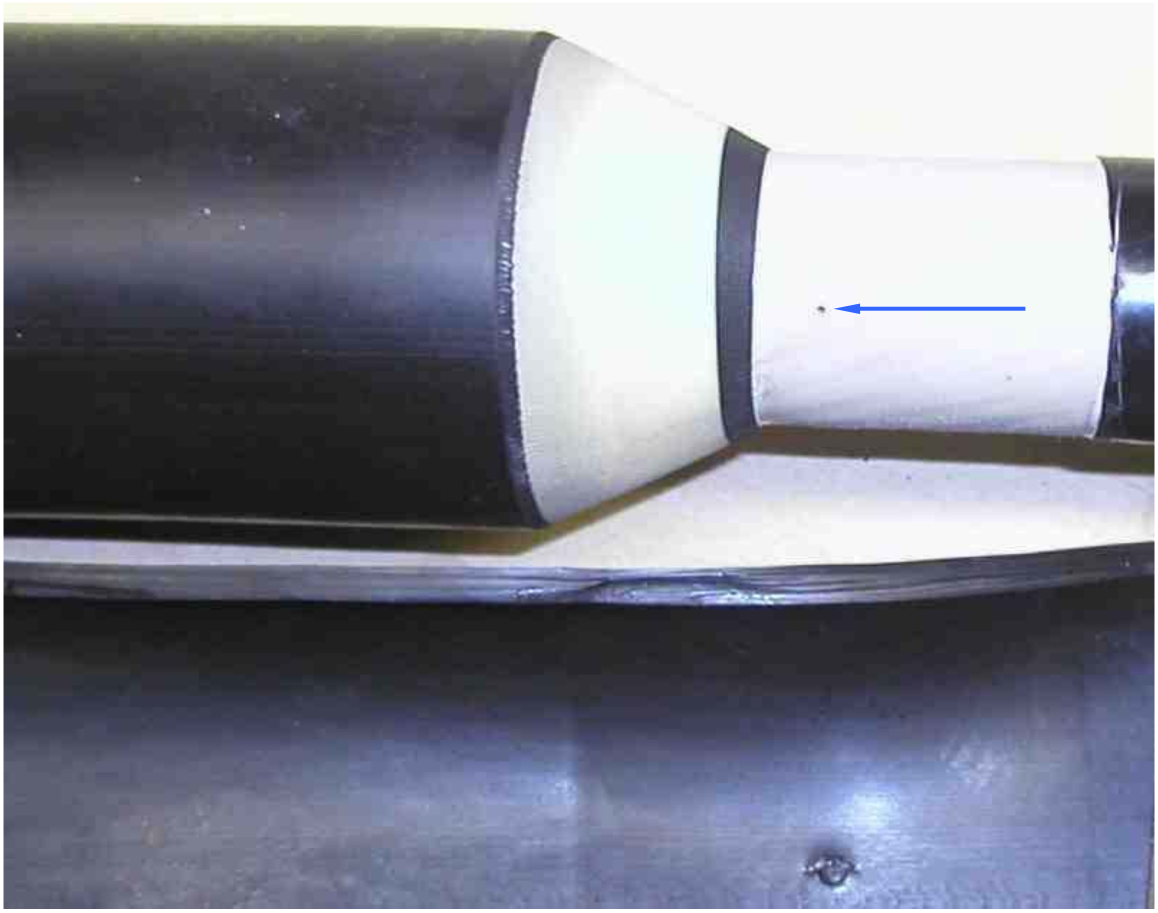

Figure B-3
Joint P6. Radial Failure at About 300 Mils from Inner Layer of Joint Body.

Figure B-4
Joint P6. Joint Body Not Properly Centered

C

3M COLD SHRINK JOINT ON 750 KCMIL, 15 KV CABLE

3M Quick-Splice III Type 5417A

- Analysis of joint assembly/fabrication – Table C-1
- Breakdown of time required for preparation of cables and assembly of joint – Table C-2
- Test results – Tables B-3 through C-15
- Test experiences and observations – Table C-16

Table C-1
Analysis of Joint Assembly/Fabrication

Assembly/Fabrication	Results
Time required to complete joint, (1 splicer)	75
Complexity of making the joint, (0 to 10)*	3
Skill required, (0 to 10)*	3
Longitudinal space required, in.	72
Length of complete joint, in.	30
Width of space required (minimum), in.	48
Other requirements: Installation area must be clean	

* Subjective rating, 10 denotes most difficult.

Table C-2
Time to Complete Joint

Preparation of Cables	**Time, min.**
Cable sections cut to length	5
Jackets removed, flat straps folded back	10
Insulation shield stripped	6
Insulation cut back	4
Installation of Joint Housing	
Joint and joint body parked, insulation cleaned, connector crimped	15
Red compound applied on exposed insulation and insulation shield cut back. Cold shrink joint positioned and installed by removing core	10
Neutral pad installed, flat straps connected using H-type connector and solid copper conductor, copper mesh applied over	15
Rubber mastic sealing tape applied on cable jacket at the joint ends	5
Jacket positioned and installed by removing core	5
Total (1 splicer)	75

Table C-3
AC Withstand Voltage Test Prior to Heat Cycling

Joint No.	Joint Identification	To be Heat Cycled in	Applied Voltage kV	Time minutes	Result
1	3M1	Air	35	5	Passed
2	3M4	Air	35	5	Passed
3	3M5	Air	35	5	Passed
4	3M8	Air	35	5	Passed
5	3M2	Water	35	5	Passed
6	3M3	Water	35	5	Passed
7	3M6	Water	35	5	Passed
8	3M7	Water	35	5	Passed

Table C-4
Partial Discharge Test Prior to Heat Cycling

Joint No.	Joint ID	To be Heat Cycled in	Partial Discharge - pC			Inception Voltage kV	Extinction Voltage kV
			at 13 kV	at 15.6 kV	at 26 kV		
1	3M1	Air	<3	<3	<3	>26	>26
2	3M4	Air	<3	<3	<3	>26	>26
3	3M5	Air	<3	<3	<3	>26	>26
4	3M8	Air	<3	<3	<3	>26	>26
5	3M2	Water	<3	<3	<3	>26	>26
6	3M3	Water	<3	<3	<3	>26	>26
7	3M6	Water	<3	<3	<3	>26	>26
8	3M7	Water	<3	<3	<3	>26	>26

Table C-5
Interface Gas Pressure Venting Test Prior to Heat Cycling

Joint Identification	3M1	3M2
Gas Pressure, psi		
5	No leak	No leak
10	No leak	No leak
15	No leak	No leak
20	No leak	No leak
25	Leaked*	Leaked*

* Leaked at start of gas application. Test discontinued.

Table C-6
Partial Discharge Test After Interface Gas Pressure Venting Test

Joint No.	Joint ID	To be Heat Cycled in	Partial Discharge - pC			Inception Voltage kV	Extinction Voltage kV
			at 13 kV	at 15.6 kV	at 26 kV		
1	3M1*	**Air**	**<3**	**<3**	**<3**	**>26**	**>26**
2	3M4	Air	<3	<3	<3	>26	>26
3	3M5	Air	<3	<3	<3	>26	>26
4	3M8	Air	<3	<3	<3	>26	>26
5	**3M2***	**Water**	**<3**	**<3**	**<3**	**>26**	**>26**
6	3M3	Water	<3	<3	<3	>26	>26
7	3M6	Water	<3	<3	<3	>26	>26
8	3M7	Water	<3	<3	<3	>26	>26

* Joint subjected to interface gas pressure venting test.

Table C-7
Thermocouple Location on Cables During Heat Cycling

Thermocouple No.	Cable Component	Location
	Control Cable	
Control	Conductor, Cable	6 ft. from center of joint
1	Conductor, Cable	1 ft. from control thermocouple
2	Conductor, Cable	5 ft. from center of joint (opposite side)
3	Connector	Outside wall of connector
4	Top of Cable Insulation Shield	6 ft. from center of joint
5	Top of Cable Insulation Shield	6 ft. from center of joint (opposite side)
6	Top of Cable Jacket	7 ft. from center of joint
7	Top of Joint Housing	Center of joint, over jacket
	A, B, C, D Cable Loop	**(A, D in Air – B, C in Water)**
8	Top of Insulation Shield (A)	4 ft. from center of joint P1
9	Top of Joint Jacket (A)	Center of joint 3M1, over jacket
10	Top of Joint Jacket (B)	Center of joint 3M2, over jacket
11	Top of Joint Jacket (C)	Center of joint 3M3, over jacket
12	Top of Joint Jacket (D)	Center of joint 3M4, over jacket
13	Water in Pipe (B)	3 ft. from center of joint 3M2
	E, F, G, H Cable Loop	**(E, H in Air – F, G in Water)**
14	Top of Insulation Shield (E)	4 ft. from center of joint 3M5
15	Top of Joint Jacket (E)	Center of joint 3M5, over jacket
16	Top of Joint Jacket (F)	Center of joint 3M6, over jacket
17	Top of Joint Jacket (G)	Center of joint 3M7, over jacket
18	Top of Joint Jacket (H)	Center of joint 3M8, over jacket
19	Top of Insulation Shield (F)	5 ft. from center of joint 3M6
20	Water in Pipe (F)	3 ft. from center of joint 3M6
21	Ambient Air	Next to joint setup

Table C-8
Heat Cycle, Daily Records After Seven-Hour Heating

Day of the Week	Thu.	Fri.	Sat.	Sun.	Mon.	Tue.	Wed.	Thu.
Date	**01/29**	**01/30**	**01/31**	**02/01**	**02/02**	**02/03**	**02/04**	**02/05**
Cycle No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Thermoc., Location								
Control Cable	**Temperature, °C**							
Cond., Contr. Cable	129	128			127	128	128	129
Conductor, Cable	128	127			127	127	127	128
Conductor, Cable	127	126			126	126	125	127
Connector	129	129			129	130	130	130
Top of Cable Insulation Shield	99	99			99	100	100	100
Top of Cable Insulation Shield	96	96			97	96	96	97
Top of Cable Jacket	82	82			83	83	83	83
Top of Joint Jacket	56	56			57	58	57	58
A, B, C, D Cable Loop	**(A, D in Air - B, C in Water)**							
Top of Insulation Shield (A)	93	94			98	97	96	98
Top of Joint Jacket (A)	58	60			62	62	62	62
Top of Joint Jacket (B)	26	33			40	39	40	40
Top of Joint Jacket (C)	25	32			39	38	40	41
Top of Joint Jacket (D)	56	57			62	62	61	61
Water in Pipe (B)	22	30			37	36	37	39
E, F, G, H Cable Loop	**(E, H in Air - F, G in Water)**							
Top of Insulation Shield (E)	96	98			99	100	101	102
Top of Joint Jacket (E)	59	60			61	62	62	62
Top of Joint Jacket (F)	25	33			40	39	40	40
Top of Joint Jacket (G)	26	35			42	41	42	42
Top of Joint Jacket (H)	56	56			59	58	59	60
Top of Insulation Shield (F)	98	100			101	102	103	103
Water in Pipe (F)	24	33			39	37	39	40
Ambient Air	14	16			17	14	16	18
Current - A	1350	1350	1350	1350	1350	1350	1350	1350

Table C-8 (continued)
Heat Cycle, Daily Records After Seven-Hour Heating

Day of the Week	Fri.	Sat.	Sun.	Mon.	Tue.	Wed.	Thu.	Fri.
Date	**02/06**	**02/07**	**02/08**	**02/09**	**02/10**	**02/11**	**02/12**	**02/13**
Cycle No.	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Thermoc., Location								
Control Cable	**Temperature, °C**							
Cond., Contr. Cable	128			128	128	129	128	129
Conductor, Cable	128			128	128	128	127	128
Conductor, Cable	128			128	128	128	126	127
Connector	130			130	130	130	131	130
Top of Cable Insulation Shield	99			98	99	100	100	100
Top of Cable Insulation Shield	98			97	98	98	97	98
Top of Cable Jacket	81			82	82	83	83	83
Top of Joint Jacket	59			60	60	61	60	61
A, B, C, D Cable Loop	**(A, D in Air - B, C in Water)**							
Top of Insulation Shield (A)	96			96	97	96	96	98
Top of Joint Jacket (A)	62			63	64	64	63	63
Top of Joint Jacket (B)	37			40	40	40	41	41
Top of Joint Jacket (C)	36			38	37	37	38	38
Top of Joint Jacket (D)	63			62	63	63	64	64
Water in Pipe (B)	33			37	38	37	38	40
E, F, G, H Cable Loop	**(E, H in Air - F, G in Water)**							
Top of Insulation Shield (E)	100			100	101	101	100	101
Top of Joint Jacket (E)	63			64	64	64	63	64
Top of Joint Jacket (F)	36			36	37	37	38	37
Top of Joint Jacket (G)	39			39	40	40	40	39
Top of Joint Jacket (H)	60			62	62	61	62	62
Top of Insulation Shield (F)	100			101	101	100	100	101
Water in Pipe (F)	35			37	38	38	38	37
Ambient Air	18			20	21	19	20	19
Current - A	1350	1350	1350	1340	1340	1340	1340	1340

Table C-8 (continued)
Heat Cycle, Daily Records After Seven-Hour Heating

Day of the Week	Sat.	Sun.	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Date	**02/14**	**02/15**	**02/16**	**02/17**	**02/18**	**02/19**	**02/20**	**02/21**
Cycle No.	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Thermoc., Location								
Control Cable	**Temperature, °C**							
Cond., Contr. Cable				129	128	129	128	
Conductor, Cable				127	126	127	127	
Conductor, Cable				127	128	126	126	
Connector				130	130	130	129	
Top of Cable Insulation Shield				100	99	99	99	
Top of Cable Insulation Shield				99	99	99	98	
Top of Cable Jacket				83	84	84	84	
Top of Joint Jacket				59	60	60	60	
A, B, C, D Cable Loop	**(A, D in Air - B, C in Water)**							
Top of Insulation Shield (A)				101	100	100	99	
Top of Joint Jacket (A)				64	64	63	63	
Top of Joint Jacket (B)				40	43	43	42	
Top of Joint Jacket (C)				37	39	40	38	
Top of Joint Jacket (D)				62	61	61	61	
Water in Pipe (B)				40	40	40	38	
E, F, G, H Cable Loop	**(E, H in Air - F, G in Water)**							
Top of Insulation Shield (E)				101	100	100	100	
Top of Joint Jacket (E)				63	63	63	62	
Top of Joint Jacket (F)				37	37	38	36	
Top of Joint Jacket (G)				39	40	40	38	
Top of Joint Jacket (H)				62	63	63	62	
Top of Insulation Shield (F)				100	101	101	100	
Water in Pipe (F)				37	37	38	36	
Ambient Air				18	21	22	18	
Current - A	1340	1340	1340	1340	1340	1340	1340	1340

Table C-8 (continued)
Heat Cycle, Daily Records After Seven-Hour Heating

Day of the Week	Sun.	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.	Sun.
Date	**02/22**	**02/23**	**02/24**	**02/25**	**02/26**	**02/27**		
Cycle No.	**25**	**26**	**27**	**28**	**29**	**30**		
Thermoc., Location								
Control Cable	**Temperature, °C**							
Cond., Contr. Cable		128	128	128	128	128		
Conductor, Cable		128	127	128	127	127		
Conductor, Cable		126	127	126	126	126		
Connector		130	131	130	130	130		
Top of Cable Insulation Shield		99	100	100	100	100		
Top of Cable Insulation Shield		99	100	99	100	100		
Top of Cable Jacket		84	85	85	85	84		
Top of Joint Jacket		60	61	61	61	60		
A, B, C, D Cable Loop	**(A, D in Air - B, C in Water)**							
Top of Insulation Shield (A)		100	101	101	102	102		
Top of Joint Jacket (A)		62	63	62	64	63		
Top of Joint Jacket (B)		43	44	44	44	43		
Top of Joint Jacket (C)		42	42	42	43	42		
Top of Joint Jacket (D)		63	64	64	65	62		
Water in Pipe (B)		42	43	43	43	42		
E, F, G, H Cable Loop	**(E, H in Air - F, G in Water)**							
Top of Insulation Shield (E)		100	101	100	101	101		
Top of Joint Jacket (E)		63	64	64	64	64		
Top of Joint Jacket (F)		41	41	42	42	42		
Top of Joint Jacket (G)		43	42	43	43	43		
Top of Joint Jacket (H)		64	64	63	63	63		
Top of Insulation Shield (F)		101	100	100	101	101		
Water in Pipe (F)		41	40	41	41	41		
Ambient Air		23	21	18	20	21		
Current - A	1340	1330	1330	1340	1340	1340		

Table C-9
Partial Discharge Test After Heat Cycling

Joint No.	Joint ID	Heat Cycled in	Partial Discharge - pC			Inception Voltage kV	Extinction Voltage kV
			at 13 kV	at 15.6 kV	at 26 kV		
1	3M1	Air	<3	<3	<3	>26	>26
2	3M4	Air	<3	<3	<3	>26	>26
3	3M5	Air	<3	<3	<3	>26	>26
4	3M8	Air	<3	<3	<3	>26	>26
5	3M2	Water	<3	<3	<3	>26	>26
6	3M3	Water	<3	<3	<3	>26	>26
7	3M6	Water	<3	<3	<3	>26	>26
8	3M7	Water	<3	<3	<3	>26	>26

Table C-10
Interface Gas Pressure Venting Test After Heat Cycling

Joint Identification	3M1	3M2
Gas Pressure, psi		
5	No leak	No leak
10	No leak	No leak
15	No leak	No leak
20	No leak	No leak
25	No leak	No leak
30	Leaked*	Leaked*

* Leaked after 1 minute of gas application. Test discontinued.

Table C-11
Partial Discharge Test After Interface Gas Pressure Venting Test

Joint No.	Joint ID	Heat Cycled in	Partial Discharge - pC			Inception Voltage kV	Extinction Voltage kV
			at 13 kV	at 15.6 kV	at 26 kV		
1	**3M1***	**Air**	**<3**	**<3**	**<3**	**>26**	**>26**
2	3M4	Air	<3	<3	<3	>26	>26
3	3M5	Air	<3	<3	<3	>26	>26
4	3M8	Air	<3	<3	<3	>26	>26
5	**3M2***	**Water**	**<3**	**<3**	**<3**	**>26**	**>26**
6	3M3	Water	<3	<3	<3	>26	>26
7	3M6	Water	<3	<3	<3	>26	>26
8	3M7	Water	<3	<3	<3	>26	>26

* Joints subjected to interface gas pressure venting test.

Table C-12
Impulse Withstand Test at 130°C Conductor Temperature

Joint No.	Joint ID	Heat Cycled in	Bend Adjacent to Joint	Withstand Voltage kV	Polarity	Number of Impulses	Result
1	3M1	Air	No	110 110	Positive Negative	10 10	Passed Passed
2	3M4	Air	No	110 110	Positive Negative	10 10	Passed Passed
3	3M5	Air	No	110 110	Positive Negative	10 10	Passed Passed
4	3M8	Air	Yes	110 110	Positive Negative	10 10	Passed Passed
5	3M2	Water	No	110 110	Positive Negative	10 10	Passed Passed
6	3M3	Water	No	110 110	Positive Negative	10 10	Passed Passed
7	3M6	Water	No	110 110	Positive Negative	10 10	Passed Passed
8	3M7	Water	Yes	110 110	Positive Negative	10 10	Passed Passed

Table C-13
Partial Discharge Test After Hot Impulse Withstand Test

Joint No.	Joint ID	Heat Cycled in	Partial Discharge - pC			Inception Voltage kV	Extinction Voltage kV
			at 13 kV	at 15.6 kV	at 26 kV		
1	3M1	Air	<3	<3	<3	>26	>26
2	3M4	Air	<3	<3	<3	>26	>26
3	3M5	Air	<3	<3	<3	>26	>26
4	3M8	Air	<3	<3	<3	>26	>26
5	3M2	Water	<3	<3	<3	>26	>26
6	3M3	Water	<3	<3	<3	>26	>26
7	3M6	Water	<3	350	600	14	11
8	3M7	Water	<3	<3	<3	>26	>26

Table C-14
AC Voltage Time Step Test to Breakdown

Joint No.	Joint ID	Heat Cycled in	Bend Adjacent to Joint	Breakdown Voltage kV	Time at Max. Voltage min.
1	3M1	Air	No	76	0.5
2	3M4	Air	No	89	3.1
3	3M5	Air	No	76	2.5
4	3M8	Air	Yes	96 86 kV avg.	0.9
5	3M2	Water	No	83	1.9
6	3M3	Water	No	96	1.5
7	3M6	Water	No	50	1.1
8	3M7	Water	Yes	43 68 kV avg.	0.3

Table C-15
Dissection After AC Voltage Breakdown Test

Joint No.	Joint Id.	Heat Cycled in	Breakdown Voltage kV	Result
1	3M1	Air	76	Longitudinal failure at the joint/cable interface. Joint previously subjected to interface gas pressure venting test (Figure C-1)
2	3M4	Air	89	Radial failure at center of the connector (Figure C-3)
3	3M5	Air	76	Radial failure next to the edge of cable insulation shield (Figure C-2)
4	3M8	Air	96	Radial breakdown at the edge of cable insulation shield
5	3M2	Water	83	Radial failure at center of the connector
6	3M3	Water	96	Radial failure at about 0.5 inch from insulation shield cut back
7	3M6	Water	50	Radial breakdown next to edge of the connector
8	3M7	Water	43	Diagonal failure in the joint body (Figure C-4)

Table C-16
Test Experiences and Observations

Special care needs to be taken when metallic shielding is applied - neutral pad and pieces of cable jacket should be installed (prescribed by manufacturer) to avoid damage to joint and cable.
During the interface gas pressure venting tests, venting occurred prior to and after heat cycling at 25 and 30 psi, respectively.
Joints 3M6 and 3M7 had low voltage breakdown levels. During microscopic examination of the breakdown paths voids up to 15 mils were found in the insulation of both joints.
Dissection revealed the presence of water under the jacket. When the jacket is applied, part of the jacket unfolds leaving a powder residue inside one end that interferes with adhesion of the inner jacket surface to the sealing mastic material.

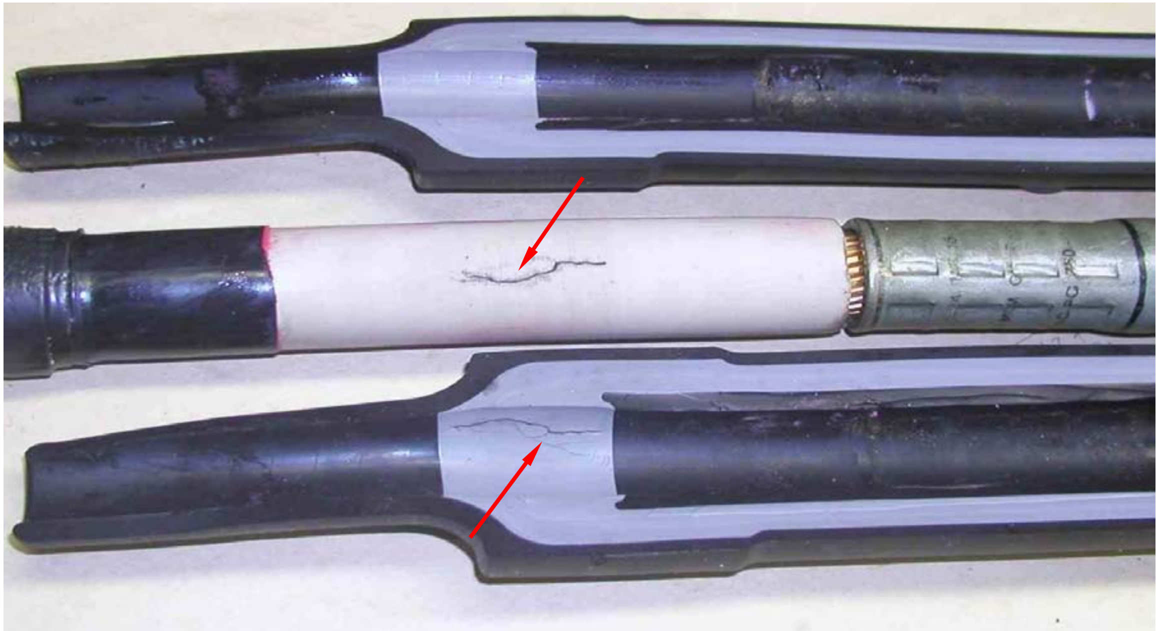

Figure C-1
Joint 3M1. Longitudinal Failure at the Interface Between Joint and Cable.

Figure C-2
Joint 3M5. Radial Failure next to the Insulation Shield Cut Back.

Figure C-3
Joint 3M4. Radial Failure at Center of the Connector.

Figure C-4
Joint 3M7. Diagonal Failure next to the Edge of the Connector.

Figure C-5
Joint 3M6. Fifteen Mils Void in Joint Insulation.

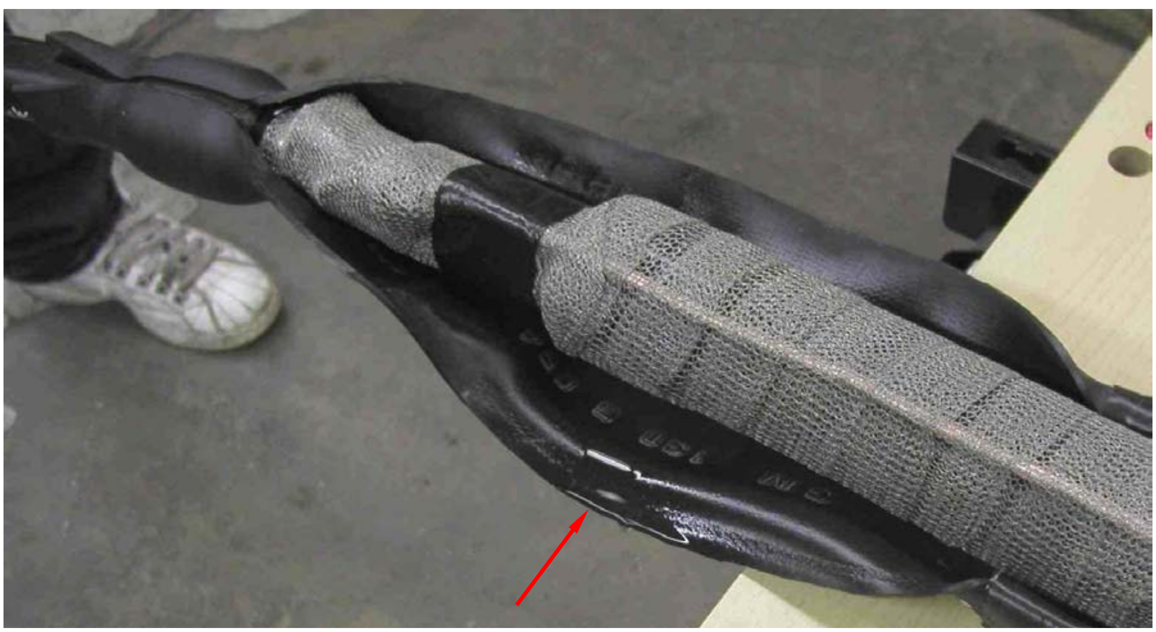

Figure C-6
Joint 3M7. Water Accumulated Under the Jacket of the Joint.

D

EASTIMOLD 600 A SEPARABLE CONNECTOR JOINT ON 750 KCMIL, 15 KV CABLE

Elastimold K656I ("I"-Type) 600 A Separable Connector Joint

- Analysis of joint assembly/fabrication – Table D-1
- Breakdown of time required for preparation of cables and assembly of joint – Table D-2
- Test results – Tables D-3 through D-12
- Test experiences and observations – Table D-13

Table D-1
Analysis of Joint Assembly/Fabrication

Assembly/Fabrication	Results
Time required to complete joint, (1 splicer)	75
Complexity of making the joint, (0 to 10)*	5
Skill required, (0 to 10)*	6
Longitudinal space required, in.	72
Length of complete joint, in.	50
Width of space required (minimum), in.	48
Other requirements: Installation area must be clean	

* Subjective rating, 10 denotes most difficult.

Table D-2
Time to Complete Joint

Preparation of Cables	**Time, min.**
Cable sections cut to length	5
Jackets removed, flat straps folded back	10
Insulation shield stripped	6
Insulation cut back	4
Installation of Joint Housings	
Sealing shrinkable tubes and receptacle housings parked on each cable	5
Inside of cable adapters lubricated and installed, lug connectors crimped	10
Retaining rings (or EPR tape bumpers) installed	8
Bus bar positioned and connected to lug connectors	10
Receptacle housings installed	10
Mastic sealing strips applied on cable jacket, cold shrinkable sealing tubes installed	7
Total (1 splicer)	75

Table D-3
AC Withstand Voltage Test Prior to Heat Cycling

Joint No.	Joint Identification	To be Heat Cycled in	Applied Voltage kV	Time minutes	Result
1	E1 (with ring)	Air	35	5	Passed
2	E4 (with tape)	Air	35	5	Passed
3	E5 (with tape)	Air	35	5	Passed
4	E8 (with ring)	Air	35	5	Passed
5	E2 (with ring)	Water	35	5	Passed
6	E3 (with tape)	Water	35	5	Passed
7	E6 (with tape)	Water	35	5	Passed
8	E7 (with ring)	Water	35	5	Passed

Table D-4
Partial Discharge Test Prior to Heat Cycling

Joint Identification	To be Heat Cycled in	Partial Discharge - pC			Inception Voltage kV	Extinction Voltage kV
		at 13 kV	at 15.6 kV	at 26 kV		
E1 (with ring)	Air	600	400	400	12	9
E4 (with tape)	Air	400	400	250	11	10
E5 (with tape)	Air	<3	<3	<3	>26	>26
E8 (with ring)	Air	<3	<3	<3	>26	>26
E2 (with ring)	Water	<3	<3	<3	>26	>26
E3 (with tape)	Water	<3	<3	<3	>26	>26
E6 (with tape)	Water	<3	<3	800	20	19
E7 (with ring)	Water	<3	<3	<3	>26	>26

Table D-5
Thermocouple Location on Cables During Heat Cycling

Thermocouple No.	Cable Component	Location
	Control Cable	
Control	Conductor, Cable	6 ft. from center of joint
1	Conductor, Cable	1 ft. from control thermocouple
2	Conductor, Cable	5 ft. from center of joint (opposite side)
3	Connector (joint with ring)	Outside wall of connector
4	Connector (joint with tape)	Outside wall of connector
5	Top of Cable Insulation Shield	6 ft. from center of joint (opposite side)
6	Top of Cable Jacket	7 ft. from center of joint
7	Top of Joint Housing	Center of housing
	A, B, C, D Cable Loop	**(A, D in Air – B, C in Water)**
8	Top of Insulation Shield (A)	4 ft. from center of joint E1
9	Top of Joint Housing (A)	Center of housing E1
10	Top of Joint Housing (B)	Center of housing E2
11	Top of Joint Housing (C)	Center of housing E3
12	Top of Joint Housing (D)	Center of housing E4
13	Water in Pipe (B)	4 ft. from center of joint E2
	E, F, G, H Cable Loop	**(E, H in Air – F, G in Water)**
14	Top of Insulation Shield (F)	4 ft. from center of joint E5
15	Top of Joint Housing (E)	Center of housing E5
16	Top of Joint Housing (F)	Center of housing E6
17	Top of Joint Housing (G)	Center of housing E7
18	Top of Joint Housing (H)	Center of housing E8
19	Water in Pipe (F)	4 ft. from center of joint E6
	Ambient Air	Next to joint setup

Table D-6
Heat Cycle, Daily Records After Seven-Hour Heating

Day of the Week	Fri.	Sat.	Sun.	Mon.	Tue.	Wed.	Thu.	Fri.
Date	**07/16**	**07/17**	**07/18**	**07/19**	**07/20**	**07/21**	**07/22**	**07/23**
Cycle No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Thermoc., Location								
Control Cable	**Temperature, °C**							
Cond., Contr. Cable	125	128		129	130	130	130	130
Conductor, Cable	126	128		128	128	130	130	129
Conductor, Cable	126	126		126	127	127	128	127
Connector (joint with ring)	130	134		140	139	140	141	142
Connector (joint with tape)	132	136		140	140	141	141	142
Top of Cable Insulation Shield	103	103		104	103	104	105	105
Top of Cable Jacket	94	94		94	94	94	95	94
Top of Joint Housing	61	62		64	63	62	63	64
A, B, C, D Cable Loop	**(A, D in Air - B, C in Water)**							
Top of Insulation Shield (A)	98	100		100	99	99	96	98
Top of Joint Housing (A)	68	69		70	68	69	67	68
Top of Joint Housing (B)	47	45		47	46	46	47	47
Top of Joint Housing (C)	48	45		45	45	46	46	46
Top of Joint Housing (D)	65	61		64	63	64	63	62
Water in Pipe (B)	46	42		43	43	45	46	46
E, F, G, H Cable Loop	**(E, H in Air - F, G in Water)**							
Top of Insulation Shield (F)	97	96		97	97	100	100	102
Top of Joint Housing (E)	67	70		69	68	68	69	69
Top of Joint Housing (F)	47	47		47	46	47	47	50
Top of Joint Housing (G)	42	44		48	48	49	48	48
Top of Joint Housing (H)	56	58		62	61	63	62	65
Water in Pipe (F)	40	40		41	41	40	42	40
Ambient Air	36	34		36	36	34	35	34
Current - A	1300	1300	1300	1300	1300	1300	1300	1300

Table D-6 (continued)
Heat Cycle, Daily Records After Seven-Hour Heating

Day of the Week	Sat.	Sun.	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Date	**07/24**	**07/25**	**07/26**	**07/27**	**07/28**	**07/29**	**07/30**	**07/31**
Cycle No.	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Thermoc., Location								
Control Cable	**Temperature, °C**							
Cond., Contr. Cable			128	127	130	126	126	
Conductor, Cable			128	126	128	128	128	
Conductor, Cable			127	126	128	127	127	
Connector (joint with ring)			147	145	146	145	145	
Connector (joint with tape)			147	147	147	147	147	
Top of Cable Insulation Shield			106	104	103	104	104	
Top of Cable Jacket			92	93	94	94	94	
Top of Joint Housing			61	61	62	61	62	
A, B, C, D Cable Loop	**(A, D in Air - B, C in Water)**							
Top of Insulation Shield (A)			97	99	100	100	100	
Top of Joint Housing (A)			65	66	67	66	66	
Top of Joint Housing (B)			45	45	46	46	46	
Top of Joint Housing (C)			47	46	46	45	45	
Top of Joint Housing (D)			60	60	61	61	61	
Water in Pipe (B)			43	44	43	44	43	
E, F, G, H Cable Loop	**(E, H in Air - F, G in Water)**							
Top of Insulation Shield (F)			99	100	101	101	100	
Top of Joint Housing (E)			67	68	68	67	68	
Top of Joint Housing (F)			47	48	48	47	48	
Top of Joint Housing (G)			49	48	48	48	48	
Top of Joint Housing (H)			59	61	61	61	60	
Water in Pipe (F)			42	42	41	41	42	
Ambient Air			32	30	31	31	32	
Current - A	1300	1300	1300	1300	1300	1300	1300	1300

Table D-6 (continued)
Heat Cycle, Daily Records After Seven-Hour Heating

Day of the Week	Sun.	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.	Sun.
Date	**08/01**	**08/02**	**08/03**	**08/04**	**08/05**	**08/06**	**08/07**	**08/08**
Cycle No.	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Thermoc., Location								
Control Cable	**Temperature, °C**							
Cond., Contr. Cable		128	129	130	130	127		
Conductor, Cable		130	130	130	130	127		
Conductor, Cable		130	130	130	130	128		
Connector (joint with ring)		146	146	146	143	143		
Connector (joint with tape)		147	147	147	145	144		
Top of Cable Insulation Shield		101	103	102	101	101		
Top of Cable Jacket		97	98	98	96	97		
Top of Joint Housing		63	63	64	65	65		
A, B, C, D Cable Loop	**(A, D in Air - B, C in Water)**							
Top of Insulation Shield (A)		99	100	100	99	100		
Top of Joint Housing (A)		67	69	70	70	70		
Top of Joint Housing (B)		48	48	49	49	50		
Top of Joint Housing (C)		48	49	48	49	50		
Top of Joint Housing (D)		66	66	66	67	68		
Water in Pipe (B)		47	47	47	48	48		
E, F, G, H Cable Loop	**(E, H in Air - F, G in Water)**							
Top of Insulation Shield (F)		98	99	99	98	98		
Top of Joint Housing (E)		67	67	66	67	67		
Top of Joint Housing (F)		49	50	50	51	50		
Top of Joint Housing (G)		50	51	51	52	52		
Top of Joint Housing (H)		63	63	64	64	62		
Water in Pipe (F)		46	47	48	48	48		
Ambient Air		37	37	38	36	34		
Current - A	1300	1300	1300	1300	1300	1300	1300	1300

Table D-6 (continued)
Heat Cycle, Daily Records After Seven-Hour Heating

Day of the Week	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.	Sun.	Mon.
Date	**08/09**	**08/10**	**08/11**	**08/12**	**08/13**	**08/14**		
Cycle No.	**25**	**26**	**27**	**28**	**29**	**30**		
Thermoc., Location								
Control Cable	**Temperature, °C**							
Cond., Contr. Cable	126	128	129	128	127			
Conductor, Cable	126	128	128	127	127			
Conductor, Cable	127	129	128	128	128			
Connector (joint with ring)	142	144	145	143	142			
Connector (joint with tape)	146	147	147	147	146			
Top of Cable Insulation Shield	105	106	106	105	104			
Top of Cable Jacket	95	96	96	97	97			
Top of Joint Housing	65	66	66	67	67			
A, B, C, D Cable Loop	**(A, D in Air - B, C in Water)**							
Top of Insulation Shield (A)	97	98	99	100	100			
Top of Joint Housing (A)	69	69	69	70	70			
Top of Joint Housing (B)	47	48	48	49	49			
Top of Joint Housing (C)	47	48	48	49	49			
Top of Joint Housing (D)	68	68	67	68	67			
Water in Pipe (B)	47	47	48	48	48			
E, F, G, H Cable Loop	**(E, H in Air - F, G in Water)**							
Top of Insulation Shield (F)	98	98	99	100	99			
Top of Joint Housing (E)	65	67	65	68	68			
Top of Joint Housing (F)	49	49	49	51	51			
Top of Joint Housing (G)	51	50	53	53	52			
Top of Joint Housing (H)	65	63	65	65	65			
Water in Pipe (F)	48	46	48	49	49			
Ambient Air	36	37	36	36	34			
Current - A	1300	1300	1300	1300	1300	1300		

Table D-7
Partial Discharge Test After Heat Cycling

Joint Identification	Heat Cycled in	Partial Discharge - pC			Inception Voltage kV	Extinction Voltage kV
		at 13 kV	at 15.6 kV	at 26 kV		
E1 (with ring)	Air	<3	<3	<3	>26	>26
E4 (with tape)	Air	<3	<3	<3	>26	>26
E5 (with tape)	Air	<3	<3	<3	>26	>26
E8 (with ring)	Air	<3	<3	<3	>26	>26
E2 (with ring)	Water	<3	<3	<3	>26	>26
E3 (with tape)	Water	<3	<3	<3	>26	>26
E6 (with tape)	Water	<3	<3	<3	>26	>26
E7 (with ring)	Water	<3	<3	<3	>26	>26

Table D-8
Impulse Withstand Test at 130°C Conductor Temperature

Joint Identification	Heat Cycled in	Bend Adjacent to Joint	Withstand Voltage kV	Polarity	Number of Impulses	Result
E1 (with ring)	Air	No	110	Positive	10	Passed
			110	Negative	10	Passed
E4 (with tape)	Air	No	110	Positive	10	Passed
			110	Negative	10	Passed
E5 (with tape)	Air	No	110	Positive	10	Passed
			110	Negative	10	Passed
E8 (with ring)	Air	Yes	110	Positive	10	Passed
			110	Negative	10	Passed
E2 (with ring)	Water	No	110	Positive	10	Passed
			110	Negative	10	Passed
E3 (with tape)	Water	No	110	Positive	10	Passed
			110	Negative	10	Passed
E6 (with tape)	Water	No	110	Positive	10	Passed
			110	Negative	10	Passed
E7 (with ring)	Water	Yes	110	Positive	10	Passed
			110	Negative	10	Passed

Table D-9
Partial Discharge Test After Impulse Withstand Test

Joint Identification	Heat Cycled in	Partial Discharge - pC			Inception Voltage kV	Extinction Voltage kV
		at 13 kV	at 15.6 kV	at 26 kV		
E1 (with ring)	Air	<3	<3	<3	>26	>26
E4 (with tape)	Air	<3	<3	<3	>26	>26
E5 (with tape)	Air	<3	<3	<3	>26	>26
E8 (with ring)	Air	<3	<3	<3	>26	>26
E2 (with ring)	Water	<3	<3	<3	>26	>26
E3 (with tape)	Water	<3	<3	<3	>26	>26
E6 (with tape)	Water	<3	<3	<3	>26	>26
E7 (with ring)	Water	<3	<3	<3	>26	>26

Table D-10
AC Voltage Time Step Test to Breakdown

Joint No.	Joint ID	Heat Cycled in	Bend Adjacent to Joint	Breakdown Voltage kV	Time at Max. Voltage min.
1	E1 (with ring)	Air	No	96	0.3
2	E4 (with tape)	Air	No	76	0.3
3	E5 (with tape)	Air	No	69	0.2
4	E8 (with ring)	Air	Yes	122 91 kV avg.	4.5
5	E2 (with ring)	Water	No	96	4.8
6	E3 (with tape)	Water	No	76	1.5
7	E6 (with tape)	Water	No	83	1.4
8	E7 (with ring)	Water	Yes	96 88 kV avg.	1.7

Table D-11
AC Voltage Time Step Test to Breakdown (Comparison Between Joints Having Retaining Ring and EPR Tape Bumper)

Joint No.	Joint ID	Heat Cycled in	Bend Adjacent to Joint	Breakdown Voltage kV	Time at Max. Voltage min.
1	E1 (with ring)	Air	No	96	0.3
5	E2 (with ring)	Water	No	96	4.8
8	E7 (with ring)	Water	Yes	96	1.7
4	E8 (with ring)	Air	Yes	122 103 kV avg.	4.5
2	E4 (with tape)	Air	No	76	0.3
6	E3 (with tape)	Water	No	76	1.5
7	E6 (with tape)	Water	No	83	1.4
3	E5 (with tape)	Air	No	69 76 kV avg.	0.2

Table D-12
Dissection After AC Voltage Breakdown Test

Joint No.	Joint Id.	Heat Cycled in	Breakdown Voltage kV	Result
1	E1 (with ring)	Air	96	Radial failure at the edge of semiconducting layer of cable adapter (Figure D-2)
2	E4 (with tape)	Air	76	Radial breakdown at the edge of cable insulation shield
3	E5 (with tape)	Air	69	Longitudinal breakdown at the interface between insulating layers of bus bar and receptacle housing (Figure D-1)
4	E8 (with ring)	Air	122	Radial failure at about 0.4 inch from semiconducting layer of cable adapter (Figure D-3)
5	E2 (with ring)	Water	96	Radial breakdown at the edge of cable insulation shield
6	E3 (with tape)	Water	76	Radial failure at the step in the semiconducting layer of cable adapter (Figure D-5)
7	E6 (with tape)	Water	83	Radial breakdown at the edge of cable insulation shield (Figure D-4)
8	E7 (with ring)	Water	96	Radial breakdown at the edge of cable insulation shield

Table D-13
Test Experiences and Observations

During installation special care needs to be taken when positioning the cable adapter. It should be flush with the cable semiconducting shield cut back.
During heat cycling, the temperature of the connector of the control cable was 15-20°C higher than that of the cable conductor. The joint is rated 600 A. However, the current required to maintain the cable conductor emergency temperature of 130°C during current-on periods was 1300 A causing excessive connector temperatures.
Of eight joints evaluated seven failed radially and one longitudinally.
Most of the joints failed at or near the cable insulation shield cut back or close to the edge of the semiconducting layer of the cable adapter. These points correspond to the location of highest electrical stress for this joint design.
Joints employing retaining rings exhibited significantly higher voltage breakdown levels than those incorporating EPR tape bumpers (103 vs. 76 kV avg.).

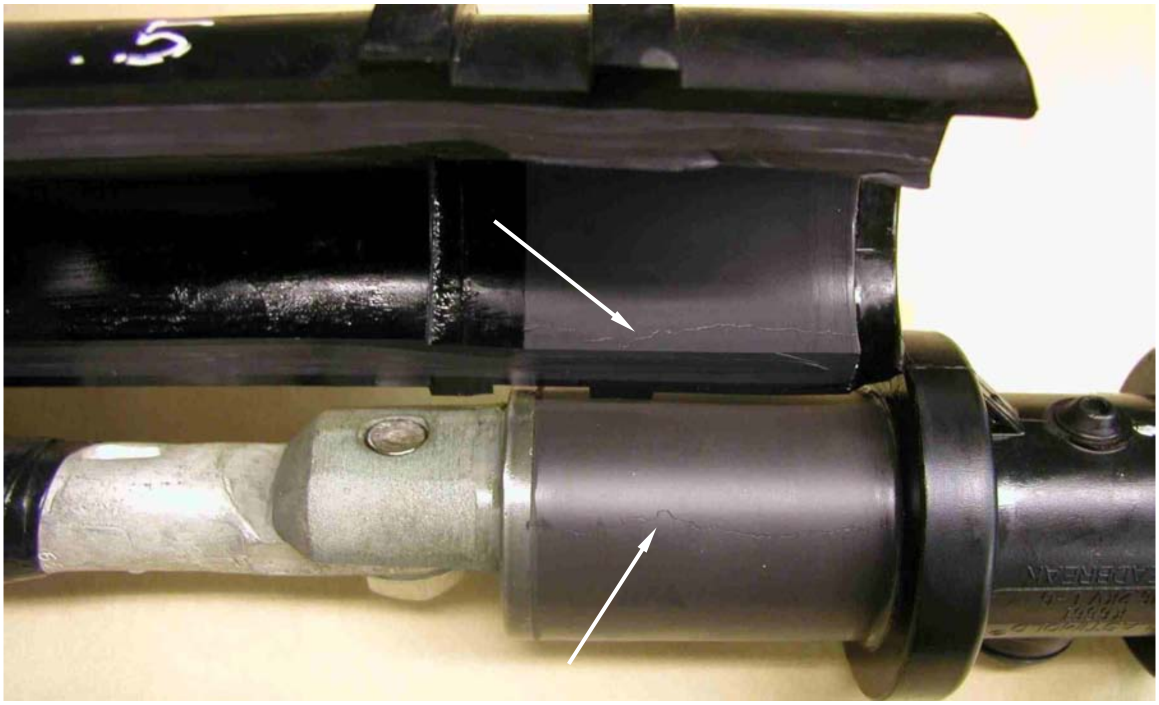

Figure D-1
Joint E5 (with EPR Tape Bumper). Longitudinal Failure at the Interface Between Bus Bar and Receptacle Housing.

Figure D-2
Joint E1 (with Retaining Ring). Radial Failure at the Edge of Semiconducting Layer of Cable Adapter.

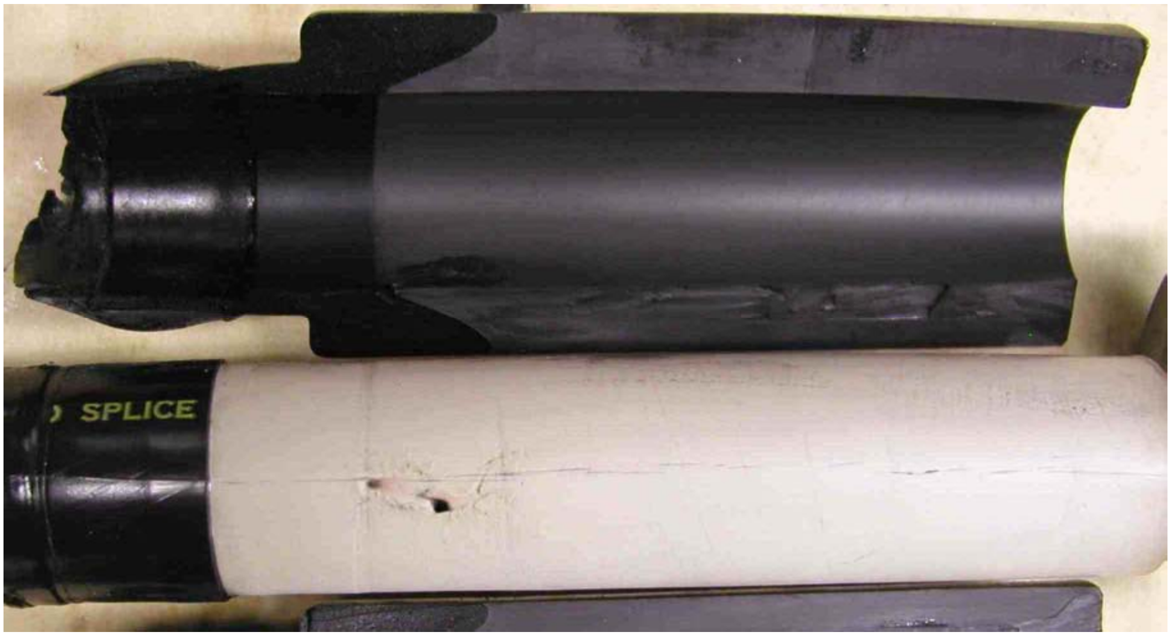

Figure D-3
Joint E8 (with Retaining Ring). Radial Failure at About 0.4 Inch from Semiconducting Layer of Cable Adapter.

Figure D-4
Joint E6 (with EPR Tape Bumper). Radial Failure at the Cable Insulation Shield Cut Back.

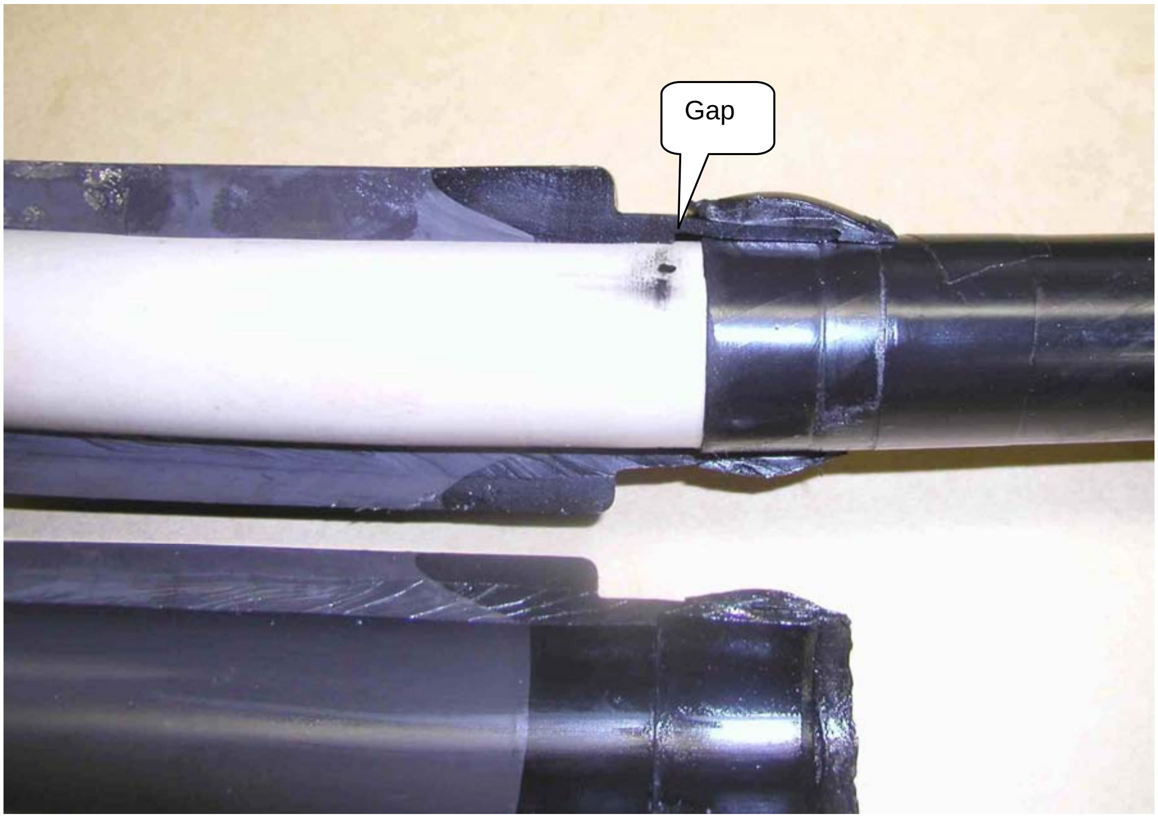

Figure D-5
Joint E3 (with EPR Tape Bumper). Radial Failure at the Step in the Semiconducting Layer of Cable Adapter. Note Gap in this Area.

E

RICHARDS 600 A SEPARABLE CONNECTOR JOINT ON 750 KCMIL, 15 KV CABLE

Richards P625JI2 (“I”-Type) 600 A Separable Connector Joint

- Analysis of joint assembly/fabrication – Table E-1
- Breakdown of time required for preparation of cables and assembly of joint – Table E-2
- Test results – Tables E-3 through E-11
- Test experiences and observations – Table E-12

Table E-1
Analysis of Joint Assembly/Fabrication

Assembly/Fabrication	Results
Time required to complete joint, (1 splicer)	75
Complexity of making the joint, (0 to 10)*	5
Skill required, (0 to 10)*	6
Longitudinal space required, in.	72
Length of complete joint, in.	50
Width of space required (minimum), in.	48
Other requirements: Installation area must be clean	

* Subjective rating, 10 denotes most difficult.

Table E-2
Time to Complete Joint

Preparation of Cables	**Time, min.**
Cable sections cut to length	5
Jackets removed, flat straps folded back	10
Insulation shield stripped	6
Insulation cut back	4
Installation of Joint Housings	
Sealing shrinkable tubes and receptacle housings parked on each cable	5
Inside of cable adapters lubricated and installed, aluminum lug connectors crimped	10
EPR tape bumpers (replacement for retaining rings) installed	8
Bus bar positioned and connected to lug connectors	10
Receptacle housings installed	10
Sealing mastic applied on cable jacket, cold shrinkable sealing tubes installed	7
Total (1 splicer)	75

Table E-3
AC Withstand Voltage Test Prior to Heat Cycling

Joint No.	Joint Identification	To be Heat Cycled in	Applied Voltage kV	Time minutes	Result
1	R1	Air	35	5	Passed
2	R4	Air	35	5	Passed
3	R5	Air	35	5	Passed
4	R8	Air	35	5	Passed
5	R2	Water	35	5	Passed
6	R3	Water	35	5	Passed
7	R6	Water	35	5	Passed
8	R7	Water	35	5	Passed

Table E-4
Partial Discharge Test Prior to Heat Cycling

Joint Identification	To be Heat Cycled in	Partial Discharge - pC			Inception Voltage kV	Extinction Voltage kV
		at 13 kV	at 15.6 kV	at 26 kV		
R1	Air	<3	<3	<3	>26	>26
R4	Air	<3	<3	<3	>26	>26
R5	Air	<3	<3	<3	>26	>26
R8	Air	<3	<3	<3	>26	>26
R2	Water	<3	<3	<3	>26	>26
R3	Water	<3	<3	<3	>26	>26
R6	Water	<3	<3	<3	>26	>26
R7	Water	<3	<3	<3	>26	>26

Table E-5
Thermocouple Location on Cables During Heat Cycling

Thermocouple No.	Cable Component	Location
	Control Cable	
Control	Conductor, Cable	6 ft. from center of joint
1	Conductor, Cable	1 ft. from control thermocouple
2	Conductor, Cable	5 ft. from center of joint (opposite side)
3	Connector (thinner wall)	Outside wall of connector
4	Connector (thicker wall)	Outside wall of connector
5	Top of Cable Insulation Shield	6 ft. from center of joint (opposite side)
6	Top of Cable Jacket	7 ft. from center of joint
7	Top of Joint Housing	Center of housing
	A, B, C, D Cable Loop	**(A, D in Air – B,C in Water)**
8	Top of Insulation Shield (A)	4 ft. from center of joint R1
9	Top of Joint Housing (A)	Center of housing R1
10	Top of Joint Housing (B)	Center of housing R2
11	Top of Joint Housing (C)	Center of housing R3
12	Top of Joint Housing (D)	Center of housing R4
13	Water in Pipe (B)	4 ft. from center of joint R2
	E, F, G, H Cable Loop	**(E, H in Air – F, G in Water)**
14	Top of Insulation Shield (F)	4 ft. from center of joint R5
15	Top of Joint Housing (E)	Center of housing R5
16	Top of Joint Housing (F)	Center of housing R6
17	Top of Joint Housing (G)	Center of housing R7
18	Top of Joint Housing (H)	Center of housing R8
19	Water in Pipe (F)	4 ft. from center of joint R6
	Ambient Air	Next to joint setup

Table E-6
Heat Cycle, Daily Records After Seven-Hour Heating

Day of the Week	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.	Sun.	Mon.
Date	**04/04**	**04/05**	**04/06**	**04/07**	**04/08**	**04/09**	**04/10**	**04/11**
Cycle No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Thermoc., Location								
Control Cable	**Temperature, °C**							
Cond., Contr. Cable	126	130	129	129	130			128
Conductor, Cable	123	127	127	127	128			126
Conductor, Cable	124	129	128	128	129			127
Connector (thinner wall)	138	143	142	141	144			140
Connector (thicker wall)	134	137	135	135	137			134
Top of Cable Insulation Shield	99	102	102	100	101			100
Top of Cable Jacket	87	89	89	89	90			88
Top of Joint Housing	57	59	60	60	59			59
A, B, C, D Cable Loop	**(A, D in Air - B, C in Water)**							
Top of Insulation Shield (A)	96	98	99	100	100			98
Top of Joint Housing (A)	54	56	57	57	56			55
Top of Joint Housing (B)	42	46	44	44	44			43
Top of Joint Housing (C)	41	45	43	42	44			42
Top of Joint Housing (D)	56	60	61	62	62			60
Water in Pipe (B)	39	42	41	40	41			40
E, F, G, H Cable Loop	**(E, H in Air - F, G in Water)**							
Top of Insulation Shield (E)	99	102	103	103	102			101
Top of Joint Housing (E)	54	57	58	59	58			56
Top of Joint Housing (F)	42	45	44	43	44			40
Top of Joint Housing (G)	43	46	45	44	45			41
Top of Joint Housing (H)	55	57	58	58	57			56
Water in Pipe (F)	34	37	37	36	37			36
Ambient Air	24	27	31	30	29			27
Current - A	1300	1300	1300	1300	1300	1300	1300	1300

Table E-6 (continued)
Heat Cycle, Daily Records After Seven-Hour Heating

Day of the Week	Tue.	Wed.	Thu.	Fri.	Sat.	Sun.	Mon.	Tue.
Date	**04/12**	**04/13**	**04/14**	**04/15**	**04/16**	**04/17**	**04/18**	**04/19**
Cycle No.	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Thermoc., Location								
Control Cable	**Temperature, °C**							
Cond., Contr. Cable	130	130	130	130			130	129
Conductor	128	128	129	127			128	126
Conductor	130	130	131	129			130	128
Connector (thinner wall)	144	144	145	142			143	142
Connector (thicker wall)	138	138	138	138			137	137
Top of Cable Insulation Shield	101	100	100	100			101	100
Top of Cable Jacket	91	93	92	91			93	93
Top of Joint Housing	58	58	59	58			60	59
A, B, C, D Cable Loop	**(A, D in Air - B, C in Water)**							
Top of Insulation Shield (A)	97	97	98	97			98	98
Top of Joint Housing (A)	56	56	57	56			57	57
Top of Joint Housing (B)	44	44	43	42			42	43
Top of Joint Housing (C)	44	43	43	42			42	42
Top of Joint Housing (D)	62	62	61	62			62	61
Water in Pipe (B)	41	41	40	39			39	39
E, F, G, H Cable Loop	**(E, H in Air - F, G in Water)**							
Top of Insulation Shield (E)	99	99	100	99			100	100
Top of Joint Housing (E)	54	56	55	55			57	56
Top of Joint Housing (F)	43	43	43	42			41	40
Top of Joint Housing (G)	43	43	42	42			41	41
Top of Joint Housing (H)	57	58	58	58			59	58
Water in Pipe (F)	37	37	38	35			35	35
Ambient Air	29	29	31	30			31	32
Current - A	1300	1300	1300	1300	1300	1300	1300	1300

Table E-6 (continued)
Heat Cycle, Daily Records After Seven-Hour Heating

Day of the Week	Wed.	Thu.	Fri.	Sat.	Sun.	Mon.	Tue.	Wed.
Date	**04/20**	**04/21**	**04/22**	**04/23**	**04/24**	**04/25**	**04/26**	**04/27**
Cycle No.	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Thermoc., Location								
Control Cable	**Temperature, °C**							
Cond., Contr. Cable	130	129	128			128	130	129
Conductor, Cable	127	126	125			126	127	126
Conductor, Cable	128	127	126			127	128	128
Connector (thinner wall)	143	143	142			142	144	144
Connector (thicker wall)	138	138	138			137	138	138
Top of Cable Insulation Shield	101	100	99			99	100	99
Top of Cable Jacket	94	93	92			92	93	93
Top of Joint Housing	61	60	58			59	60	59
A, B, C, D Cable Loop	**(A, D in Air - B, C in Water)**							
Top of Insulation Shield (A)	99	98	97			97	98	98
Top of Joint Housing (A)	57	57	56			56	57	56
Top of Joint Housing (B)	44	44	43			43	44	44
Top of Joint Housing (C)	44	43	42			42	42	42
Top of Joint Housing (D)	62	62	61			62	62	61
Water in Pipe (B)	42	42	41			41	41	41
E, F, G, H Cable Loop	**(E, H in Air - F, G in Water)**							
Top of Insulation Shield (E)	100	100	99			99	99	98
Top of Joint Housing (E)	57	57	56			56	57	56
Top of Joint Housing (F)	43	43	42			43	44	43
Top of Joint Housing (G)	43	43	42			43	44	43
Top of Joint Housing (H)	58	58	57			58	57	56
Water in Pipe (F)	38	38	38			39	39	38
Ambient Air	28	28	27			29	30	30
Current - A	1300	1300	1300	1300	1300	1300	1300	1300

Table E-6 (continued)
Heat Cycle, Daily Records After Seven-Hour Heating

Day of the Week	Thu.	Fri.	Sat.	Sun.	Mon.	Tue.	Wed.	Thu.
Date	**04/28**	**04/29**	**04/30**	**05/01**	**05/02**	**05/03**	**05/04**	**05/05**
Cycle No.	**25**	**26**	**27**	**28**	**29**	**30**		
Thermoc., Location								
Control Cable	**Temperature, °C**							
Cond., Contr. Cable	130	130			130	130		
Conductor, Cable	126	126			126	126		
Conductor, Cable	127	128			127	127		
Connector (thinner wall)	145	144			144	145		
Connector (thicker wall)	140	139			139	140		
Top of Cable Insulation Shield	100	100			100	99		
Top of Cable Jacket	91	92			91	91		
Top of Joint Housing	60	59			60	59		
A, B, C, D Cable Loop	**(A, D in Air - B, C in Water)**							
Top of Insulation Shield (A)	98	98			98	97		
Top of Joint Housing (A)	57	56			57	56		
Top of Joint Housing (B)	45	44			45	44		
Top of Joint Housing (C)	45	44			45	43		
Top of Joint Housing (D)	63	62			63	62		
Water in Pipe (B)	42	41			40	41		
E, F, G, H Cable Loop	**(E, H in Air - F, G in Water)**							
Top of Insulation Shield (E)	99	98			99	99		
Top of Joint Housing (E)	56	56			56	56		
Top of Joint Housing (F)	45	44			45	43		
Top of Joint Housing (G)	43	43			42	43		
Top of Joint Housing (H)	57	56			57	56		
Water in Pipe (F)	40	38			39	38		
Ambient Air	31	30			26	26		
Current - A	1300	1300	1300	1300	1300	1300		

Table E-7
Partial Discharge Test After Heat Cycling

Joint Identification	Heat Cycled in	Partial Discharge - pC			Inception Voltage kV	Extinction Voltage kV
		at 13 kV	at 15.6 kV	at 26 kV		
R1	Air	<3	<3	<3	>26	>26
R4	Air	<3	<3	<3	>26	>26
R5	Air	<3	<3	<3	>26	>26
R8	Air	<3	<3	<3	>26	>26
R2	Water	<3	<3	<3	>26	>26
R3	Water	<3	<3	<3	>26	>26
R6	Water	<3	<3	<3	>26	>26
R7	Water	<3	<3	<3	>26	>26

Table E-8
Impulse Withstand Test at 130°C Conductor Temperature

Joint Identification	Heat Cycled in	Bend Adjacent to Joint	Withstand Voltage kV	Polarity	Number of Impulses	Result
R1	Air	No	110 110	Positive Negative	10 10	Passed Passed
R4	Air	No	110 110	Positive Negative	10 10	Passed Passed
R5	Air	No	110 110	Positive Negative	10 10	Passed Passed
R8	Air	Yes	110 110	Positive Negative	10 10	Passed Passed
R2	Water	No	110 110	Positive Negative	10 10	Passed Passed
R3	Water	No	110 110	Positive Negative	10 10	Passed Passed
R6	Water	No	110 110	Positive Negative	10 10	Passed Passed
R7	Water	Yes	110 110	Positive Negative	10 10	Passed Passed

Table E-9
Partial Discharge Test After Impulse Withstand Test

Joint Identification	Heat Cycled in	Partial Discharge - pC			Inception Voltage kV	Extinction Voltage kV
		at 13 kV	at 15.6 kV	at 26 kV		
R1	Air	<3	<3	<3	>26	>26
R4	Air	<3	<3	<3	>26	>26
R5	Air	<3	<3	<3	>26	>26
R8	Air	<3	<3	<3	>26	>26
R2	Water	<3	<3	<3	>26	>26
R3	Water	<3	<3	<3	>26	>26
R6	Water	<3	<3	<3	>26	>26
R7	Water	<3	<3	<3	>26	>26

Table E-10
AC Voltage Time Step Test to Breakdown

Joint No.	Joint ID	Heat Cycled in	Bend Adjacent to Joint	Breakdown Voltage kV	Time at Max. Voltage min.
1	R1	Air	No	69	3.1
2	R4	Air	No	83	4.3
3	R5	Air	No	76	3.5
4	R8	Air	Yes	76 76 kV avg.	2.7
5	R2	Water	No	83	2.3
6	R3	Water	No	83	0.3
7	R6	Water	No	76	4.3
8	R7	Water	Yes	102 86 kV avg.	4.2

Table E-11
Dissection After AC Voltage Breakdown Test

Joint No.	Joint ID.	Heat Cycled in	Breakdown Voltage kV	Result
1	R1	Air	69	Radial failure at the location of the step in the semiconducting layer of cable adapter (about 100 mils from the cable insulation shield cut back).
2	R4	Air	83	Radial failure at the location of the step in the semiconducting layer of cable adapter (about 60 mils from the cable insulation shield cut back).
3	R5	Air	76	Radial failure at the location of the step in the semiconducting layer of cable adapter (about 60 mils from the cable insulation shield cut back).
4	R8	Air	76	Radial failure at the location of the step in the semiconducting layer of cable adapter (about 120 mils from the cable insulation shield cut back) (Figure E-1)
5	R2	Water	83	Longitudinal breakdown at the interface between insulation of cable adapter and receptacle housing (Figure E-3)
6	R3	Water	83	Radial failure at the location of the step in the semiconducting layer of cable adapter (about 80 mils from the cable insulation shield cut back).
7	R6	Water	76	Radial failure at the location of the step in the semiconducting layer of cable adapter (about 90 mils from the cable insulation shield cut back) (Figure E-2)
8	R7	Water	102	Combination of radial failure through the cable insulation and longitudinally along the interface between the insulation of the cable and adapter (Figure E-4)

Table E-12
Test Experiences and Observations

Aluminum connectors with 330 or 180 mils wall thickness were employed (one type for each four joint assemblies). Connectors with thicker wall run 5-6°C cooler than those with thinner wall.
Of eight joints evaluated seven failed radially and one longitudinally.
In six joints the failure took place in coincidence with the step in the semiconducting layer of the cable adapter. When the adapter is properly installed on the cable, this step should be flush with the cable semiconducting shield cut back.
Employing an EPR tape bumper instead of the retaining ring may result in shifting of the cable adapter during installation of the receptacle housing and the creation of a gap at the interface between the cable insulation and inner semiconducting layer of the cable adapter.
During dissection it was found that in several joints the receptacle housing exhibited erosion on the surface of its inner semiconducting layer, in the area coinciding with the location of the hex-head bolt. This erosion, most likely, takes place during impulse voltage withstand tests.

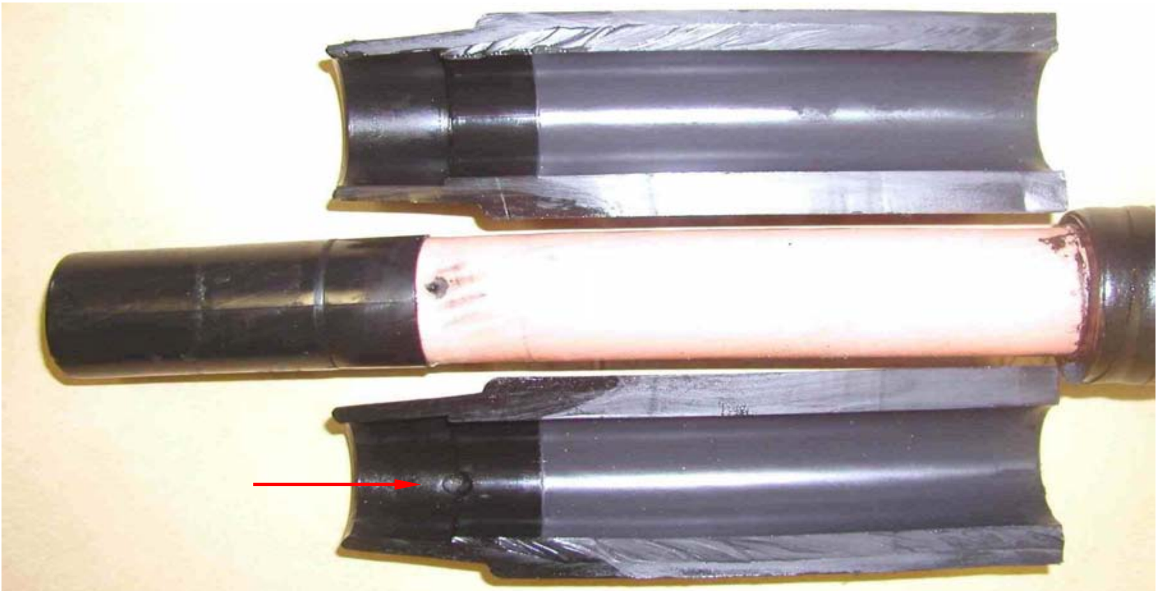

Figure E-1
Joint R8. Radial Failure at the Location of the Step in the Semiconducting Layer of Cable Adapter (120 Mils from the Cable Insulation Shield Cut Back).

Figure E-2
Joint R6. Radial Failure at the Location of the Step in the Semiconducting Layer of Cable Adapter (90 Mils from the Cable Insulation Shield Cut Back).

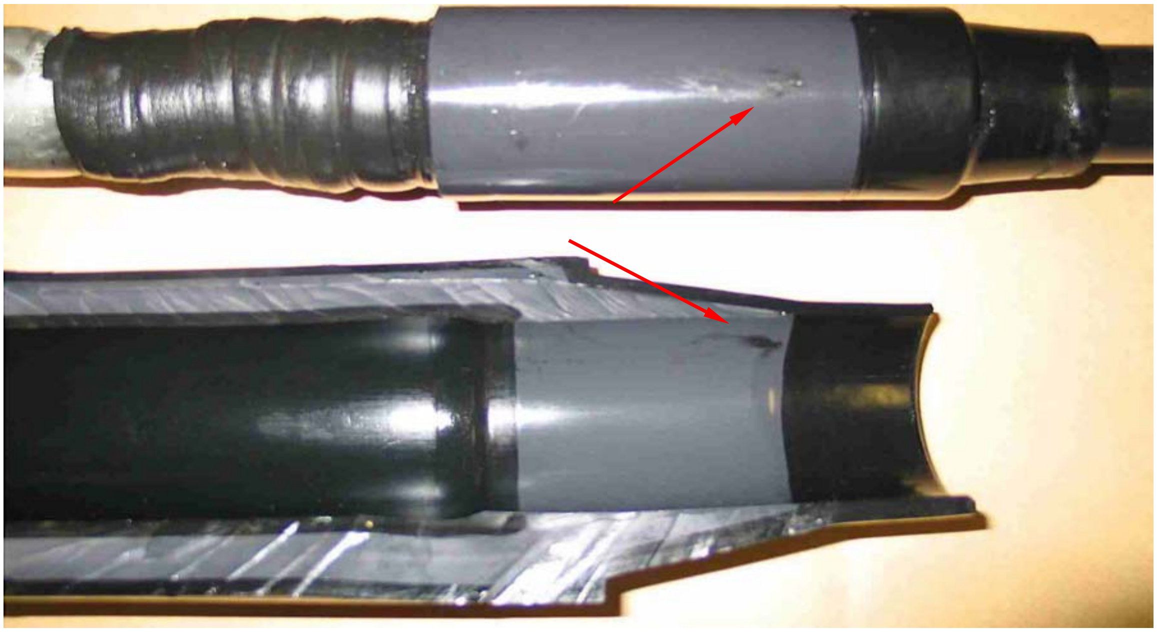

Figure E-3
Joint R2. Longitudinal Failure at the Interface Between the Insulation of the Cable Adapter and Receptacle Housing.

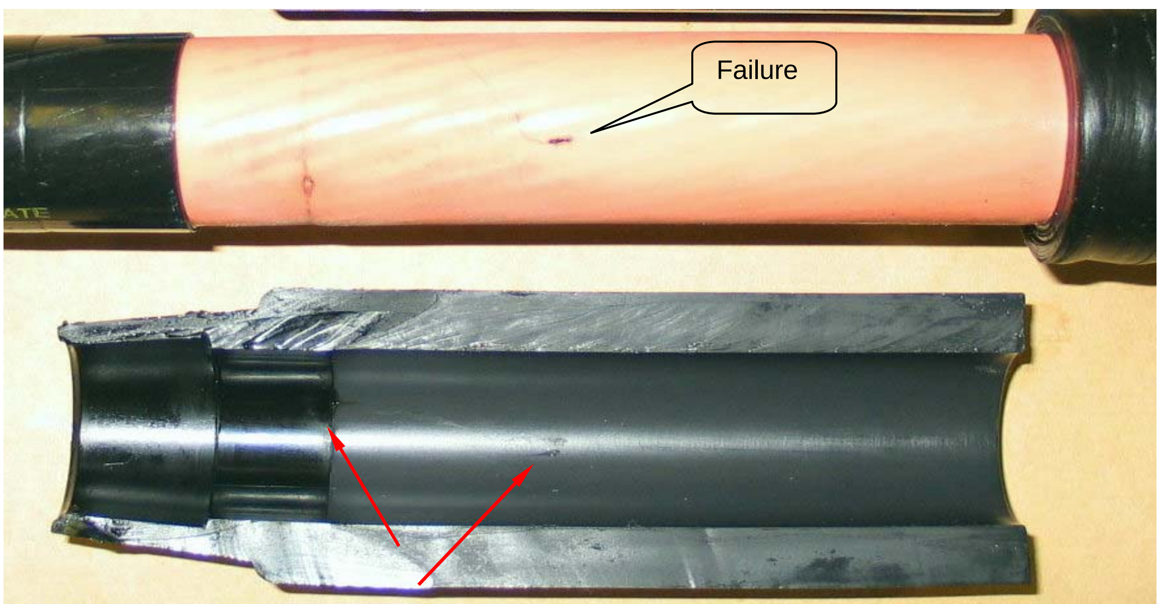

Figure E-4
Joint R7. Failure Follows the Interface Between Insulation of the Cable and the Cable Adapter and Radially Through the Cable Insulation.

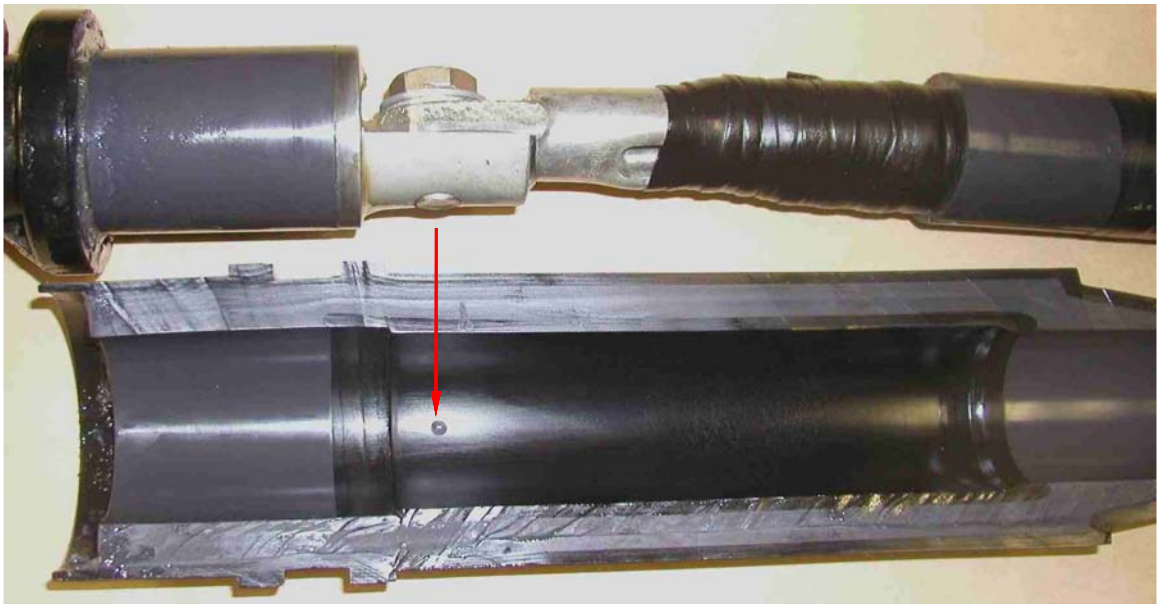

Figure E-5
Joint R8. Eroded Area in the Inner Semiconducting Layer of the Receptacle Housing at the Location of the Exposed Edge of the Hex-Head Bolt. A Similar Condition was Observed in Several Other Joints.

Figure E-6
Joint R8. Microscopic View of Erosion Caused by Sparking Through the Air Gap Between the Inner Semiconducting Layer of the Receptacle Housing and the Hex-Head Bolt.

F

RICHARDS 900 A SEPARABLE CONNECTOR JOINT ON 750 KCMIL, 15 KV CABLE

Richards P925JI2 (“I”-Type) 900 A Separable Connector Joint

- Analysis of joint assembly/fabrication – Table F-1
- Breakdown of time required for preparation of cables and assembly of joint – Table F-2
- Test results – Tables F-3 through F-11
- Test experiences and observations – Table F-12

Table F-1
Analysis of Joint Assembly/Fabrication

Assembly/Fabrication	Results
Time required to complete joint, (1 splicer)	75
Complexity of making the joint, (0 to 10)*	5
Skill required, (0 to 10)*	6
Longitudinal space required, in.	72
Length of complete joint, in.	50
Width of space required (minimum), in.	48
Other requirements: Installation area must be clean	

* Subjective rating, 10 denotes most difficult.

Table F-2
Time to Complete Joint

Preparation of Cables	**Time, min.**
Cable sections cut to length	5
Jackets removed, flat straps folded back	10
Insulation shield stripped	6
Insulation cut back	4
Installation of Joint Housings	
Sealing shrinkable tubes and receptacle housings parked on each cable	5
Inside of cable adapters lubricated and installed, aluminum lug connectors crimped	10
EPR tape bumpers (replacement for retaining rings) installed	8
Bus bar positioned and connected to lug connectors	10
Receptacle housings installed	10
Sealing mastic applied on cable jacket, cold shrinkable sealing tubes installed	7
Total (1 splicer)	75

Table F-3
AC Withstand Voltage Test Prior to Heat Cycling

Joint No.	Joint Identification	To be Heat Cycled in	Applied Voltage kV	Time minutes	Result
1	R1	Air	35	5	Passed
2	R4	Air	35	5	Passed
3	R5	Air	35	5	Passed
4	R8	Air	35	5	Passed
5	R2	Water	35	5	Passed
6	R3	Water	35	5	Passed
7	R6	Water	35	5	Passed
8	R7	Water	35	5	Passed

Table F-4
Partial Discharge Test Prior to Heat Cycling

Joint Identification	To be Heat Cycled in	Partial Discharge - pC			Inception Voltage kV	Extinction Voltage kV
		at 13 kV	at 15.6 kV	at 26 kV		
R1	Air	<3	<3	<3	>26	>26
R4	Air	<3	<3	<3	>26	>26
R5	Air	<3	<3	<3	>26	>26
R8	Air	<3	<3	<3	>26	>26
R2	Water	<3	<3	<3	>26	>26
R3	Water	<3	<3	<3	>26	>26
R6	Water	<3	<3	<3	>26	>26
R7	Water	<3	<3	<3	>26	>26

Table F-5
Thermocouple Location on Cables During Heat Cycling

Thermocouple No.	Cable Component	Location
	Control Cable	
Control	Conductor, Cable	6 ft. from center of joint
1	Conductor, Cable	1 ft. from control thermocouple
2	Conductor, Cable	5 ft. from center of joint (opposite side)
3	Connector	Outside wall of connector
4	Connector	Outside wall of connector
5	Top of Cable Insulation Shield	6 ft. from center of joint (opposite side)
6	Top of Cable Jacket	7 ft. from center of joint
7	Top of Joint Housing	Center of housing
	A, B, C, D Cable Loop	**(A, D in Air – B,C in Water)**
8	Top of Insulation Shield (A)	4 ft. from center of joint R1
9	Top of Joint Housing (A)	Center of housing R1
10	Top of Joint Housing (B)	Center of housing R2
11	Top of Joint Housing (C)	Center of housing R3
12	Top of Joint Housing (D)	Center of housing R4
13	Water in Pipe (B)	4 ft. from center of joint R2
	E, F, G, H Cable Loop	**(E, H in Air – F, G in Water)**
14	Top of Insulation Shield (F)	4 ft. from center of joint R5
15	Top of Joint Housing (E)	Center of housing R5
16	Top of Joint Housing (F)	Center of housing R6
17	Top of Joint Housing (G)	Center of housing R7
18	Top of Joint Housing (H)	Center of housing R8
19	Water in Pipe (F)	4 ft. from center of joint R6
	Ambient Air	Next to joint setup

Table F-6
Heat Cycle, Daily Records After Seven-Hour Heating

Day of the Week	Wed.	Thu.	Fri.	Sat.	Sun.	Mon.	Tue.	Wed.
Date	**01/26**	**01/27**	**01/28**	**01/29**	**01/30**	**01/31**	**02/01**	**02/02**
Cycle No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Thermoc., Location								
Control Cable	**Temperature, °C**							
Cond., Contr. Cable	128	128	128			129	129	130
Conductor, Cable	125	126	126			127	127	128
Conductor, Cable	126	127	127			128	128	128
Connector	112	113	114			115	115	116
Connector	112	114	115			116	115	116
Top of Cable Insulation Shield	101	101	102			103	103	103
Top of Cable Jacket	90	90	90			91	91	92
Top of Joint Housing	47	48	48			50	49	50
A, B, C, D Cable Loop	**(A, D in Air - B, C in Water)**							
Top of Insulation Shield (A)	97	98	99			100	100	101
Top of Joint Housing (A)	43	44	45			46	46	46
Top of Joint Housing (B)	34	35	35			36	36	36
Top of Joint Housing (C)	33	34	35			36	35	36
Top of Joint Housing (D)	46	47	48			49	49	49
Water in Pipe (B)	34	34	34			35	35	36
E, F, G, H Cable Loop	**(E, H in Air - F, G in Water)**							
Top of Insulation Shield (F)	100	100	101			102	101	101
Top of Joint Housing (E)	50	50	51			51	51	50
Top of Joint Housing (F)	35	36	36			37	37	36
Top of Joint Housing (G)	36	36	36			39	38	37
Top of Joint Housing (H)	48	48	48			49	49	49
Water in Pipe (F)	34	35	35			36	37	36
Ambient Air	20	20	19			22	23	22
Current - A	1350	1350	1350	1350	1350	1350	1350	1350

Table F-6 (continued)
Heat Cycle, Daily Records After Seven-Hour Heating

Day of the Week	Thu.	Fri.	Sat.	Sun.	Mon.	Tue.	Wed.	Thu.
Date	**02/03**	**02/04**	**02/05**	**02/06**	**02/07**	**02/08**	**02/09**	**02/10**
Cycle No.	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Thermoc., Location								
Control Cable	**Temperature, °C**							
Cond., Contr. Cable	129	129			129	129	130	
Conductor, Cable	127	127			127	128	128	
Conductor, Cable	128	128			127	128	128	
Connector	115	115			115	116	116	
Connector	115	116			115	116	116	
Top of Cable Insulation Shield	103	103			102	103	103	
Top of Cable Jacket	91	91			91	92	92	
Top of Joint Housing	49	50			50	50	50	
A, B, C, D Cable Loop	**(A, D in Air - B, C in Water)**							
Top of Insulation Shield (A)	99	99			100	100	101	
Top of Joint Housing (A)	47	47			47	46	47	
Top of Joint Housing (B)	36	35			36	36	36	
Top of Joint Housing (C)	36	35			35	36	36	
Top of Joint Housing (D)	49	49			49	49	49	
Water in Pipe (B)	35	36			35	35	36	
E, F, G, H Cable Loop	**(E, H in Air - F, G in Water)**							
Top of Insulation Shield (F)	100	101			101	102	101	
Top of Joint Housing (E)	50	51			50	51	51	
Top of Joint Housing (F)	37	37			36	37	37	
Top of Joint Housing (G)	38	38			37	39	38	
Top of Joint Housing (H)	48	49			49	49	49	
Water in Pipe (F)	36	37			36	36	37	
Ambient Air	21	22			22	22	23	
Current - A	1350	1350	1350	1350	1350	1350	1350	1350

Table F-6 (continued)
Heat Cycle, Daily Records After Seven-Hour Heating

Day of the Week	Fri.	Sat.	Sun.	Mon.	Tue.	Wed.	Thu.	Fri.
Date	**02/11**	**02/12**	**02/13**	**02/14**	**02/15**	**02/16**	**02/17**	**02/18**
Cycle No.	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Thermoc., Location								
Control Cable	**Temperature, °C**							
Cond., Contr. Cable	130			130	129	130	129	128
Conductor, Cable	127			127	127	127	127	127
Conductor, Cable	129			129	128	129	127	128
Connector	117			117	116	117	115	115
Connector	116			116	116	116	115	115
Top of Cable Insulation Shield	103			103	102	102	100	100
Top of Cable Jacket	91			92	90	91	89	89
Top of Joint Housing	50			50	49	51	49	49
A, B, C, D Cable Loop	**(A, D in Air - B, C in Water)**							
Top of Insulation Shield (A)	99			100	100	100	99	99
Top of Joint Housing (A)	47			48	47	48	46	46
Top of Joint Housing (B)	39			39	39	40	38	38
Top of Joint Housing (C)	38			38	38	38	37	37
Top of Joint Housing (D)	50			50	49	50	49	48
Water in Pipe (B)	35			38	37	37	35	35
E, F, G, H Cable Loop	**(E, H in Air - F, G in Water)**							
Top of Insulation Shield (F)	102			103	102	101	100	101
Top of Joint Housing (E)	52			53	52	51	51	50
Top of Joint Housing (F)	40			40	40	39	37	37
Top of Joint Housing (G)	42			42	41	41	38	38
Top of Joint Housing (H)	48			49	49	48	49	48
Water in Pipe (F)	38			38	39	36	37	36
Ambient Air	23			25	25	24	18	20
Current - A	1350	1350	1350	1350	1350	1350	1350	1350

Table F-6 (continued)
Heat Cycle, Daily Records After Seven-Hour Heating

Day of the Week	Sat.	Sun.	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
Date	**02/19**	**02/20**	**02/21**	**02/22**	**02/23**	**02/24**	**02/25**	**02/26**
Cycle No.	**25**	**26**	**27**	**28**	**29**	**30**		
Thermoc., Location								
Control Cable	**Temperature, °C**							
Cond., Contr. Cable				129	130	129		
Conductor, Cable				126	127	127		
Conductor, Cable				128	129	128		
Connector				115	117	115		
Connector				114	116	115		
Top of Cable Insulation Shield				101	102	100		
Top of Cable Jacket				90	91	90		
Top of Joint Housing				49	49	48		
A, B, C, D Cable Loop	**(A, D in Air - B, C in Water)**							
Top of Insulation Shield (A)				98	99	99		
Top of Joint Housing (A)				45	46	46		
Top of Joint Housing (B)				36	39	38		
Top of Joint Housing (C)				36	38	37		
Top of Joint Housing (D)				48	49	48		
Water in Pipe (B)				36	37	36		
E, F, G, H Cable Loop	**(E, H in Air - F, G in Water)**							
Top of Insulation Shield (F)				101	102	101		
Top of Joint Housing (E)				52	52	51		
Top of Joint Housing (F)				38	39	38		
Top of Joint Housing (G)				40	42	41		
Top of Joint Housing (H)				48	49	48		
Water in Pipe (F)				37	39	38		
Ambient Air				23	22	20		
Current - A	1350	1350	1350	1350	1350	1350	1350	1350

Table F-7
Partial Discharge Test After Heat Cycling

Joint Identification	Heat Cycled in	Partial Discharge - pC			Inception Voltage kV	Extinction Voltage kV
		at 13 kV	at 15.6 kV	at 26 kV		
R1	Air	<3	<3	<3	>26	>26
R4	Air	<3	<3	<3	>26	>26
R5	Air	<3	<3	<3	>26	>26
R8	Air	<3	<3	<3	>26	>26
R2	Water	<3	<3	<3	>26	>26
R3	Water	<3	<3	<3	>26	>26
R6	Water	<3	<3	<3	>26	>26
R7	Water	<3	<3	<3	>26	>26

Table F-8
Impulse Withstand Test at 130°C Conductor Temperature

Joint Identification	Heat Cycled in	Bend Adjacent to Joint	Withstand Voltage kV	Polarity	Number of Impulses	Result
R1	Air	No	110	Positive	10	Passed
			110	Negative	10	Passed
R4	Air	No	110	Positive	10	Passed
			110	Negative	10	Passed
R5	Air	No	110	Positive	10	Passed
			110	Negative	10	Passed
R8	Air	Yes	110	Positive	10	Passed
			110	Negative	10	Passed
R2	Water	No	110	Positive	10	Passed
			110	Negative	10	Passed
R3	Water	No	110	Positive	10	Passed
			110	Negative	10	Passed
R6	Water	No	110	Positive	10	Passed
			110	Negative	10	Passed
R7	Water	Yes	110	Positive	10	Passed
			110	Negative	10	Passed

Table F-9
Partial Discharge Test After Impulse Withstand Test

Joint Identification	Heat Cycled in	Partial Discharge - pC			Inception Voltage kV	Extinction Voltage kV
		at 13 kV	at 15.6 kV	at 26 kV		
R1	Air	<3	<3	<3	>26	>26
R4	Air	<3	<3	<3	>26	>26
R5	Air	<3	<3	<3	>26	>26
R8	Air	<3	<3	<3	>26	>26
R2	Water	<3	<3	<3	>26	>26
R3	Water	<3	<3	<3	>26	>26
R6	Water	<3	<3	<3	>26	>26
R7	Water	<3	<3	<3	>26	>26

Table F-10
AC Voltage Time Step Test to Breakdown

Joint No.	Joint ID	Heat Cycled in	Bend Adjacent to Joint	Breakdown Voltage kV	Time at Max. Voltage min.
1	R1	Air	No	89	4.8
2	R4	Air	No	128	1.5
3	R5	Air	No	76	0.5
4	R8	Air	Yes	89 96 kV avg.	4.5
5	R2	Water	No	76	0.2
6	R3	Water	No	83	0.7
7	R6	Water	No	69	4.5
8	R7	Water	Yes	102 83kV avg.	2.1

Table F-11
Dissection After AC Voltage Breakdown Test

Joint No.	Joint ID.	Heat Cycled in	Breakdown Voltage kV	Result
1	R1	Air	89	Radial breakdown next to the edge of cable insulation shield.
2	R4	Air	128	Longitudinal breakdown at the interface between insulation of bus bar and receptacle housing (Figure F-1)
3	R5	Air	76	Radial failure at the location of the step in the semiconducting layer of cable adapter (about 450 mils from the cable insulation shield cut back) (Figure F-3)
4	R8	Air	89	Radial breakdown at the edge of cable insulation shield (Figure F-2)
5	R2	Water	76	Radial failure at the location of the step in the semiconducting layer of cable adapter (about 150 mils from the cable insulation shield cut back).
6	R3	Water	83	Radial failure in the cable insulation, following longitudinally along the interface between the insulation of the cable and cable adapter (Figure F-4)
7	R6	Water	69	Radial failure at the location of the step in the semiconducting layer of cable adapter (about 250 mils from the cable insulation shield cut back) (Figure F-5)
8	R7	Water	102	Longitudinal breakdown at the interface between insulation of bus bar and receptacle housing.

Table F-12
Test Experiences and Observations

During heat cycling, the copper connectors run 11-13°C cooler than the copper cable conductor due to the larger cross-section of the connector.
Of eight joints evaluated six failed radially and two longitudinally.
In some of the joints (R2, R5 and R6) the failure took place in coincidence with the step in the semiconducting layer of the cable adapter. These joints exhibited lower voltage breakdown levels than other joints in the group.
Employing an EPR tape bumper instead of the retaining ring resulted in shifting of the cable adapter and the creation of a gap at the interface between the cable insulation and the cable adapter.
During dissection it was found that in several joints the receptacle housing exhibited erosion on the surface of its inner semiconducting layer, in the area coinciding with the location of the hex-head bolt. This erosion, most likely, takes place during impulse voltage withstand tests.

Figure F-1
Joint R4. Longitudinal Failure at the Interface Between the Insulation of the Bus Bar and Receptacle Housing.

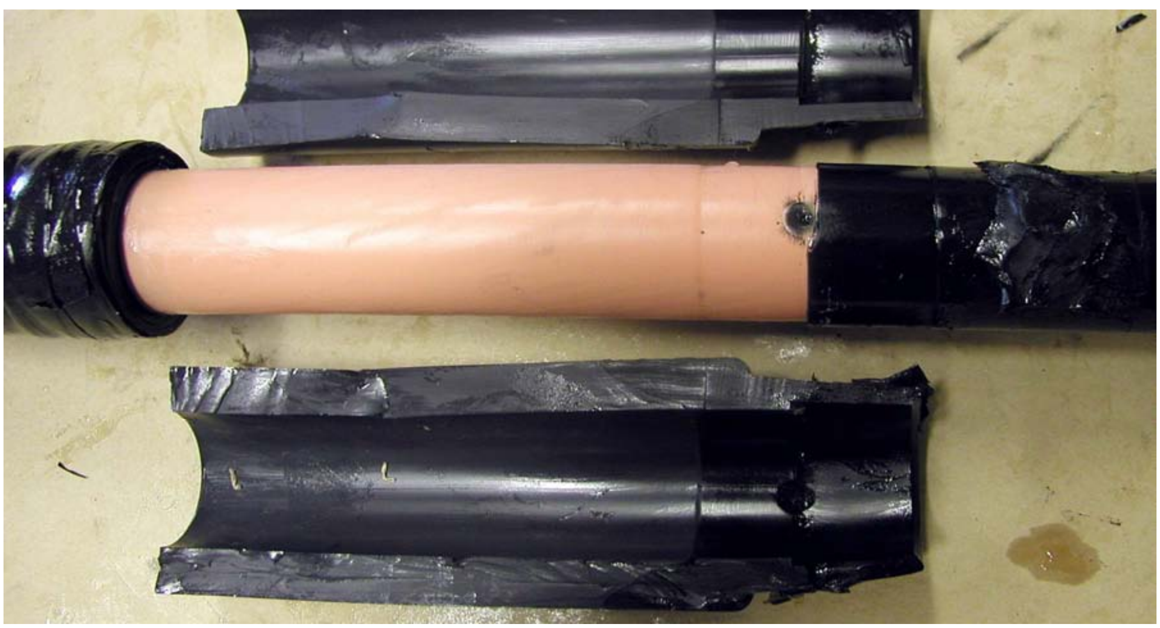

Figure F-2
Joint R8. Radial Failure at the Cable Insulation Shield Cut Back.

Figure F-3
Joint R5. Radial Failure in Coincidence with the Step in the Semiconducting Layer of the Cable Adapter (About 450 Mils from the Cable Insulation Shield Cut Back).

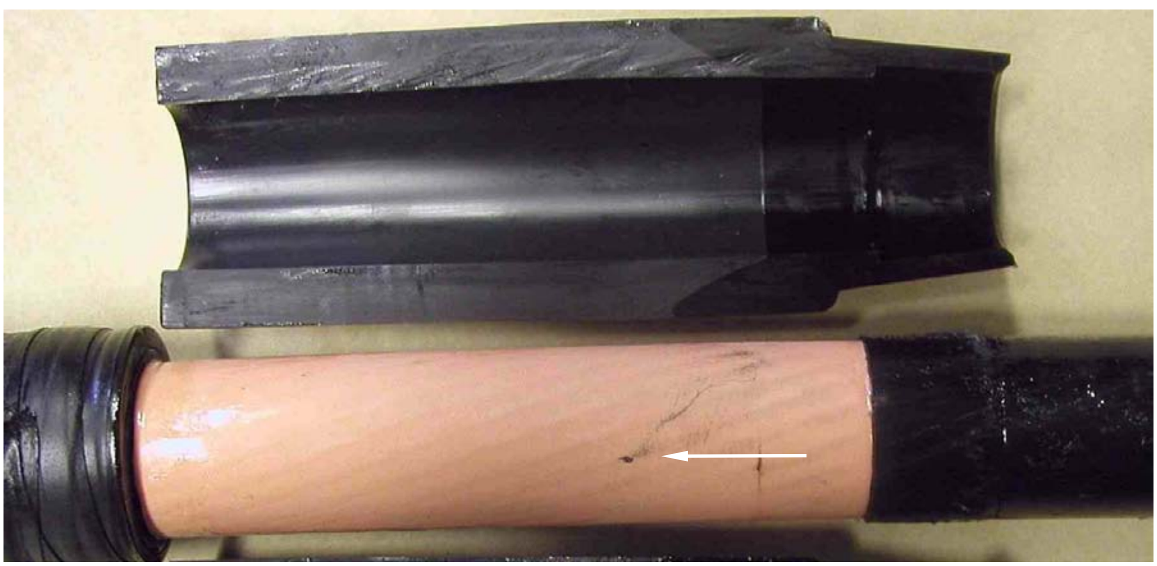

Figure F-4
Joint R3. Radial Failure in the Cable Insulation After Following Longitudinally Along the Interface Between the Insulation of the Cable and the Cable Adapter.

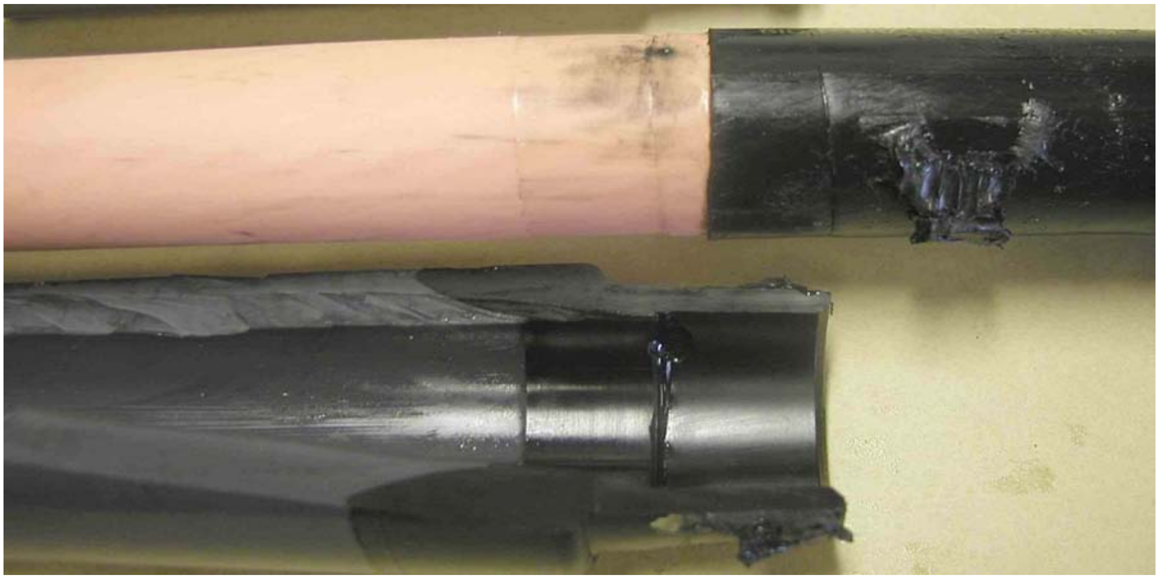

Figure F-5
Joint R6. Radial Failure in Coincidence with the Step in the Semiconducting Layer of the Cable Adapter (About 250 Mils from the Cable Insulation Shield Cut Back).

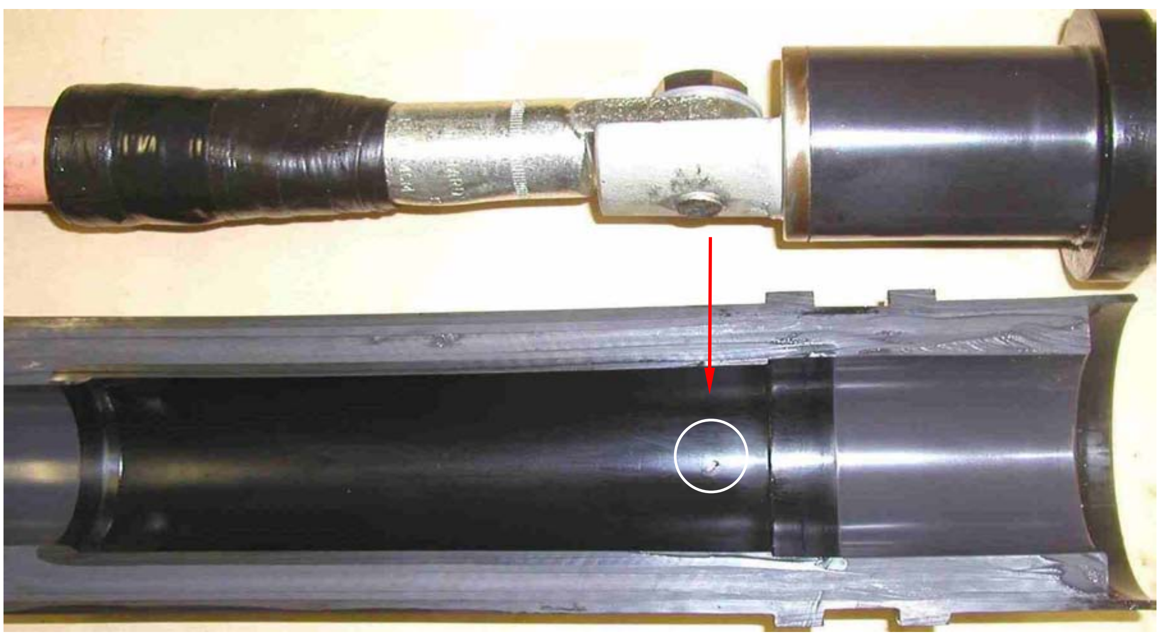

Figure F-6
Joint R1. Eroded Area in the Inner Semiconducting Layer of the Receptacle Housing, at the Location of the Exposed Edge of the Hex-Head Bolt. A Similar Condition was Observed in Several Other Joints.

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