Development of an Improved Extruded Dielectric Cable Rated 230 KV

Final Report

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1.0   ABSTRACT

This report details work performed on developing an Improved 230kV Extruded Solid Dielectric Cable, the techniques of jointing such cables and the testing of terminations suitable for operation at that voltage level.

Difficulties were encountered during manufacture in applying the semi-conducting extruded conductor shield. It was first thought that the difficulty was related to machine alignment but this was found not to be the case. A new higher melt point compound gave good results.

A joint capable of operating at the 230kV level was developed but showed a deficiency under voltage impulse testing while the conductor was at elevated temperature. A reduction in contract scope terminated the effort but it is felt that further work could have corrected the deficiency without appreciable reduction in 60 Hertz capabilities of the joint which were found to be acceptable based on the minimal amount of testing that was performed.

Two terminals rated for 230kV were found to be commercially available from domestic manufacturers. The limited testing performed showed them to be compatible with the cable cross-linked polyethylene insulation and electrically sound under 60 Hertz testing. No direct voltage or impulse voltage testing was performed on the terminations.

A sample circuit, consisting of cable and joint was subjected to impulse voltages at both room temperature and normal conductor operating temperature of 90C. While cable only was able to withstand voltage impulses in excess of the Basic Impulse Level (BIL) at room temperature, it failed at BIL while conductor was heated to 90C. In like manner, a cable and joint circuit was assembled. Similar voltages were impressed at room temperature without incident. The joint failed at 90C conductor temperature.

Cable, joint and termination were assembled in a simulated circuit and subjected to conductor loading to elevate temperature while 60 Hz voltages in excess of normal operating levels were continuously applied.

DEVELOPMENT OF AN IMPROVED

EXTRUDED DIELECTRIC CABLE

2.0   INTRODUCTION

In 1971, the Edison Electric Institute and the Electric Research Council Task Force on Advanced Concepts in Power Transmission engaged the services of the Arthur D. Little Company for the performance of a systems analysis of methods of reducing costs of underground power transmission. Among other major recommendations, was one for an improved extruded dielectric cable which hopefully would extend the operating range to 345kV by 1980 (Reference 2.1). Along with this was the desire to develop these cables to include larger conductor sizes, reliable installation and jointing techniques and economically improved manufacturing techniques that provide excellent control of quality.

In November of 1974, the United States Energy Research and Development Administration, still under the Department of the Interior, issued a request for proposals for an improved extruded solid dielectric cable for operation at 138kV or 230kV. Request for Proposal #TD 75-04 was intended to cover a time span of from twelve to thirty-six months and involve the manufacture of 5000-feet of cable and provide two joints and two terminals. The basic design of the cable as to materials utilized was left largely to the discretion of the individual offeror.

Kaiser Aluminum and Chemical Corporation was a successful offeror, electing to propose a cable rated at 230kV. The basic construction was cross-linked polyethylene insulated cable employing a 1000 kcmil aluminum conductor and cross-linked polyethylene semi-conducting conductor and insulation shields. The basic premise was to operate this cable at significantly higher voltage stresses thereby reducing the thickness of the insulating wall and effecting a commensurate decrease in the use of raw materials. Designs were also proposed which would have conductor sizes to 2500 kcmil and would further decrease the unit maximum operating stresses and set the stage for even higher voltages in ensuing designs.

In June of 1975, a contract was signed between the United States Energy Research and Development Administration and the Kaiser Aluminum and Chemical Corporation to manufacture the required amount of cable necessary to perform basic testing, to develop suitable jointing techniques and to test commercially available terminations. Work was divided into these three major areas of

interest and development progressed to a point where considerable difficulty was encountered in manufacturing a suitable amount of cable capable of operating at the higher stresses proposed. The difficulty was traced to gross conductor shield imperfections and attempts to correct the deficiency through normal manufacturing techniques proved futile. Throughout this period of time, work was continuing on the purchase of acceptable terminating materials and on various techniques of jointing.

The project, as originally conceived, assumed that materials and processes available for production of 138kV cable could be modified to successfully produce 230kV cable. The results of our work at the 2000-feet test cable manufacturing milestone indicated that this assumption was incorrect and that a major modification of materials and/or processes was required.

Early in 1976, another attempt was made at producing cable which represented the modified approach. Instead of using cross-linked polyethylene as the conductor shield a substitution was made for this component using a high melt temperature thermoplastic rubber (TPR) compound. This attempt appeared to be reasonably successful except that the surface of the semi-conducting conductor shield possessed a granular surface which conceivably could lead to further problems at this troublesome interface with the primary insulation. The sole U.S. supplier of this material indicated that they could produce materials which would provide a smoother extruded surface and present greater adhesion to the overlying insulation without sacrificing any of the properties of the compound. An order was placed in April of 1976 for an additional 1000 pounds of the improved materials. In November of 1976, after repeated promises of performance on delivery, the supplier had not yet fulfilled the requirements. The results to that point dictated a complete re-appraisal of the program.

Preliminary tests on the limited quantity of cable produced using the TPR semi-conducting compound were promising. However, it was considered desirable to conduct a comprehensive survey of materials including the new promising TPR semi-conducting compound prior to manufacture of the cable for which such a comprehensive evaluation program was contemplated. Further, it would have to be established that the TPR semi-conducting material could be made available in development and production quantities.

A review of the results at the test quantity manufacturing milestone led to the conclusion that the project should be reduced in scope to the work completed to that point except that additional testing of the available cable made with the TPR semi-conducting conductor shield should be carried out.

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Considerable investigations were made in the area of splicing. There were five planned approaches encompassing all phases of presently available technology. The largest gains were made in the areas of hand-applied taped joints since this appeared to be the category where the greatest amount of technology was available. The field vulcanized type of joint was worked on and progress in this category was slower since the available information was largely restricted to voltage classes generally considered as medium voltages requiring a larger field of knowledge to be developed. Alternate jointing concepts were also planned as part of the initial program but time did not permit a significant effort along these lines. Some work was done in developing a uniform computer program which would serve as an aid in the design of joints taking into consideration the selection and compatibility of any and all components which go into the construction of a joint.

A program was started which was designed to determine the capabilities of connectors used in cable joints. The products of three different manufacturers were tested prior to termination of the work.

Terminations were also investigated with emphasis being placed on compatibility of materials and electrical integrity. Since there are a limited number of domestic terminal manufacturers capable of supplying 230kV terminals, the approach was to search out those suppliers with presently available components. In addition, a close watch was kept on developments in the field to assure that anything new would be considered for acceptability and tested if the development appeared feasible.

In the following sections, work completed on joint development and test, termination testing, and cable design and testing will be discussed.

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2.1   REFERENCES TO SECTION 2.0

1.   UNDERGROUND POWER TRANSMISSION,
      Arthur D. Little, Inc., Contract No. 14-01-0001-1407,
      ERC Publication 1-72, October 1971, Page 4-15.

3.0   PROGRAM OBJECTIVES

3.1   DEVELOPMENT OF IMPROVED EXTRUDED SOLID DIELECTRIC CABLE

The Principal Objective was to develop an improved extruded dielectric cable system which represented a significant improvement in the current State-of-the-Art and to verify its performance for use in electric utility systems at 230kV.

3.2   DEVELOPMENT OF 230kV JOINT

Another objective was the development of a joint suitable for operation at 230kV that would be compatible with the improved extruded solid dielectric cable. At least one, and more if possible, methods of jointing were to be developed and performance verified in the laboratory for use on cables in electric utility systems at 230kV.

3.3   TESTING OF SUITABLE TERMINATIONS

A third objective was to test terminations to meet IEEE Standard No. 48, for Potheads (REFERENCE 3.1) that are commercially available and are compatible with the improved extruded dielectric cable being developed.

3.4   SIMULATED TESTING UNDER ACCELERATED CONDITIONS

The final objective was to set up and test, in a circuit designed to simulate an actual installation used in electric utility systems, the manufactured cable, a joint, and two terminations. The intent was to verify system integrity and performance of the 230kV system employing extruded solid dielectric cable.

3.5 REFERENCES TO SECTION 3.0

1. IEEE Standard Test Procedures And Requirements For High-Voltage Alternating Current Cable Terminations

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4.0   CIRCUIT DESIGN CONCEPTS

4.1   STATEMENT AND DISCUSSION OF THE REQUIREMENTS

A 230kV cable system requires logical designs of cables, joints, and terminators which will provide long life at low cost. Practices involving the manufacture of cable must ensure that high quality cable and components are produced which are capable of exploiting newer designs without excessive safety factors. For this purpose, it became mandatory that cables and associated components would be required to operate at higher voltage stresses in order to control the requirement for thicker insulating mediums and reduce thermal paths so that normal and emergency operating temperatures could be maintained. In the case of extruded solid dielectric cable systems these temperatures are generally accepted by the industry as being 90 C and 130 C respectively.

4.1.1   CABLE DESIGN CONCEPTS

Limiting voltage stresses in cable designs were based on a 60 Hertz average stress of around 90 to 100 volts per mil and a maximum stress of 135 to 175 volts per mil (REFERENCE 4.5). Previous work on 138kV systems had shown that cables designed to utilize these values of stress were capable of operating for sustained periods of time, at multiples of their design values, without evidence of system deterioration (REFERENCE 4.6). It followed therefore, that designs employing higher stresses could be utilized. Experience indicated that an improvement in the State-of-the-Art could be achieved by increasing design stress levels beyond those generally accepted. Within that context, the proposal was made to manufacture and test a 230kV cable having a 1000 kcmil aluminum conductor and a 1050 mil wall of natural unfilled cross-linked polyethylene insulation. For that design, the maximum stress at the surface of the semi-conducting conductor shield would be 210 volts per mil and the average stress across the insulation would be 127 volts per mil.

Consideration was also given to cables having conductor sizes of 1500, 2000 and 2500 kcmil. The increased conductor diameter for these larger conductors would reduce the maximum stress compared to the 210 volt per mil level of the initial design assuming a constant insulation wall thickness. As an example, the 2500 kcmil conductor would operate at a maximum stress of 183 volts per mil. Any of those conductor sizes would operate at maximum stresses which were lower than those sustained in prior accelerated test experiments.

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4.1.2   JOINT DESIGN CONCEPTS

As in design considerations for cable, attention was given to voltage stresses in a number of critical areas within the joint. Considerable experimentation with joints for 138kV solid dielectric insulated cables had been done and analysis of test results for hand-applied EPR taped joints showed that the creepage distance, consisting of the prepared portion of the cable, could be reduced to provide a smaller, more economical joint. Original designs required a creepage distance calculated on the basis of 2.75kV per inch. Final designs permitted a creepage distance of 5kV per inch. Accelerated voltage and thermal testing over sustained periods led to the conclusion that, as in the case for cables, properly constructed joints could be designed to operate at even higher stresses providing a basis for the feasibility of a joint design capable of operating at 230kV without sacrificing thermal operating requirements of 90C normal and 130C emergency conductor temperatures. The tapes used for that joint were made with an ethylene-propylene-rubber (EPR) compound and thermal tests showed that temperatures at the conductor in the joint were significantly higher than temperatures at the conductor in the cable. For example, when the conductor attained a temperature of 130 C the joint attained a temperature of 170C. Despite this high temperature, results were always such that the joints operated successfully for the entire test programs. In the case of work done on the taped joint under this contact, the program progressed through all phases of test, including installation on the 230kV cable and a moderate amount of voltage testing.

The program outlined called for investigations into other jointing techniques. These included field vulcanizing of joints with cross-linked polyethylene materials and with EPR based materials. For these portions of the investigation a substantial amount of effort was expended but it did not lead to building or testing of joints at the 230kV voltage level. There were some significant results. Our work at making vulcanized joints rated at 69kV on a 500 kcmil conductor led us to conclude, after visual analysis, that this was probably the limit which could be attained without a pressurized vessel to control void formation. Work was initiated on the design of that pressure vessel which would allow curing of the joints under constant pressure in a dry nitrogen atmosphere. The use of heat shrinkable semi-conducting tubing, in lieu of semi-conducting vulcanizable tapes for use as conductor shielding also gave good results and appeared to be a significant development. Work was also done on the use of tapes made of an ethylene-propylene rubber compound and field vulcanized. Another form of field vulcanized joint, the Hotsplicer technique, was considered as a part of the overall program (REFERENCE 4.1). A 138kV splice was installed and   accumulated accelerated voltage life. The Hotsplice organization, a division of the Hexcel Corporation, has not yet developed an insulating material which they feel is satisfactory for use at 230kV voltages. As a result, our effort was confined to the work at the 138kV level.

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4.1.3   230kV TERMINATORS

The approach for this undertaking as it relates to termin-
ators was to assess the market for commercially available 230kV terminators.
230kV terminators, of a different design, manufactured by the G&W Electric
Specialty Company, Blue Island, Illinois, have been used for years in our lab-
oratory (REFERENCE 4.2). This terminator was designed for oil-filled cables
and was adapted for use on extruded solid dielectric cables. That work was
primarily in connection with impulse and steady-state over-voltage testing of
69kV, 115kV, and 138kV cables. The paper-oil approach was not totally suitable
for use on extruded cross-linked polyethylene cables because of the larger thermal
expansion characteristic of the polyethylene cable. A pre-assembled slip-on
type terminator was developed for use on systems through 138kV.   G&W Electric
Specialty Company was confident that the design could be modified to be adapted
for use at 230kV. In the end, the approach was to purchase the necessary stress
control materials to assembly a G&W 230kV terminator in the laboratory.

The Joslyn Manufacturing Corporation, Chicago, Illinois,
(REFERENCE 4.3),   was another manufacturer of terminators that were suitable
for use through 138kV voltage classes and, they too, were confident that a de-
sign could be made available for evaluation as part of the program. In the case
of the Joslyn design, no laboratory porcelain was available to use so a completely
assembled unit was purchased on the basis that it could be returned to the manu-
facturer, after testing, to be refurbished and forwarded to ERDA as partial ful-
fillment of contract requirements. We were assured of the opportunity to evaluate
designs of at least two manufacturers as part of the program.

It was further envisioned that a periodic review of new
available designs would be made and a program of test would be worked into our
program as situations demanded. Along this line, a design developed by the
Raychem Corporation, Menlo Park, California (REFERENCE 4.4), was tested with
good results as part of a test sequence established for proving out field vulcanized
cross-linked polyethylene joints at the 69kV voltage level. This type of terminal
was experimental above 69kV and no further work was performed within the scope
of this program.

1.   HEXCEL CORPORATION
      Hotsplicer Division
      Electrical Products Department
      5131 Santa Fe Street
      San Diego, California 92109

2.   G & W ELECTRIC SPECIALTY COMPANY
      3500 West 127th Street
      Blue Island, Illinois 60406

3.   JOSLYN MANUFACTURING & SUPPLY COMPANY
      155 North Wacker Drive
      Chicago, Illinois 60638

4.   RAYCHEM CORPORATION
      300 Constitution Drive
      Menlo Park, California 94025

5.   John P. Lozes, Jr., "Special Report on Development
      of 138kV Cable Systems For Tests EEI Waltz Mill
      Station", IEEE Transactions, Power Apparatus and
      Systems, Volume PAS 91, page 1422, Table II,
      1972.

6.   Leo D. Blais, "Development and Installation of 138kV
      Cable For Tests at EEI Waltz Mill Station: Cable 24",
      IEEE Transactions, Power Apparatus and Systems,
      Volume PAS 91, pp 1448-1456, 1972.

5.0 EXTRUDED SOLID DIELECTRIC CABLE FOR 230kV OPERATION

Three attempts were made at manufacturing the cable intended for use at the 230kV level. The first two attempts ended in failure, the cause for which was attributed to severe conductor shield disturbances in the extruded semi-conducting layer. The third attempt proved successful by changing the type of material used for that application.

5.1 INITIAL MANUFACTURING RUN

In the first manufacturing run, 2365 feet of cable, in three lengths of 1260, 575, and 530 feet, was manufactured and brought through final manufacturing processes and final electrical test. The cable had the following geometry:

Component	Thickness Added	Diameter Added	Cumulative Diameter
1000 kcmil Die-Sized Aluminum Conductor	---	1.117	1.117
.008" Nylon Semi-Conducting Half-Lapped Tape	.014	.028	1.145
Extruded Semi-Conducting Conductor Shielding	.060	.120	1.265
Natural Unfilled Cross-Linked Polyethylene Insulation	1.065	2.130	3.395
Extruded Semi-Conducting Insulation Shield	.060	.120	3.515
2- .005" Bare Copper Tapes	.013	.026	3.541
Black PVC External Sheath	.151	.302	3.843

All dimensions are given in inches.

5.2   MATERIALS

5.2.1   Material used for conductor shielding and insulation shielding was manufactured by Union Carbide Corporation and is known in the trade as compound numbers HFDB-0580 and HFDB-0590, both of which are semi-conducting vulcanizable polyolefin copolymer compounds (REFERENCE 5.1).

5.2.2   Material used for insulation was manufactured by Union Carbide Corporation and is known in the trade as compound number HFDB-4201, which is a natural unfilled vulcanizable polyethylene compound.

5.2.3   The conductor was made from aluminum made by Kaiser Aluminum's Ravenswood, West Virginia Plant, drawn and stranded at the Portsmouth, Rhode Island Facility, having a conductivity of 61% International Annealed Copper Standard (IACS). (REFERENCE 5.2)

5.2.4   The cable construction, as manufactured, had a 1000 kcmil aluminum conductor and an insulation wall of 1.050 inches. A cross-sectional drawing of the cable is shown in Figure 5.1.

The two lengths measuring 575 feet and 530 feet were subjected to a 250kV ac Withstand Test of 5 minute duration and both successfully withstood the test. The 530 foot length was further subjected to a dc Test of 730kV dc and suffered four successive failures at, or slightly below the desired potential level. It was then decided to abandon that length of cable since any future work would be viewed with suspicion, having successfully withstood the desired ac potential but constantly failing the desired dc potential level. Simultaneously, the length measuring 1260 feet was subjected to an ac voltage of 250kV and it failed after 2.5 minutes into the test. After removal of the failed section, the remaining portions were tested and both failed either at or slightly below the 250kV ac level.

At that point, the decision was made to abandon any future attempts at testing and to re-schedule a new production run of 2000 feet.

All failed sections were examined microscopically and all failures were attributed to the conductor shield imperfections noted. It was anticipated that corrections for the defects would be achieved through modifications in the manufacturing processes and no changes in the basic design were being considered.

5.3   SECOND MANUFACTURING RUN

   The second manufacturing run of cable was attempted in December of 1975. Although it was known that the causes of failure in the first cable manu-factured were attributable to imperfections in the conductor shield, there was not a full appreciation of the existing problem at that time. The technique of analysis employed was in cutting a short sample of the cable into a continuous helix, with adjacent wafers approximately .025" thick, and examining the wafers for degree of conductor shield disturbances. This technique provided an appreciation of the degree of amplitude in the radial direction but failed to consider the axial dimen-sion. When the practice was started of looking at this interface with the sections cut longitudinally rather than in helical wafers, it revealed streamers of semi-conducting material that were broken away from the main body of the extruded conductor shield and separated from it by a thin layer of insulation. Under further microscopic examination, it was found that the surface of the extruded semi-conducting layer was not smooth. There appeared to be a gentle waviness with some kind of regular periodicity. These high spots were causing excessive stresses within the primary insulation wall and were considered responsible for the voltage failures.

   A review of the manufacturing process with respect to machine speeds, compound, and extruder temperatures indicated that the most likely cause for the problem was related to the flow of compound through the extruder head. A small modification was made to the cable design. The thickness of the extruded semi-conducting conductor shield was increased to .100 inches from its original thick-ness of .060". It was felt that this increased wall would provide a more stable process operation by allowing higher operating speeds in the tandem extruder being used to apply the layer. In addition, a considerable number of measurements were made on the extruder system in the belief that this also might be contributing to the faulty condition. Although some minor adjustments were made, it was concluded that the major portion of the problem did not lie in the machine itself but rather in the process. Nevertheless, prior to the start of the second run, all possible pre-cautions were taken to assure that the root cause of the problem did not exist in the extruder system itself but rather in the process. Parameters such as movements of one portion of the system with respect to a baseline were carefully examined during the start-up operation after the extruder system components had been optically aligned prior to start-up. The start-up operation confirmed the fact that movement in any direction was minimal and that if the strand shield problem still existed that it would be due to other causes. The condition of the semi-conducting strand shield was excellent after application with only very minute specks appearing on the sur-face. It was felt that this would be a totally acceptable condition if the surface were to remain in that state. There appeared to be no rubbing or chafing on the main ex-truder head tooling and it seemed as though that run would achieve a fair degree of success. After approximately 500 feet had been manufactured, that length was cut.

The insulation/conductor shield interface appeared significantly rougher than desired. The run was cut again after 1000 feet and also after 1500 feet had been made and the surface condition at the interface seemed to be getting progressively worse. At that point it was decided to abort the effort.

Before securing the machine, some work was done to see if it could be determined if the conductor shield deformation was taking place as a result of the conductor rubbing on the extruder tooling as it passed through the head. By shutting down the main extruder and running the tandem extruder so that only the conductor semi-conducting layer was being applied, the cable was drastically buffeted within the main extruder head. It was found that the applied layer could withstand significant movement without experiencing damage to the degree witnessed in the finished product. This led to the conclusion that some other phenomenon was being experienced and that the cause of the problem would have to be resolved by other means.

5.3.1 ELECTRICAL TESTING

A systematic investigation was made of the condition of the semi-conducting conductor shield considering both the radial and axial dimensions. The same general condition was found as was observed in samples of the first cable run. An 80 foot length of the cable was assembled for corona testing with the following results.

TABLE 5.1 PARTIAL DISCHARGE VALUES OBTAINED ON SECTION OF 230kV CABLE 80 FEET IN LENGTH. SECOND PRODUCTION RUN.

Applied Voltage (kV)	Percent of Rated Voltage (%)	Partial Discharge (pC) *	Remarks
50	38	NM	
70	53	NM	
80	60	NM	
86	65	13	Ignition Voltage
82	62	NM	Extinction Voltage
100	76	13	
133	100	20	

* The calibration pulse (equal to 5 pico-coulombs per inch) is a reference against which any discernible discharges are compared. Where no visible discharges are evident, the letters NM (not-measurable) are shown. Measurable discharges are denoted by an actual numerical value.

The high discharge values tended to corroborate our findings of the ex- istence of defects within the cable system. This was further substantiated when the section of eighty feet in length, was subjected to an ac voltage of 250kV and failed after 2.5 minutes. Analysis of the faulted section revealed the severe strand shield disturbance and projections of semi-conducting materials from the strand shield into the main body of the insulation.

5.3.1.1   VISUAL ANALYSIS IN THE AXIAL DIMENSION

A section of the cable, two feet long, was next set up in a lathe and most of the main insulation was machined away from the section about 10 inches long. The remaining material was machined off in .005" layers until the highest point in the extruded semi-conducting conductor shield was exposed. Layers were then removed in thicknesses of .0025" so that a reasonably good idea of the degree of roughness could be formed by gradually exposing the black semi- conducting compound and contrasting it against the white color of the main in- sulation and by noting the thickness of white insulation remaining between the machined surface and the constructed interface.

Samples of the material were then immersed in hot silicone oil and the insulation allowed to stabilize at the 150 C temperature of the hot oil. At this temperature, the insulation becomes transparent while still remaining intact. After examining several samples in this manner, two conditions were found to exist. The first was a longitudinal abrasion largely restricted to a section of the circum- ference of the cable. The second condition observed was a rippled and folded effect that completely encircled the conductor shield. It was first believed that the former condition was caused by the cable rubbing on the extruder tooling while the second condition was caused by the hot semi-conducting compound being softened as it transited the head in the main extruder and being moved as it interfaced with the main insulation entry into the head. As mentioned earlier, testing was per- formed at the conclusion of production run number two which seemed to exclude the possibility of damage due to rubbing or chafing of the conductor against the extruder tooling. It is now felt that both conditions observed were the result of a single occurrence related to thermal softening and relative velocities of the materials as they interfaced in the extruder head.

Our analysis finally led us to conclude that a higher deformation- resistant material was required for the semi-conducting conductor shield. In February of 1976, a third production run of 2000 feet of cable was started. A change was made from Union Carbide 0590 compound to Uniroyal #TPR-065 com- pound for the conductor shield material (REFERENCE 5.3).

5.4   THIRD MANUFACTURING RUN

The same precautions were taken in this manufacturing run as for the #2

run. It was necessary to make several modifications to the tandem extruder material delivery system to deliver the TPR compound to the tandem extruder head. The extrudability of the TPR compound was first tested and found to be acceptable. Special precautions were required since head temperatures were in the range of 232 C, significantly higher than temperatures used for extruding polyethylene. The surface of the semi-conducting TPR compound was shiny and relatively uniform but a graininess was noted which was improved but not totally eliminated by a minor change in the temperature profile of the extruder. The production run was then started and closely monitored. When the conductor core exited the vulcanizing tube, samples were cut for examination of the interface between the extruded semi-conducting conductor shield and the insulation. Observation of the conductor shield/insulation interface, after this change was made, revealed a substantial improvement of the surfaces. In essence, the surface condition of the extruded semi-conducting materials exiting the main extruder head was substantially the same condition as when entering the head. The problem of interfacial disturbances which caused troublesome interfacial undulations, streamers, and protrusions to occur was no longer present. Since new materials had been used, it was deemed prudent to investigate the interfacial adhesion between the semi-conducting and insulating materials. A firmly bonded surface is important to avoid the possibility of gaseous voids forming which in turn could produce discharges and possibly destroy the cable under operating conditions.

The first checks of interfacial bond revealed that little or no bond existed at the interface. The cable core at this time, however, possessed little or no cure since it was early in the production run. When samples were taken from a section of cable that had received a full time period under the specified steam pressure of 150 pounds per square inch, it was found to possess a measurable bond. The steam pressure was then increased to 250 pounds per square inch and measurements of adhesion were found to be in the same general range. In all, approximately seven hundred feet of cable was run, 500 at the 150 pounds per square inch pressure and 200 at the 250 pounds per square inch pressure. After the run of cable was completed samples were taken at various points in the run and the interfacial bond was again checked and found to be at a tolerable level. Since no prior data was available as to what constitutes a tolerable level it was felt that measurements would be acceptable if the force exceeded 10 pounds per inch of width. In all, about 400 feet of cable was finally selected, in one continuous length for processing through the finishing manufacturing process. The balance of the manufacturing run was scrapped. The large amount of waste was a result of the numerous cuts made for examinations and tests. Concentricity of the separate components of the cable core was found to be very good. Values of the forces measured of the interfacial adhesion are given in TABLE 5.2. The procedure used for testing is given in APPENDIX 5.1.

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TABLE 5.2   ADHESIVE STRENGTH AT INTERFACE OF CONDUCTOR SEMI-
            CONDUCTING SHIELD AND PRIMARY INSULATION
            AT ROOM TEMPERATURE - 230kV CABLE.
            (CABLE SAMPLES FROM PRODUCTION RUN #3)

Sample No.	Extrusion Pressure (psi)	Bond (#/in.)	Remarks
1	150	28 - 31	
2	150	22 - 26	
3	150	15 - 18	
4	150	16 - 22	
5	150	12 - 20	
6	150	21 - 26	
7	150	22 - 30	
8	150	28 - 32	
1A	250	20	Sample Broke
1B	250	10 - 16	
2	250	24 - 32	
3	250	18 - 24	
4	250	17 - 21	
5	250	22 - 25	Sample Broke
6A	250	18 - 24	Sample Broke
6B	250	17 - 23	
7A	250	14 - 19	
7B	250	28 - 35	

        Being satisfied that sufficient bond existed at the interface, it was
planned to proceed with electrical testing of a short sample approximately 80 feet
in length. The sample successfully passed a corona level test achieving a reading
of 3 pico-coulombs at 200kV with a circuit sensitivity of 5 pico-coulombs per inch
of deflection on the Cathode Ray tube of the corona detector. The maximum allow-
able discharge was 5 pico-coulombs at 200kV (150% operating voltage). The corona
level test was followed immediately by a 5 minute ac voltage Withstand Test at
230kV which was successfully passed. Finally, the 80 foot section was subjected
to a dc voltage Withstand Test of 655kV positive polarity for 15 minutes and it met
this requirement. Additional dc testing was performed to voltages as high as 750kV
dc for sustained periods and it successfully withstood these test levels.

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The remaining section of cable, approximately 320 feet in length, was then completed through manufacturing and subjected to the production proof tests outlined above. The cable satisfactorily met all electrical tests. These tests are summarized in TABLE 5.3, which gives the test results of all tests attempted on the three production runs of cable for comparative purposes. A copy of the test report is included in FIGURE 5.2, along with a copy of the X-Y recording for the partial discharge test, FIGURE 5.3.

Photographs showing the conditions existing at the semi-conducting conductor shield/insulation interface for each production run are given in APPENDIX 5.2. Photos are also shown of the breakdown paths for the first two production runs.

5.5 REFERENCES TO SECTION 5.0

1. UNION CARBIDE CORPORATION
   River Road
   Bound Brook, New Jersey 08805

2. NBS HANDBOOK NO. 100
   Copper Wire Tables, 1966
   National Bureau of Standards
   Washington, D. C.

3. UNIROYAL CHEMICAL
   Division of Uniroyal Inc.
   Elm Street
   Naugatuck, Conn. 06770

TABLE 5.3   ELECTRICAL TESTS PERFORMED ON 230kV CABLE
            HAVING 1050 MIL WALL CROSS-LINKED POLYETHY-
            LENE INSULATION AND 1000 kcmil ALUMINUM
            CONDUCTOR

Production Run No.	Sample Length Feet	Voltage Withstand		Partial Discharge pC	REMARKS
		AC Test kV (Time) **	DC Test kV (Time)**		
1	1260	250 (2.5)		Not Tested	Failed AC
1	575	250 (5.0)		Not Tested	Passed AC
1	530	250 (5.0)	730 (–) *	Not Tested	Passed AC
					Failed AC
2	80	250 (2.5)	---	20 pC @133kV	Failed AC
2	1400	Not Tested	Not Tested	Not Tested	
3	80	250 (5.0)	655 (75) 700 (60) 750 (60) 750 (300) 750 (180)	3 pC @ 200kV	Passed All Factory Tests (Total Hours @ 750kV dc = 10 Hours)
3	320	250 (5.0)	655 (75)	5 pC @ 200kV	Passed All Factory Tests (One Hr. Additional @ 655kV)

*   Four successive failures at or below 730 kV dc.

**   All times in this column are given in minutes.

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5. Semi-Conducting
   Insulation Shield

8. Jacket

4. Insulation

1. Conductor

6 & 7. Metal Tape Shield

2. Semi-Conducting Tape

3. Extruded Semi-Conducting Compound
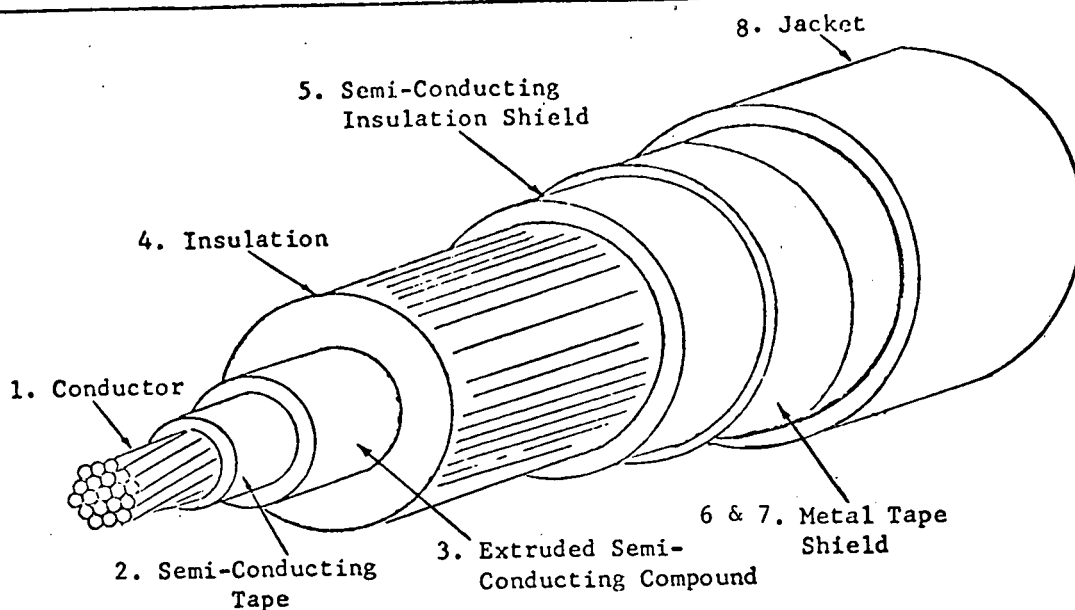
CABLE DESCRIPTION

Nominal Diameter Over

1.   __61__ Strands __0.1280"__ Conductors, 1000 kcmil Aluminum . . . Conductor   __1.117"__

2.   Semi-Conducting Butyl/Nylon Strand Shielding Tape

3.   __.060"__ Average Wall Semi-Conducting Cross-Linked
     Polyethylene Strand Shielding - Kaiser 169   . . . Strand Shield   __1.270"__

4.   __1.050"__ Average Wall Cross-Linked Polyethylene
     Insulation - Kaiser 160   . . . Insulation   __3.395"__

5.   __.060"__ Average Wall Semi-Conducting Cross-Linked
     Polyethylene Insulation Shield - Kaiser 169   . . . Ins. Shield   __3.515"__

6.   1st __.005"__   Bare Copper Tape - Spirally Wrapped   . . . 1st Tape   __3.530"__

7.   2nd __.005"__   Bare Copper Tape - Spirally Wrapped and
     applied in the opposite Direction   . . . 2nd Tape   __3.540"__

8.   __0.140"__ Average Wall PVC Kaiser 2340   . . . Jacket   __3.840"__

Approximate Cable Wgt. - Lbs./Ft.   __6.24__

Figure 5.1   1000 kcmil Die-Sized Aluminum

230kV Cable with Standard

Shield Design

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KAISER ALUMINUM & CHEMICAL CORPORATION
PORTSMOUTH, RHODE ISLAND

FIGURE 5.2

ELECTRICAL TEST REPORT

F.O. 668-789

Tested Length	Test No.	Withstand Voltage Passed	Corona Requirements		Required Megohms/1000'
		250,000 AC	200,000V 5pC		19,785
		5 Min.			
320'	1- 46896	655,000 DC			
		15 Min.			
		Passed			
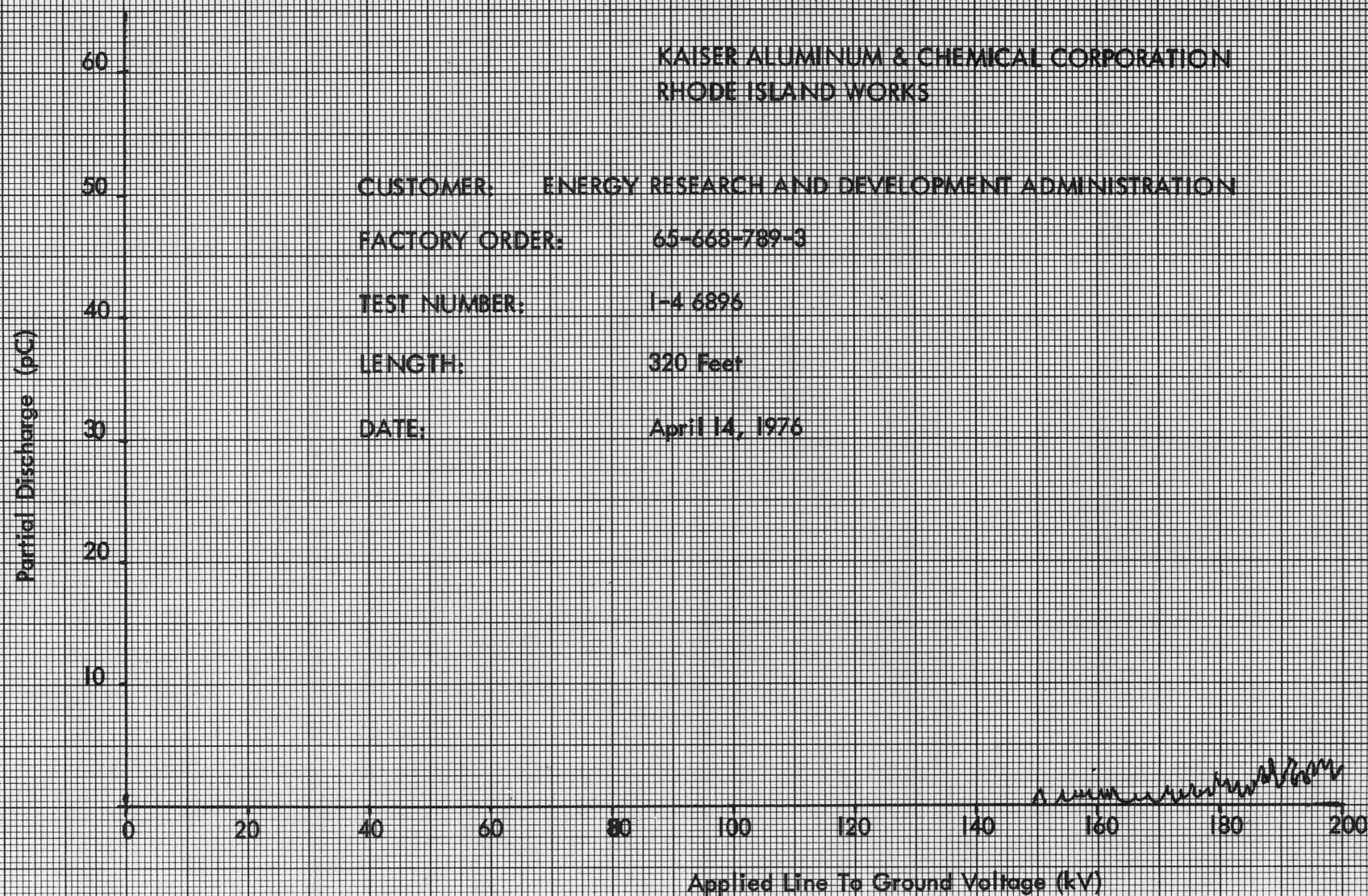
FIGURE 5.3   X-Y RECORDING OF PARTIAL DISCHARGE VS. APPLIED VOLTAGE - 230kV CROSS-LINKED POLYETHYLENE CABLE WITH 1000 kcmil ALUMINUM CONDUCTOR.

TEST PROCEDURE FOR EVALUATING INTER-FACIAL ADHESION

OF TWO ADJACENT LAYERS

(1)   USE A CABLE SAMPLE 12-15 INCHES LONG. PRESS THE CONDUCTOR
      OUT OF THE CABLE SAMPLE AND DISCARD.

(2)   CUT THE CABLE SAMPLE IN HALF, LENGTHWISE, EXPOSING THE SEMI-
      CONDUCTING MATERIAL OF THE CONDUCTOR SHIELD.

(3)   MAKE TWO CUTS, HALF-INCH APART, IN THE SEMI-CONDUCTING MATERIAL
      LONGITUDINALLY AND VERTICALLY DOWN TO THE INSULATION.

(4)   FOR ATTACHMENT TO A MEASURING DEVICE, REMOVE APPROXIMATELY
      TWO INCHES OF THE 1/2 INCH STRIP FROM EACH END OF THE CABLE
      BY PULLING IT AT A 90° ANGLE AWAY FROM THE CABLE.

(5)   MEASURE THE PULLING TENSION IN POUNDS BY INCREASING THE FORCE
      ON THE STRIP UNTIL THE STRIP SEPARATES FROM THE INSULATION AT
      A SPEED OF APPROXIMATELY 1/2 INCH PER SECOND. PERFORM TWO
      TESTS AT EACH END OF THE CABLE 180° APART.

(6)   TERMINATE EACH TEST AT CENTER OF CABLE SAMPLE. RECORD MINIMUM
      AND MAXIMUM PULLING TENSIONS MEASURED AT THE SPECIFIED PULLING
      SPEED.

PHOTOGRAPHS OF FAILED SECTIONS SHOWING CONDUCTOR SHIELD
DISTURBANCES
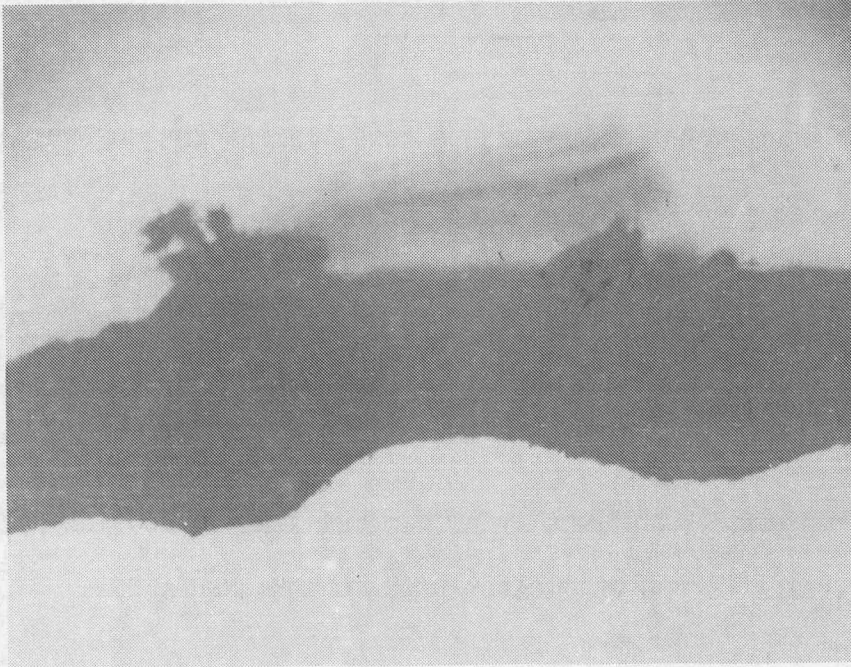
PHOTO 1

RUN #1: CONDUCTOR
SHIELD DISTURBANCE
AT INSULATION
INTERFACE.

(8x Magnification)
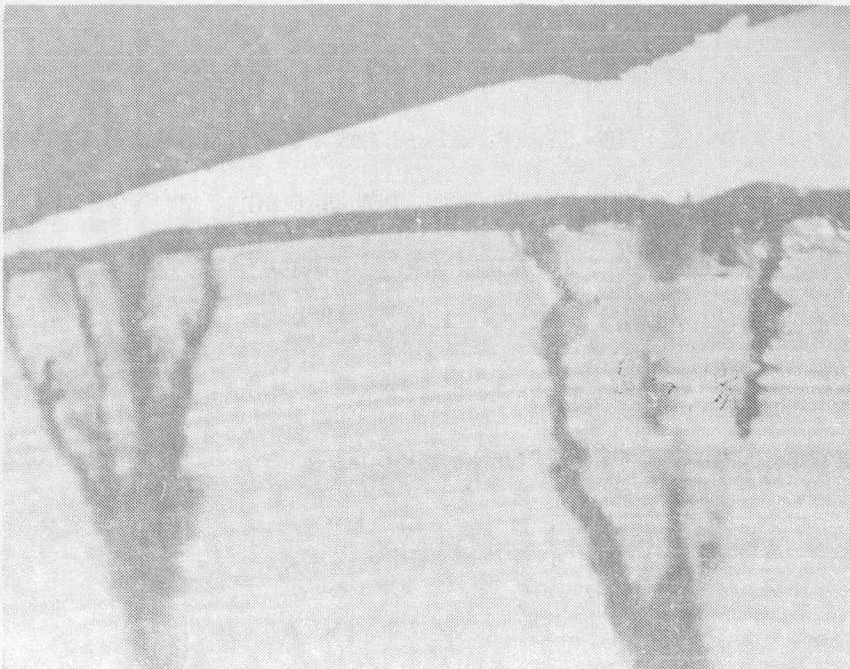
PHOTO 2

RUN #1: TREEING
CAUSED BY DC PROOF
TESTING SHOWN AT
INSULATION SHIELD/
INSULATION INTER-
FACE.
DIRECTION OF PROPA-
GATION IS OUTWARD.

(8x Magnification)
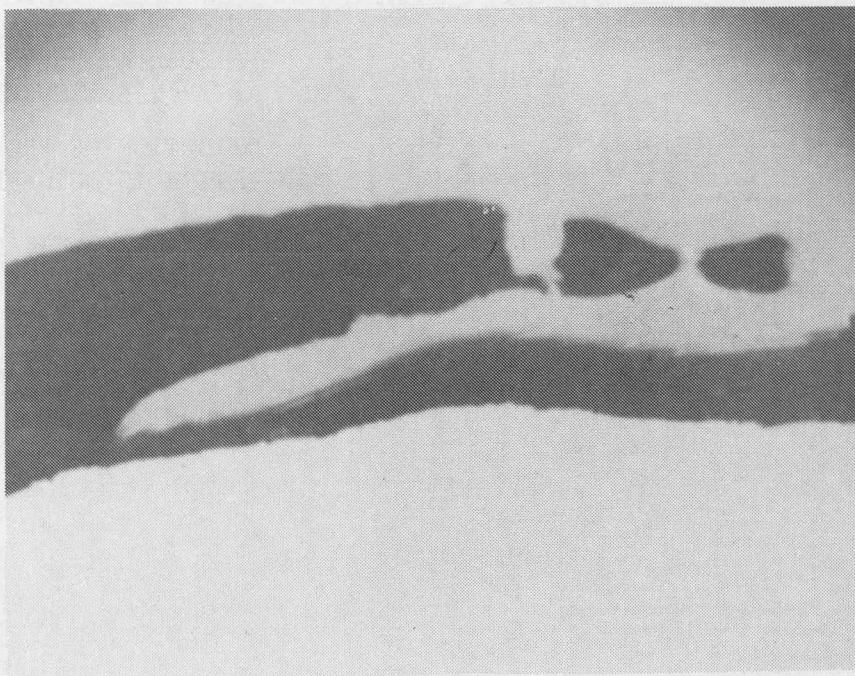
PHOTO #3

RUN #2: CONDUCTOR
SHIELD DISTURBANCES
SHOWING MIGRATION
OF INSULATION
BETWEEN SURFACES
OF SEMI-CONDUCTING
MATERIALS.
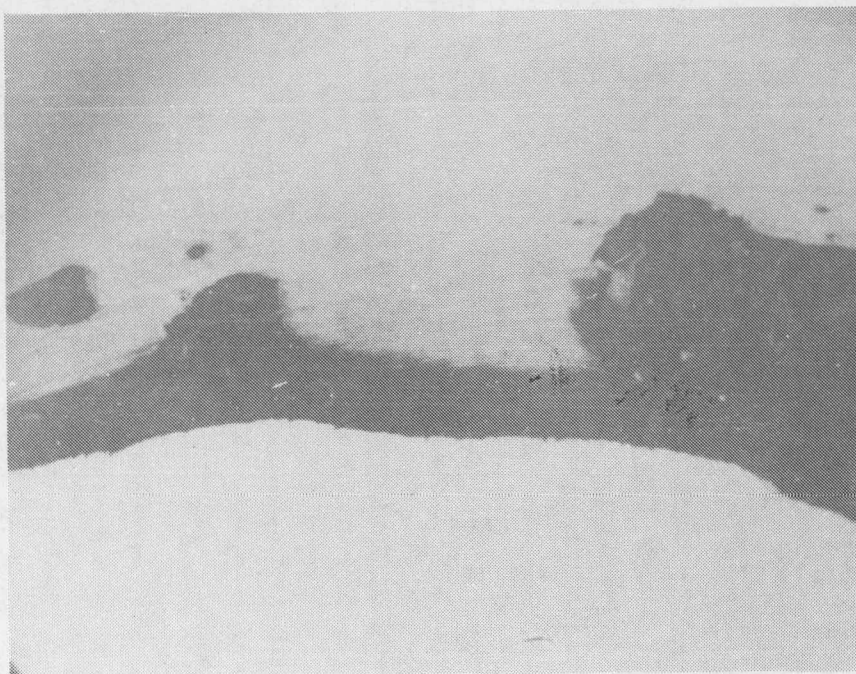
(8x Magnification)

PHOTO #4

RUN #2: CONDUCTOR
SHIELD DISTURBANCES
SHOWING LOOSE
PARTICLES OF SEMI-
CONDUCTING
MATERIALS.

(8x Magnification)
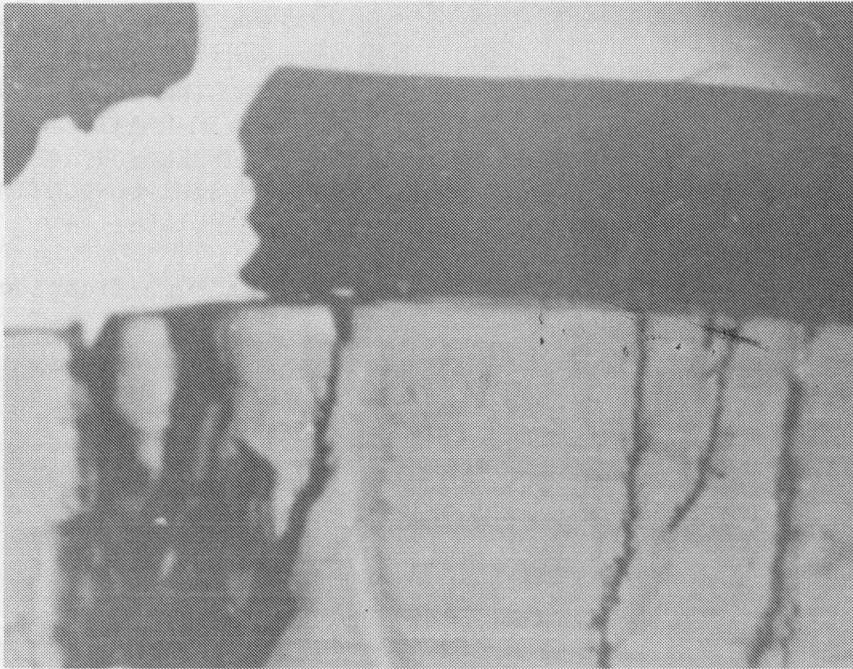
PHOTO #5

RUN #2: AC VOLTAGE
FAILURE AT 250kV
AFTER 2.5 MINUTES.

DIRECTION OF PROPA-
GATION IS OUTWARD.

INSULATION SHIELD/
INSULATION INTER-
FACE SHOWN.

(8x Magnification)
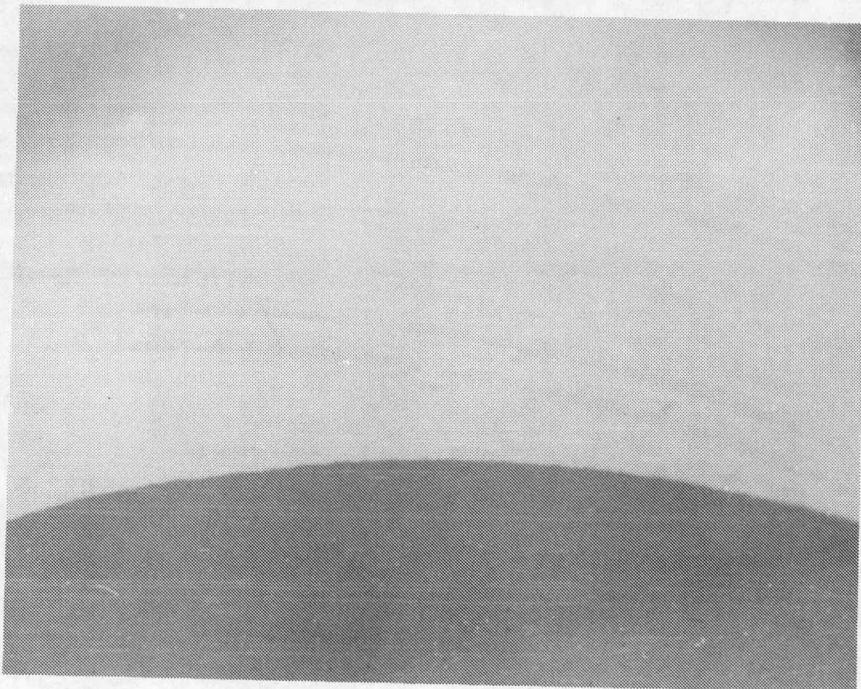
PHOTO #6

RUN #3: CONDUCTOR
SHIELD/INSULATION
INTERFACE OF
TYPICAL SECTION.
CABLE PASSED ALL
PRODUCTION PROOF
TESTS.

(8x Magnification)

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6.0 VOLTAGE ENDURANCE AND CURRENT CYCLING TESTS ON 230kV EXTRUDED SOLID DIELECTRIC CABLE

Upon completion of preliminary factory tests on the approximately 400 feet of completed cable, and after receipt of the terminating components, work began on the preparation of a cable sample for long-term voltage endurance and current cycling. This sample was 70 feet long, which included an allowance of 10 feet for each terminal end, resulting in an active test length of approximately 50 feet.

6.1 CABLE PREPARATION

Actual cable end preparation involved the removal of the PVC jacket, copper shielding tapes and extruded semi-conducting insulation shield. Stripping dimensions for each component were in accordance with the specifications provided by the terminal suppliers. Considerable care was exercised in the removal of the insulation shield to insure that no physical damage was caused to the insulation. As is our practice, the utilization of knives was kept to a minimum, substituting round files for making circumferential cuts through the insulation shield. This method is employed so as to eliminate the risks of knife cuts in the cable insulation which would, in turn, provide an entrapment for air, resulting in a potential for corona discharges. Open flames were completely avoided as a means of breaking the bond between insulation and insulation shield, in favor of electric heat guns. Therefore, blistering of the insulation did not occur. The final step in preparing the cable ends was to use successively finer grits of aluminum oxide cloth to effect a smooth, highly polished cable insulation surface. The terminations were installed and made operational following the procedures outlined by each manufacturer.

Finally, in preparation for current loading of the cable, aerial lugs were bolted to each terminal connector and a bare 1000 kcmil aluminum conductor installed, effectively closing the loop between the two ends of the cable conductor. This arrangement permitted the more convenient method of inducing desired currents in the cable conductor. In order to prevent the bare jumper cable from emitting corona-like discharges at elevated voltages, the jumper was housed in coupled lengths of 2 inch diameter aluminum pipes. The pipe was expected to provide an effective shield against potential spurious discharges from this bare conductor.

6.2 EXTENDED 60 HERTZ AND CURRENT CYCLING TEST

The first electrical tests performed on the cable system were measurements to determine the dissipation factor and capacitance characteristics at several voltage levels. Some instability was noted at 100kV which was indicative of corona discharge activity. Corona measurements were then made which did reveal massive discharges beginning at approximately 60kV, in the form of air corona. A subsequent scan of the test area with a sonic detector, pinpointed the source of these discharges. The problem was corrected and, thereafter, corona measurements were made up to and including 200kV with no discharges noted. Dissipation factor and capacitance

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measurements were then made at the operating voltage level of 133kV. The results of these initial dielectric measurements are given in TABLE 6.1.

A 60 Hz proof test was then performed and consisted of the application of 200kV and 266kV successively for five minutes each. These voltages represented the 150% and 200% operating voltage levels respectively. Following successful completion of the proof test, the system was made ready for initial current loading as follows:

1.   Six hours at 945 Amperes followed immediately by
2.   Six hours at 1092 Amperes

The given ampere loads were determined through experimentation as those required to raise the conductor temperature to 90 and 130 C respectively. However, because of the physical size and thermal characteristics of the cable, these temperatures could not have been realized in the allotted times. An investigation associated with cable joint development revealed that this construction required some-what longer periods to stabilize with these ampere loads applied. Due to our concern about the interfacial bond between a relatively unknown semi-conducting material and the cross-linked polyethylene insulation, it was felt that the application of these loads would show a tendency for the two materials to separate if that tendency existed. This initial current loading was done without an applied voltage. The system was allowed to cool for more than twelve hours, then the dielectric measurements were repeated to determine the effects, if any, of the current loading on these cable proper-ties. The results of these measurements are given in TABLE 6.2 and were not suggestive of any significant change.

The system was next energized continuously at operating voltage (133kV) for 63-1/2 hours, without load. Following these preliminary series of tests, the long-term voltage endurance and load cycling test described by the following, began:

6.2.1   The circuit was load cycled at 125% of operating voltage (166kV) and 90 C conductor temperature (945 Amperes) for 1 cycle. A cycle was defined as 12 hours of current loading and 12 hours of cooling. Voltage was continuously applied. The voltage was increased to 150% of operating level (200kV) while maintaining 90 C conductor loading, for an additional 8 cycles.

6.2.2   The voltage was decreased to 125% of operating level (166kV) and current loading was increased to 1092 Amperes, to produce 130 C conductor temperature. Seven cycles were logged under these conditions.

6.2.3   The voltage was increased to 175% of operating level (233kV) and cycled at 90 C conductor temperature (945 Amperes) for 11 cycles.

6.2.4   The voltage was decreased to 125% of operating level (166kV) and cycled at 130 C conductor temperature (1092 Amperes) for 8 cycles.

During the course of the load cycling described above, dielectric measurements (dissipation factor, capacitance and corona discharge) were made at frequent intervals. Additionally, temperature measurements of system components and cable shield resistance measurements were conducted. The dielectric measurements were usually done while system was at room temperature. However, dissipation factor and capacitance measurements were made once each while the system was at 90 and 130 C conductor temperature, near the end of the heating portion of the cycle. This permitted us the opportunity to observe the apparent stability of the insulation system relative to a large change in conductor temperature.

No significant changes were noted in the corona discharge characteristics during the course of the test. Five pico-coulombs of discharge was the highest measured at any time, including the one-time measurement at 233kV. These discharges, which varied between a non-measurable value and a maximum of 5 pico-coulombs were inconsistent and were believed to have originated outside of the active test system. However, no concerted attempt was made to verify the ultimate source because of the task involved, and the relative insignificance of these discharges at the high voltage levels at which they occurred.

After several cycles at 130 C, a significant change occurred in the dissipation factor measurements made at room temperature. During the prior cycling at 90 C, the dissipation factor generally ranged between 0.05-0.06%. However, two successive measuring periods showed the dissipation factor to be increasing noticeably, to a high of 0.11%. It was our suspicion that what we were seeing was not the true cable losses but rather, the effects of a physical change in the cable components as a result of prolonged operation at this high temperature. Specifically, the extruded insulation expands and contracts with significant temperature variations. The extent of the dimensional excursions is a function of the temperature differential; at the 130 C level, this differential is on the order of 105 C. This change of 105 C is based on an ambient of about 25 C. The insulation expansion causes the surrounding cable components, the copper tapes in particular, to also expand. The extruded cable core through the insulation shield contracts to their approximate original dimensions as the system returns to room temperature. However,

the contraction of the copper tape is not complete and results in a loose fit around the cable at room temperature. As a result, the contact between semi-conducting insulation shield and shielding tape is not intimate and the appearance would be that of an increase in the loss angle of the cable insulation.

The preceding was verified by the results of measurements made while the system was at the 130 C level. Here, the values -- although slightly higher than those seen during the 90 C cycling -- were significantly lower than those recorded during the cooling phases of the preceding 130 C cycles. This was verified further by the succeeding room temperature measurement which showed the dissipation factor to have again increased.

The results of dissipation factor, capacitance and corona discharge measurements made during the course of these load cycles are tabulated in TABLES 6.3 through 6.11. Unless otherwise noted, all measurements were made with cable system at room temperature. No provisions were made to allow isolation of the cable or terminals for purposes of determining the dielectric characteristics of any of these three components independently. Therefore all results of dielectric measurements reflect the combined contribution of the cable and each terminator.

A total of 35 current cycles, consisting of 12 hours of current loading and 12 hours of cooling, were logged on this test length. Twenty cycles were with the conductor loaded to achieve 90 C, and the remaining 15 cycles loaded for a conductor temperature of 130 C. During the course of the test, a voltage was constantly applied except during periods when interruptions were unavoidable. The applied voltage ranged from 100% of operating (133kV) to 175% of operating (233kV), resulting in an accumulation of approximately 809.5 voltage-hours. A summary of this data is found in TABLE 6.12.

6.3   CONSTRUCTION OF 230kV TAPED JOINT

After completion of the preceding tests described in Section 6.2, the cable length was cut at the approximate mid-point in preparation for installation of a taped joint. The joint - design number I - is illustrated in FIGURE 7.II of Section 7, and the design parameters described in Section 7.1.2.

Following the installation of the joint, the circuit was energized at 200kV (150% of rated voltage) for 63.5 consecutive hours, with no load applied. Dissipation factor, capacitance and corona discharge measurements were made after concluding the preceding voltage-conditioning period. Included in the design of the joint was a method of interrupting the cable shield at the joint. This discontinuity of the shield effectively permitted the isolation of segments of the circuit, when desired, for dissipation factor and capacitance measurements. These properties therefore, could be measured of the cable joint alone and/or either half of the cable alone. The results of these initial measurements of dissipation factor, capacitance and corona discharge are tabulated in Tables 6.13, 6.14 and 6.18.

The voltage endurance and current cycling test was resumed and the following was subsequently accomplished during this test sequence:

6.3.1   Sixteen load cycles at a conductor temperature of 90 C (945 amperes) and the following voltage-hours;

    a)   20.8 hours @ 133kV   (100% of rated voltage)
    b)   25.4 hours @ 166kV   (125% of rated voltage)
    c)   436.4 hours @ 200kV   (150% of rated voltage)

6.3.2   Sixteen load cycles at a conductor temperature of 130 C (1092 amperes) and the following voltage-hours;

    a)   95.8 hours @ 133kV (100% of rated voltage)
    b)   291.8 hours @ 166kV (125% of rated voltage)

6.3.3   Twenty load cycles at a conductor temperature of 90 C (945 amperes) while energized at 200 kV (150% of rated voltage) for 468.3 hours (culmination of testing).

The foregoing test history is summarized in Table 6.23. Additionally, during the course of the test, dissipation factor, capacitance and corona discharge

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measurements were made at various intervals. The results of these measurements are tabulated in TABLES 6.15 through 6.17 and 6.19 through 6.22. FIGURES 7.20A and 7.20B of SECTION 7.1.3 are graphs of the joint's dissipation factor profile at 90 and 130C conductor temperature, respectively. These plots reflect measurements that were made at regular intervals over an extended number of hours, during the transition from room ambient to the desired temperature. Finally, all of the data collected indicated that the joint was compatible with the cable and exhibited good operating stability under accelerated voltages and load currents.

6.4   IMPULSE VOLTAGE WITHSTAND TEST

A sample with an active test length of 19 feet – exclusive of terminal ends – was prepared for impulse testing as required by IEEE Standard No. 82, Test Procedure for Impulse Voltage Tests on Insulated Conductors (REFERENCE 6.1). This sample had previously been subjected to prolonged periods of dc testing at voltages up to 750kV dc. Those tests were reported in TABLE 5.3 and SECTION 5.3. Terminating of the sample was effected by using a taped, resistance-graded method, eliminating the need for the more involved conventional porcelain terminals.

A test sequence was adopted which was somewhat more exten-sive in scope than the requirements of Standard No. 82. Basically, the impulse test is defined by a waveform having a front (or rise-time) of 1-1/2 microseconds, and a duration (or tail) of 40 to 50 microseconds. The established Basic Insulation Level (BIL) for the 230kV cable is 1050kV. Standard No. 82 requires that three surges be applied to the test specimen at each voltage level, commencing at 75% BIL, then 100% BIL and, thereafter, increasing the voltage in 10 percent BIL steps until a breakdown occurs. The polarity of the impulse wave can be either negative or positive, at the discretion of the tester. For our tests, this procedure was modi-fied upward by increasing the number of surges applied to five at each voltage level, and using both polarities, for a total of 10 impulses at each voltage level.

Cable breakdown was not established as the objective of this test. Instead, successful completion of the 125% BIL level (1313kV) was the desired objective set for the cable. Sequentially, the test plan was outlined as follows:

6.4.1   Impulse the sample with the conductor at room ambient temper-ature, applying 5 negative and 5 positive waves at 75% BIL (788kV), 100% BIL (1050kV) and negative waves at 125% BIL (1313kV).

6.4.2   Current-load the sample to achieve and sustain a conductor temperature of 90C (945 amperes) and repeat the test of 6.4.1.

6.4.3   Install a taped joint (design #1) as described by FIGURE 7.11 of SECTION 7. Repeat the test of 6.4.1 above with the cable conductor at room ambient temperature, except discontinue impulsing after completing the 100% BIL level.

6.4.4   Current-load the sample to achieve and sustain a conductor temperature of 90C (945 amperes) and repeat the test sequence of 6.4.1, except continue beyond the 125% BIL level, increasing the voltage in approximate 10% BIL steps, until a cable, joint or terminal failure occurs.

Following the procedure described by the foregoing, the first test resulted in a terminal failure on the 3rd negative impulse at the 125% BIL level. The failure occurred prior to performing the positive polarity series at that level. Because of the short length, and the completeness of the failure, this sample could not be re-terminated and submitted to further testing. The conduct of this test is summarized in TABLE 6.24.

A second cable sample with an active test length of 25 feet was prepared for testing. This sample was taken from the reel previously identified as containing 320 feet of cable (SECTION 5.0, TABLE 5.3). This sample successfully passed the room temperature impulse test as outlined. Subsequently, this sample was current-loaded for a conductor temperature of 90C and that test sequence began. A cable failure occurred in the active length on the first acceptable impulse at BIL (1050kV). Analysis of the failed section was done by immersing the approximately 6-inch sample (of the area surrounding the fault), in hot silicone oil and visually examining the resulting transparent insulation wall, and the clearly visible strand shield surface. The failure was directed from conductor to insulation shield, as determined from the dendritic structure of the fault. A pimple-like deposit was discovered on the strand shield surface some distance away from, but in-line with, the fault. This deposit was identified as semi-conducting material and although it could not have been related to the eventual failure, it was considered possible that another such imperfection may have been present at the fault site. The strand shield surface was otherwise smooth and no other defects were visually evident. This test sequence is summarized in TABLE 6.25.

The taped joint was installed in this second cable sample and impulsed with the conductor at room temperature. As outlined, this test sequence was not to go beyond BIL. Having successfully passed this test, the sample was current-loaded to 90C conductor temperature and impulse tested. The joint sustained a fault on the third acceptable negative impulse at BIL. The positive impulse series had not been accomplished. The test is summarized in TABLE 6.26. Subsequently, the joint was cut out, dissected and examined. A discussion of the joint breakdown is con-

tained in SECTION 7.1.3. Finally, throughout these impulse tests, those surges whose magnitude were not within approximately 10kV of the particular voltage level desired, were considered unacceptable and not counted in the 5-surge series. However, these surges were recorded for informational purposes.

6.5   CABLE SHIELD RESISTANCE MEASUREMENTS

Prior to installing the joint in the test cable circuit, two sets of shield resistance measurements were taken. These measurements coincided with the end of 90 and 130C cycles respectively. The initial measurements - corresponding to both a 90 and a 130C cycle - were taken over a one-hour period, starting at the instant the respective heating phase ended. It was apparent, however, that due to the slow cooling rate, a one hour time span was not sufficient to produce significant resistance changes. Consequently, these tests were repeated at intervals during a six hour period.

The results of the six hour measurements suggested relative resistance stability with respect to the temperature differences. The resistance data are summarized in TABLES 6.27 and 6.28. FIGURES 6.1 and 6.2 are plots of these data.

6.6   CABLE COMPONENTS TEMPERATURE MEASUREMENTS

Temperature measurements of the various system components were made primarily to insure that no potential thermal run-away conditions existed during periods of conductor loading. In every instance, the components monitored were at temperature levels that were reasonable in relation to the prevailing conductor temperature. For informational purposes, these data are tabulated in TABLE 6.29.

6.7   VOLUME RESISTIVITY MEASUREMENTS

Samples taken from both the virgin cable and the test length which had undergone the Extended 60 Hertz and Current Cycling Tests (SECTION 6.2), were prepared and tested in accordance with the procedure of IPCEA Publication S-66-524, IPCEA-NEMA Standards publication Crosslinked-Thermosetting Polyethylene-Insulated Wire And Cable for the Transmission And Distribution of Electric Energy (REFERENCE 6.2). Samples were taken from the test length upon completion of the first test sequence, preparatory to cutting in the taped joint.

Volume resistivity is a measure of the relative resistance stability of a semi-conducting material, at various temperatures over an extended period of time. Although industry standards refer primarily to maximum allowable

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resistivity values, it is equally important that the resistance achieve a degree of stability at the respective test temperature. Similarly, the time required to achieve that stability is a measure of the materials' uniformity.

In accordance with the IPCEA specifications referenced above, the tests involved samples of the insulation shield and the strand shield. The insulation shield sample was approximately 6 inches long -- in completed form, with the conductor, copper shielding tape and the outer coverings removed, exposing the semi-conducting insulation shield. Silver conducting paint was applied in 4 narrow annular bands around the cable sample's circumference and spaced apart as specified by the test standards. The silver paint served as electrodes to which measuring leads from the resistance bridges, were attached. The strand shield sample was prepared by removing the conductor and all outer coverings, exposing the insulation surface of a whole six inch long sample. This sample was then halved longitudinally and the half to be tested prepared by painting electrodes across the strand shield, resulting in half-annular rings to which measuring leads were connected.

After samples were properly prepared, initial resistance measurements were made while the samples were at room ambient temperature. Then, the insulation shield samples were placed in 90 and 110 C circulating air ovens. Similarly, strand shield samples were placed in 90 and 130 C air ovens. After 24 hours at the given temperature, resistance measurements were made, and thereafter, at regularly scheduled intervals during the course of the tests. Table 6.30 gives the results of these tests which spanned a period of 49 days. Shown are volume resistivities in ohm-centimeters, derived through the application of the following formulae:

Strand Shield

$$P = \frac{R(D^2 - d^2)}{L}$$

Where

P = Volume resistivity (in ohm-centimeters)
R = Measured resistance (in ohms)
D = diameter over conductor shield (in inches)
d = diameter over conductor (in inches)
L = linear distance between measuring electrodes which defines the area being measured (2 inches)

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Insulation Shield

$$P = \frac{2R\,(D^2 - d^2)}{L}$$

where

P = Volume resistivity (in ohm-centimeters)
R = Measured resistance (in ohms)
D = diameter over insulation shield (in inches)
d = diameter over insulation (in inches)
L = Linear distance between measuring electrodes which defines the area being measured (2 inches)

The values representing the maximum allowable resistivities are included below TABLE 6.30. The samples tested were well within the specified limits and exhibited good stability. Some divergence from a smooth unidirectional trend in resistivities occurred with all except the 110C samples on the 28th day measurements. However, that reversal was directly attributable to a power outage which interrupted these tests for an approximate 9 hour period, on the 27th day. The fact that the low values achieved through the 21st day measurements were never achieved again over the remainder of the tests did not detract significantly from the overall excellent results. No explanation is offerred for the apparent lack of repeatability noted here.

Finally, the strand shield was tested to the requirements of thermosetting materials, although it was not in fact a thermoset. A discussion of the strand shield material is included in SECTION 5.4.

6.8   SOLVENT EXTRACTION TESTS

Thermoset (or crosslinked) polyethylene insulating and semi-conducting materials, differ from thermoplastic polyethylene materials in several ways. The most notable difference results basically from the processing techniques employed. Through the introduction of an additive (catalytic agent), heat and pressure, a chemical bonding takes place between the molecular chains of the polyethylene compound. An infusible, insoluble super-molecular chain is formed; the polyethylene material has been crosslinked. Higher temperature resistance, higher bond density and increased rigidity are some of the advantages thermoset compounds offer.

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The extent to which crosslinking can be achieved during the manufacture of solid extruded dielectric cables with crosslinkable compounds, can vary from one manufacturing run to another. Indeed, it can vary within a given manufacturing run if any of several variables (i.e. heat, pressure, etc.) changes during processing. However, testing methods have been devised and rigid standards established, that permit the rather accurate determination of the degree of cure – by selective sampling – achieved.

The test standard by which crosslinked polyethylene (XLPE) cable insulations are judged, is ASTM D2765-68 Standard Methods of Tests For Degree of Crosslinking In Crosslinked Ethylene Plastics As Determined By Solvent Extraction (REFERENCE 6.3). Three alternative methods are offered, of which Method B is most commonly used, and was the method selected for these tests, the results of which are shown in Table 6.31.

The test results were consistent with those ordinarily seen in typical extractions on properly cured cables. For informational purposes, the thermoplastic strand shield was also submitted to the solvent extraction test -- which is applicable to thermoset materials only. However, the strand shield passed the requirements set by the AEIC No. 5-75 Specifications For Polyethylene And Crosslinked Polyethylene Insulated Shielded Power Cables Rated 5 Through 69kV (REFERENCE 6.4).

6.9   TEST EQUIPMENT USED

The following are the major pieces of equipment used during the conduct of these tests:

1.   Haefely 1000kV, 2 MVA ac Transformer
2.   Haefely 3200kV, 160kJ Impulse Generator
3.   Kaiser Model 16kVA Load Cycle Consoles with Hipotronics split-core Current Transformers
4.   Hartmann & Braun Compressed Gas 500kV Standard Capacitor
5.   General Electric 3-Stage Blocking Capacitor
6.   General Electric "Direk Read" Dissipation Factor/ Capacitance Bridge
7.   F. C. Robinson's ERA Corona Discharge Detector
8.   Hewlett-Packard Model 4917A Ultrasonic Detector
9.   J. G. Biddle portable Kelvin Bridge
10.   Thermo Electric Multimite Digital Thermometer
11.   J. G. Biddle portable Wheatstone Bridge
12.   Textronix Model 507 High Voltage Surge-Test Oscilloscope

6.10   REFERENCES TO SECTION 6.0

1.   IEEE Std. 82.   Test Procedure for Impulse Voltage Tests On Insulated Conductors.   The Institute of Electrical and Electronics Engineers, Inc., New York, N.Y.

2.   IPCEA Pub. No. S-66-524/Nema. Pub. No. WC 7-1971. IPCEA-Nema Standards Publication Crosslinked-Thermosetting Polyethylene-insulated Wire And Cable for the Transmission And Distribution of Electric Energy.   National Electrical Manufacturers Association, New York, N.Y.

3.   ASTM D 2765-68.   Standard Methods of Test for Degree of Crosslinking in Crosslinked Ethylene Plastics As Determined By Solvent Extraction.   American Society For Testing And Materials, Philadelphia, Pa.

4.   AEIC No. 5-75.   Specifications For Polyethylene And Crosslinked Polyethylene Insulated Shielded Power Cables Rated 5 Through 69kV.   Association of Edison Illuminating Companies, New York, N.Y.

TABLE 6.1

PRELIMINARY DIELECTRIC MEASUREMENTS

a)

Voltage, kV	Diss.Factor, %	Capacitance, Farads	Sensi-tivity*	Attenua-tion,db**	Corona Dis-charge,pC***
50	0.066	2.4578×10^{-9}	12	67	NM
75	0.066	2.4578	12	Inception of massive air corona.	
100	0.068	2.4579	12		

b)

Voltage, kV	Attenua-tion,db**	Corona Dis-charge,pC***	Diss.Factor, %	Capacitance, Farads	Sensi-tivity *
50	67	NM	--	--	--
75	67	NM	--	--	--
100	67	NM	--	--	--
133	67	NM	0.065	2.4614×10^{-9}	12
170	67	NM	--	--	--
200	67	NM	--	--	--

*   Refers to the sensitivity of the Dissipation Factor/Capacitance Bridge, which ranges from 0 to 12. The maximum sensitivity corresponds to a detector sensitivity of 1 microvolt and dissipation factor resolution of $\pm$ 0.002%.

**   Refers to the Corona Discharge Detector, and defines the attentuation required to establish a sensitivity of 5 pico-coulombs (pC) per inch.

***   The calibration pulse (equal to 5 pico-coulombs per inch) is a reference against which any discernible discharges are compared. Where no visible discharges are evident, the letters NM (not-measurable) are shown. Measurable discharges are denoted by an actual numerical value.

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TABLE 6.2

DIELECTRIC MEASUREMENTS AFTER INITIAL
CURRENT-LOADING AT 90 AND 130 C

Voltage, kV	Diss. Factor, %	Capacitance, Farads	Sensi- tivity *	Attenua- tion, db**	Corona Dis- discharge,pC***
200	0.068	2.4473×10^{-9}	12	67	NM
166	0.065	2.4472	12	67	NM
133	0.063	2.4472	12	67	NM
100	0.061	2.4471	12	67	NM

TABLE 6.3

DIELECTRIC MEASUREMENTS AFTER 2ND 90 C
LOAD CYCLE

Voltage, kV	Diss. Factor, %	Capacitance, Farads	Sensi- tivity *	Attenua- tion, db**	Corona Dis- discharge,pC***
200	0.064	2.4535×10^{-9}	11	67	NM
166	0.061	2.4534	11	67	NM
133	0.059	2.4534	11	67	NM
100	0.057	2.4534	11	67	NM

* Refers to the sensitivity of the Dissipation Factor/Capacitance Bridge, which ranges from 0 to 12. The maximum sensitivity corresponds to a detector sensitivity of 1 microvolt and dissipation factor resolution of $\pm$ 0.002%.

** Refers to the Corona Discharge Detector, and defines the calibration required to establish a detector sensitivity of 5 pico-coulombs (pC) per inch.

*** The calibration pulse (equal to 5 pico-coulombs per inch) is a reference against which any discernible discharges are compared. Where no visible discharges are evident, the letters NM (not-measurable) are shown. Measurable discharges are denoted by an actual numerical value.

TABLE 6.4

DIELECTRIC MEASUREMENTS AFTER 4TH 90 C LOAD CYCLE

Voltage, kV	Diss. Factor, %	Capacitance, Farads	Sensi-tivity*	Attenua-tion,db**	Corona Dis-charge,pC ***
200	0.061	2.4528×10^{-9}	12	68	4
166	0.059	2.4528	12	67	NM
133	0.057	2.4528	12	67	NM
100	0.055	2.4528	12	67	NM

TABLE 6.5

DISSIPATION FACTOR AND CAPACITANCE MEASUREMENTS WITH CONDUCTOR AT 90 C

Voltage, kV	Diss. Factor, %	Capacitance, Farads	Sensi-tivity*
200	0.049	2.3753×10^{-9}	11
166	0.048	2.3754	11
133	0.048	2.3755	11
100	0.050	2.3756	11

* Refers to the sensitivity of the Dissipation Factor/Capacitance Bridge, which ranges from 0 to 12. The maximum sensitivity corresponds to a detector sensitivity of I microvolt and dissipation factor resolution of $\pm 0.002\%$.

** Refers to the Corona Discharge Detector, and defines the calibration required to establish a detector sensitivity of 5 pico-coulombs (pC) per inch.

*** The calibration pulse (equal to 5 pico-coulombs per inch) is a reference against which any discernible discharges are compared. Where no visible discharges are evident, the letters NM (not-measurable) are shown. Measurable discharges are denoted by an actual numerical value.

TABLE 6.6

DIELECTRIC MEASUREMENTS AFTER 6TH 90 C
LOAD CYCLE

Voltage, kV	Diss. Factor, %	Capacitance, Farads	Sensi-tivity*	Attenua-tion,db**	Corona Discharge,pC ***
200	0.059	2.4519×10^{-9}	12	67	5
166	0.057	2.4519	12	67	NM
133	0.055	2.4519	12	67	NM
100	0.053	2.4520	12	67	NM

TABLE 6.7

DIELECTRIC MEASUREMENTS AFTER 3RD 130 C
LOAD CYCLE

Voltage kV	Diss. Factor, %	Capacitance, Farads	Sensi-tivity*	Attenua-tion,db**	Corona Discharge,pC ***
200	0.083	2.4472×10^{-9}	11	67	NM
166	0.075	2.4471	11	67	NM
133	0.068	2.4471	11	67	NM
100	0.063	2.4470	11	67	NM

* Refers to the sensitivity of the Dissipation Factor/Capacitance Bridge, which ranges from 0 to 12. The maximum sensitivity corresponds to a detector sensitivity of 1 microvolt and dissipation factor resolution of $\pm$ 0.002%

** Refers to the Corona Discharge Detector, and defines the calibration required to establish a detector sensitivity of 5 pico-coulombs (pC) per inch.

*** The calibration pulse (equal to 5 pico-coulombs per inch) is a reference against which any discernible discharges are compared. Where no visible discharges are evident, the letters NM (not-measurable) are shown. Measurable discharges are denoted by an actual numerical value.

TABLE 6.8

DIELECTRIC MEASUREMENTS AFTER 4TH 130 C LOAD CYCLE

Voltage, kV	Diss. Factor, %	Capacitance, Farads	Sensitivity*	Attenuation, db**	Corona Discharge, pC ***
200	0.112	2.4488×10^{-9}	11	74	2
166	0.102	2.4487	11	67	NM
133	0.093	2.4486	11	67	NM
100	0.080	2.4485	11	67	NM

TABLE 6.9

DISSIPATION FACTOR AND CAPACITANCE MEASUREMENTS WITH CONDUCTOR AT 130 C

Voltage, KV	Diss. Factor, %	Capacitance, Farads	Sensitivity *
200	0.072	2.2635×10^{-9}	11
166	0.069	2.2635	11
133	0.068	2.2635	12
100	0.069	2.2634	12

*   Refers to the sensitivity of the Dissipation Factor/Capacitance Bridge, which ranges from 0 to 12. The maximum sensitivity corresponds to a detector sensitivity of 1 microvolt and dissipation factor resolution of $\pm$ 0.002%.

**   Refers to the Corona Discharge Detector, and defines the calibration required to establish a detector sensitivity of 5 pico-coulombs (pC) per inch.

***   The calibration pulse (equal to 5 pico-coulombs per inch) is a reference against which any discernible discharges are compared. Where no visible discharges are evident, the letters NM (not-measurable) are shown. Measurable discharges are denoted by an actual numerical value.

TABLE 6.10

DIELECTRIC MEASUREMENTS AFTER 7th 130 C LOAD CYCLE

Voltage, kV	Diss. Factor, %	Capacitance, Farads	Sensi-tivity*	Attenua-tion,db**	Corona Dis-charge,pC***
200	0.106	2.4437×10^{-9}	11	70	4
166	0.093	2.4436	11	67	NM
133	0.078	2.4436	12	67	NM
100	0.060	2.4436	12	67	NM

TABLE 6.11

DIELECTRIC MEASUREMENTS PRIOR TO CYCLIC PERIODS
AT 233kV AND 90 C

Voltage, kV	Diss. Factor, %	Capacitance, Farads	Sensi-tivity*	Attenua-tion,db**	Corona Dis-charge,pC***
233	0.076	2.4366×10^{-9}	11	70	4
200	0.068	2.4365	11	70	4
166	0.062	2.4365	12	67	NM
133	0.056	2.4365	12	67	NM

*   Refers to the sensitivity of the Dissipation Factor/Capacitance Bridge, which ranges from 0 to 12. The maximum sensitivity corresponds to a detector sensitivity of 1 microvolt and dissipation factor resolution of $\pm$ 0.002%.

**   Refers to the Corona Discharge Detector, and defines the calibration required to establish a detector sensitivity of 5 pico-coulombs (pC) per inch.

***   The calibration pulse (equal to 5 pico-coulombs per inch) is a reference against which any discernible discharges are compared. Where no visible discharges are evident, the letters NM (not-measurable) are shown. Measurable discharges are denoted by an actual numerical value.

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TABLE 6.12

SUMMARY OF EXTENDED 60 Hz AND CURRENT CYCLING
TESTS (BEFORE INSTALLATION OF JOINT)

# Cycles	Conductor Load	Time (Hours)	Applied Voltage (kV)	Rated Voltage (%)
--	None	63.4	133	100
1	945 Amperes (90 C)	28.8	166	125
8	945 Amperes (90 C)	172.2	200	150
11	945 Amperes (90 C)	243.8	233	175
15	1092 Amperes (130 C)	301.3	166	125

35 Cycles   809.5 Voltage-Hours

TABLE 6.13

INITIAL DISSIPATION FACTOR AND CAPACITANCE MEASUREMENTS ON ENTIRE CIRCUIT (AFTER JOINTING)

Voltage, kV	Diss. Factor, %	Capacitance, pico-Farads	Sensitivity *
133	0.060	2330.7	12
166	0.061	2330.7	12
200	0.062	2330.6	12

TABLE 6.14

INITIAL DISSIPATION FACTOR AND CAPACITANCE MEASUREMENTS ON JOINT ONLY

Voltage, kV	Diss. Factor, %	Capacitance, pico-Farads	Sensitivity *
133	0.115	128.30	12
166	0.118	128.30	12
200	0.121	128.31	12

TABLE 6.15

DISSIPATION FACTOR AND CAPACITANCE MEASUREMENTS AT ROOM TEMPERATURE AFTER CURRENT-LOADING AT 90 C (AFTER JOINTING)

a) Entire Circuit

Voltage, kV	Diss. Factor, %	Capacitance, pico-Farads	Sensitivity *
133	0.061	2334.5	12
200	0.062	2334.3	12

b) Joint Only

Voltage, kV	Diss. Factor, %	Capacitance, pico-Farads	Sensitivity *
133	0.111	130.84	12
200	0.113	130.83	12

* Refers to the sensitivity of the Dissipation Factor/Capacitance Bridge, which ranges from 0 to 12. The maximum sensitivity corresponds to a detector sensitivity of 1 microvolt and dissipation factor resolution of $\pm$ 0.002%.

TABLE 6.16

DISSIPATION FACTOR AND CAPACITANCE MEASUREMENTS DURING 51st LOAD CYCLE (AFTER JOINTING) AT 90 C

Voltage, kV	Diss. Factor, %	Capacitance, pico-Farads	Sensitivity *
a) Entire Circuit			
133	0.082	2248.4	12
166	0.083	2248.3	12
200	0.085	2248.2	12
b) 1/2 Cable & Joslyn Terminal			
133	0.077	1018.6	12
166	0.076	1018.6	12
200	0.076	1018.5	12
c) Joint Only			
133	0.420	126.63	12
166	0.433	126.61	12
200	0.451	126.59	12

* Refers to the sensitivity of the Dissipation Factor/Capacitance Bridge, which ranges from 0 to 12. The maximum sensitivity corresponds to a detector sensitivity of 1 microvolt and dissipation factor resolution of $\pm$ 0.002%.

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TABLE 6.17

DISSIPATION FACTOR AND CAPACITANCE MEASURE-MENTS AFTER 51st LOAD CYCLE (AFTER JOINTING) AT ROOM TEMPERATURE

	Voltage, kV	Diss. Factor, %	Capacitance, pico-Farads	Sensitivity *
a)	**Entire Circuit**			
	133	0.083	2327.0	12
	166	0.083	2327.0	12
	200	0.084	2326.9	12
b)	**1/2 Cable & Joslyn Terminal**			
	133	0.107	1054.6	12
	166	0.106	1054.5	12
	200	0.106	1054.5	12
c)	**1/2 Cable & G&W Terminal**			
	133	0.059	1141.1	12
	166	0.060	1141.1	12
	200	0.062	1141.1	12
d)	**Joint Only**			
	133	0.098	131.21	12
	166	0.098	131.21	12
	200	0.100	131.21	12

* Refers to the sensitivity of the Dissipation Factor/Capacitance Bridge, which ranges from 0 to 12. The maximum sensitivity corresponds to a detector sensitivity of 1 microvolt and dissipation factor resolution of $\pm$ 0.002%.

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TABLE 6.18

INITIAL CORONA DISCHARGE MEASUREMENTS
(AFTER JOINTING)

Voltage, kV	Attenuation, * db	Corona Discharge, ** pC
200	63	10
166	72	4
153	72	NM
133	72	NM

TABLE 6.19

CORONA DISCHARGE MEASUREMENTS
(AFTER JOINTING)

a) <u>Circuit @ 90 C</u>

Voltage, kV	Attenuation, * db	Corona Discharge, ** pC
200	69	NM

b) <u>Circuit @ Room Temperature</u>

200	69	5

TABLE 6.20

CORONA DISCHARGE MEASUREMENTS AT ROOM
TEMPERATURE AFTER CURRENT-LOADING AT 130 C
(AFTER JOINTING)

Voltage, kV	Attenuation, * db	Corona Discharge, ** pC
200	65	8
180	69	5
174	69	NM

* Refers to the Corona Discharge Detector, and defines the attenuation required to establish a sensitivity of 5 pico-coulombs (pC) per inch.

** The calibration pulse (equal to 5 pico-coulombs per inch) is a reference against which any discernible discharges are compared. Where no visible discharges are evident, the letters NM (not-measurable) are shown. Measurable discharges are denoted by an actual numerical value.

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TABLE 6.21

CORONA DISCHARGE MEASUREMENTS ON ENTIRE
CIRCUIT DURING 5lst LOAD CYCLE (AFTER JOINTING)
AT 90 C

Voltage, kV	Attenuation, * db	Corona Discharge, ** pC
200	69	NM

TABLE 6.22

CORONA DISCHARGE MEASUREMENTS ON ENTIRE
CIRCUIT AFTER 5lst LOAD CYCLE (AFTER JOINTING)
AT ROOM TEMPERATURE

Voltage, kV	Attenuation, * db	Corona Discharge ** pC
200	69	5
196	69	NM

*   Refers to the Corona Discharge Detector, and defines the attenuation required to establish a sensitivity of 5 pico-coulombs (pC) per inch.

**   The calibration pulse (equal to 5 pico-coulombs per inch) is a reference against which any discernible discharges are compared. Where no visible discharges are evident, the letters NM (not-measurable) are shown. Measurable discharges are denoted by an actual numerical value.

TABLE 6.23

SUMMARY OF VOLTAGE-HOURS AND LOAD CYCLES
AFTER INSTALLATION OF TAPED JOINT

# Cycles	Conductor Load	Time (Hours)	Applied Voltage (kV)	Rated Voltage (%)
16	945 Amperes (90 C)	20.8	133	100
		25.4	166	125
		436.4	200	150
16	1092 Amperes (130 C)	95.8	133	100
		291.8	166	125
20	945 Amperes (90 C)	468.3	200	150

52 Cycles

116.6	hours	@ 133 kV
317.2	"	@ 166 kV
904.7	"	@ 200kV

1338.5 Voltage-hours

TABLE 6.24

IMPULSE WITHSTAND TEST
(SAMPLE #1)   BIL: 1050 kV   Cond.Temp.   25 C

% BIL	Polarity	Applied Voltage, (kV)	Waveform
75	Negative	796, 802, 802, 796, 802	FW, FW, FW, FW, FW
75	Positive	802, 802, 802, 802, 802	FW, FW, FW, FW, FW
100	Positive	1029, 1035, 1052, 1052 1052, 1052, 1052	FW, FW, FW, FW, FW, FW, FW
100	Negative	864, 1029, 978, 1012, 1081, 1035, 1041, 1086, 893, 1035, 1069, 1064	FW, FW, FW, FW, FW FW, FW, FW, FW, FW, FW, FW
125	Negative	1263, 1143, 1126, 1305, 1271, 1297, 1297 *	FW, FW, FW, FW, FW, FW, BD *

FW   =   Full wave

BD   =   Impulse breakdown

___   =   Underlined figures are unacceptable Voltage magnitudes

*   Failure occurred in termination.

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TABLE 6.25

IMPULSE WITHSTAND TEST

(SAMPLE #2) BIL: 1050 kV Cond.Temp. 22 C

% BIL	Polarity	Applied Voltage, (kV)	Waveform
80	Negative	848, 870, 870, 876, 876	FW, FW, FW, FW, FW
80	Positive	842, 842, 843, 842, 842	FW, FW, FW, FW, FW
100	Positive	1029, 1041, 1046, 1058, 1058, 1052	FW, FW, FW, FW, FW, FW
100	Negative	1058, 1069, 1069, 1075, 1075	FW, FW, FW, FW, FW
125	Negative	1254, 1246, 1280, 1280, 1288, 1297, 1297, 1305, 1305, 1305	FW, FW, FW, FW, FW FW, FW, FW, FW, FW
125	Negative	1314, 1322, 1331, 1314, 1322	FW, FW, FW, FW, FW

Sample current-loaded (945 Amperes) for 90 C conductor temperature.

% BIL	Polarity	Applied Voltage, (kV)	Waveform
75	Negative	717, 802, 756, 785, 853, 808, 808	FW, FW, FW, FW, FW, FW, FW
75	Positive	830, 847, 859, 876, 882	FW, FW, FW, FW, FW
100	Positive	995, 1046 *	FW, BD *

FW = Fullwave

BD = Impulse breakdown

—— = Underlined figures are unacceptable Voltage magnitudes

* Failure occurred in active cable length.

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TABLE 6.26

IMPULSE WITHSTAND TEST
(SAMPLE #2 WITH TAPED JOINT INSTALLED)

BIL: 1050 kV   Cond.Temp.   22 C

% BIL	Polarity	Applied Voltage (kV)	Waveform
70	Positive	688, 677, 734, 728, 728, 739, 711	FW, FW, FW, FW FW, FW, FW
70	Negative	678, 682, 717, 745, 711	FW, FW, FW, FW, FW
100	Negative	1029, 955, 1012, 989, 1041, 1046, 1041, 1046, 1046	FW, FW, FW, FW, FW, FW, FW, FW, FW
100	Positive	1012, 1001, 1029, 1006, 967, 927, 1018, 1052, 1052, 1039, 967, 1018, 841, 967, 1052	FW, FW, FW, FW, FW, FW, FW, FW, FW, FW, FW, FW, FW, FW, FW

Sample current-loaded (945 Amperes) for 90 C conductor temperature.

% BIL	Polarity	Applied Voltage (kV)	Waveform
90	Negative	859, 995, 944, 876, 927, 944, 910, 853, 944	FW, FW, FW, FW, FW, FW, FW, FW, FW
100	Negative	1029, 1041, 1069, 1080 *	FW, FW, FW, BD *

FW = Full wave

BD = Impulse breakdown .

___ = Underlined figures are unacceptable Voltage magnitudes

*   Failure occurred in Taped Joint.

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TABLE 6.27

CABLE SHIELD RESISTANCE MEASUREMENTS AT ELEVATED TEMPERATURES *

Elapsed Time (Minutes)	Resistance (ohms)	
	@ 90 C (21 C Amb.)	@ 130 C (29 C Amb.)
0	0.00440	0.00554
1	0.00450	0.00551
2	0.00454	0.00549
3	0.00455	0.00547
4	0.00456	0.00546
5	0.00456	0.00547
10	0.00456	0.00550
15	0.00454	0.00555
20	0.00456	0.00555
25	0.00455	0.00560
30	0.00453	0.00564
40	0.00450	0.00564
50	0.00449	0.00562
60	0.00446	0.00556

* Measurements commenced simultaneously with the end of the heating phase of the cycle.

TABLE 6.28

CABLE SHIELD RESISTANCE MEASUREMENTS AT
ELEVATED TEMPERATURES *

Elapsed Time (Minutes)	Resistance (ohms) @ 90 C (22 C Amb.)	@ 130 C (23 C Amb.)
0	0.00424	0.00387
1	0.00425	0.00401
2	0.00426	0.00405
3	0.00426	0.00405
4	0.00428	0.00407
5	0.00427	0.00407
6	0.00427	0.00407
7	0.00430	0.00409
8	0.00430	0.00411
9	0.00431	0.00411
10	0.00429	0.00412
15	0.00429	0.00416
20	0.00430	0.00422
25	0.00430	0.00428
30	0.00428	0.00434
45	0.00424	0.00437
60	0.00424	0.00436
75	0.00420	0.00434
90	0.00417	0.00432
105	0.00417	0.00430
120	0.00415	0.00426
135	0.00415	0.00425
150	0.00413	0.00423
180	0.00411	0.00420
210	0.00408	0.00416
240	0.00408	0.00415
300	0.00406	0.00412
360	0.00403	0.00412

*   Measurements commenced simultaneously with the end of the heating phase of the cycle.

TABLE 6.29

TEMPERATURES OF CABLE COMPONENTS AND ACCESSORIES AT ELEVATED SYSTEM TEMPERATURES

Cycle No.	Cable Conductor	Ambient	PVC Jacket	CU Tape	Insulation Shield	JOSLYN TERMINAL		G & W TERMINAL	
						Connector	Adjacent Conductor	Connector	Adjacent Conductor
5	90	24	--	--	--	74	74	71	71
10	130	25	45	52	49	88	91	87	90
14	90	22	39	42	46	67	70	64	73
20	130	23	43	56	55	79	89	84	92

NOTES:

1. All entries under the indicated component headings are temperature readings.

2. All temperatures given in degree Centigrade (C).

TABLE 6.30

VOLUME RESISTIVITY MEASUREMENTS

DAY	90 C				130 C		110 C	
	Cl (STR)	Sl (STR)	C3 (IN)	S3 (IN)	C2 (STR)	S2 (STR)	C4 (IN)	S4 (IN)
Initial	48.638	26.844	94.944	97.492	38.268	21.144	83.654	90.377
After 1 Day	61.908	59.510	2,149	1,680	17.786	26.105	1,970	1,746
After 7 Days	30.269	45.209	2,375	1,816	11.059	17.604	2,094	1,800
After 14 Days	24.912	40.894	2,637	2,045	10.570	16.709	2,217	1,853
After 21 Days	22.966	38.489	2,855	2,248	10.745	16.769	2,032	1,727
After 28 Days	29.823	50.959	3,948	3,159	14.796	23.130	1,925	1,506
After 35 Days	29.968	50.490	3,935	3,142	15.492	24.201	1,804	1,534
After 42 Days	28.488	47.949	3,851	3,107	15.290	23.757	--	--
After 49 Days	27.511	46.024	3,838	3,123	15.353	23.736	1,537	1,279

SPECIFICATION LIMITS
(in ohm-centimeters)

	90 C	110 C	130 C
Extruded Conductor Shield (STR)	100,000	--	100,000
Extruded Insulation Shield (IN)	50,000	50,000	--

NOMENCLATURE

C - Sample taken from virgin cable.
S - Sample taken from Voltage Endurance sample after prolonged Voltage/Current testing.

NOTES:
1. All Volume Resistivities are in Ohm-Centimeters.
2. The initial measurements were made prior to heating sample.

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TABLE 6.31

SOLVENT EXTRACTION TESTS ON SAMPLES FROM
230kV CABLE

SAMPLE LOT #1 *

Sample #	Sample Description	% Extractables
I A	Semi-Conductive insulation shield	17.0
I B	Outer 0.100" of XLPE insulation	15.7
I C	Center 0.100" of XLPE insulation	15.6
I D	Inner 0.100" of XLPE insulation	22.3
I E ***	Semi-Conductive strand shield	58.5

SAMPLE LOT #2 **

Sample #	Sample Description	% Extractables
2 A	Semi-Conductive insulation shield	18.6
2 B	Outer 0.100" of XLPE insulation	14.4
2 C	Center 0.100" of XLPE insulation	13.7
2 D	Inner 0.100" of XLPE insulation	19.4
2 E ***	Semi-Conductive strand shield	51.1

Specification Limits -- 30% Maximum Extractables.

* Samples taken from virgin cable length exposed to factory voltage proof tests only.

** Samples taken from test length following 809.5 hours of 60 Hz overvoltage testing and current loading at 90 C for 20 cycles and at 130 C for 15 cycles.

*** Strand shield was not a thermosetting material, and not subject to the requirements of these tests. Extractions conducted for informational purposes only. However, strand shield samples passed the requirements of AEIC 5-75.

AMBIENT TEMPERATURE: 22°C

62

SHIELD RESISTANCE - OHMS X 10^{-3}

ELAPSED TIME - MINUTES
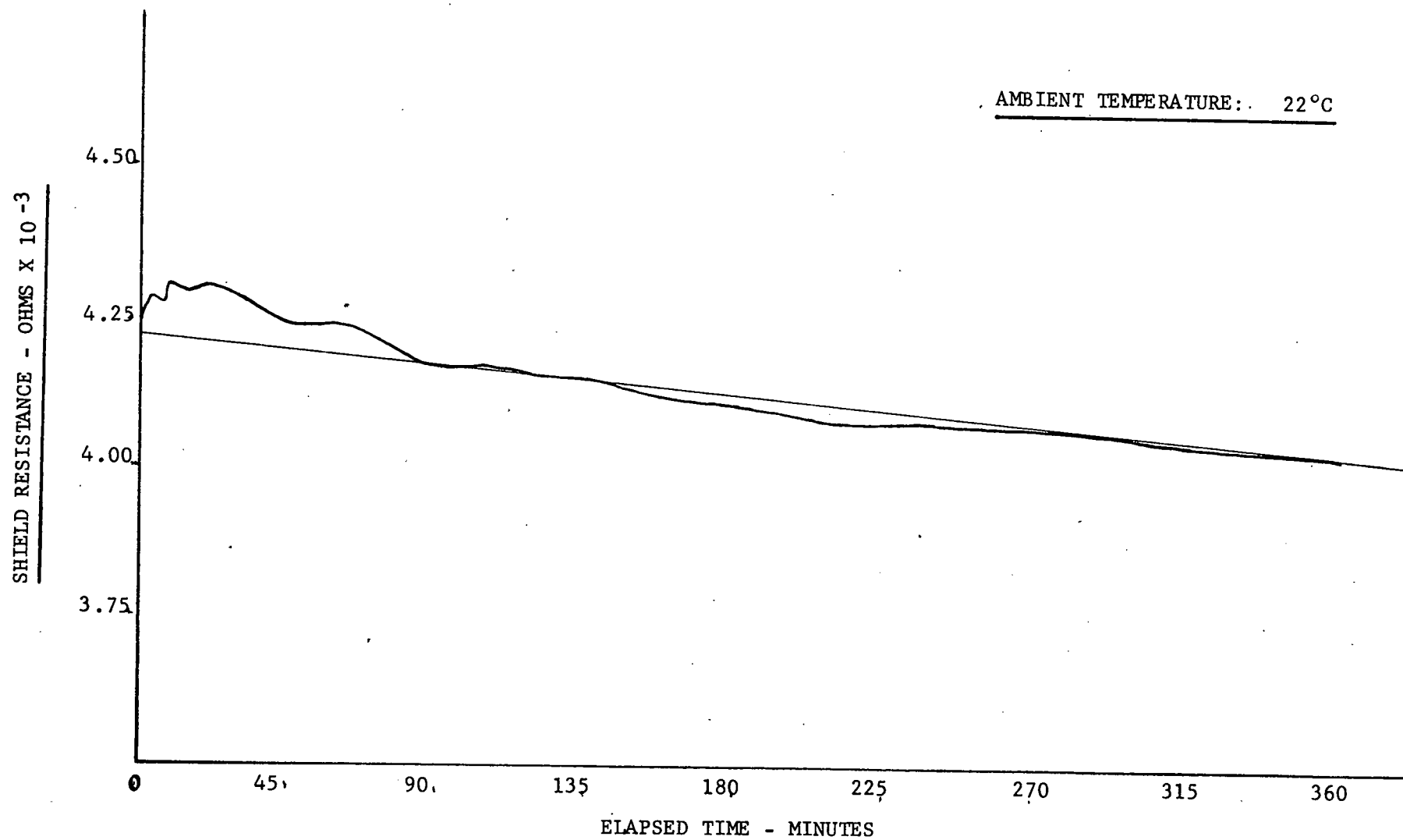
FIGURE 6.1
GRAPH OF CABLE SHIELD RESISTANCE
VS. ELAPSED TIME DURING TRANSITION FROM 90C.

AMBIENT TEMPERATURE: 23°C

SHIELD RESISTANCE – OHMS X 10^{-3}

ELAPSED TIME – MINUTES
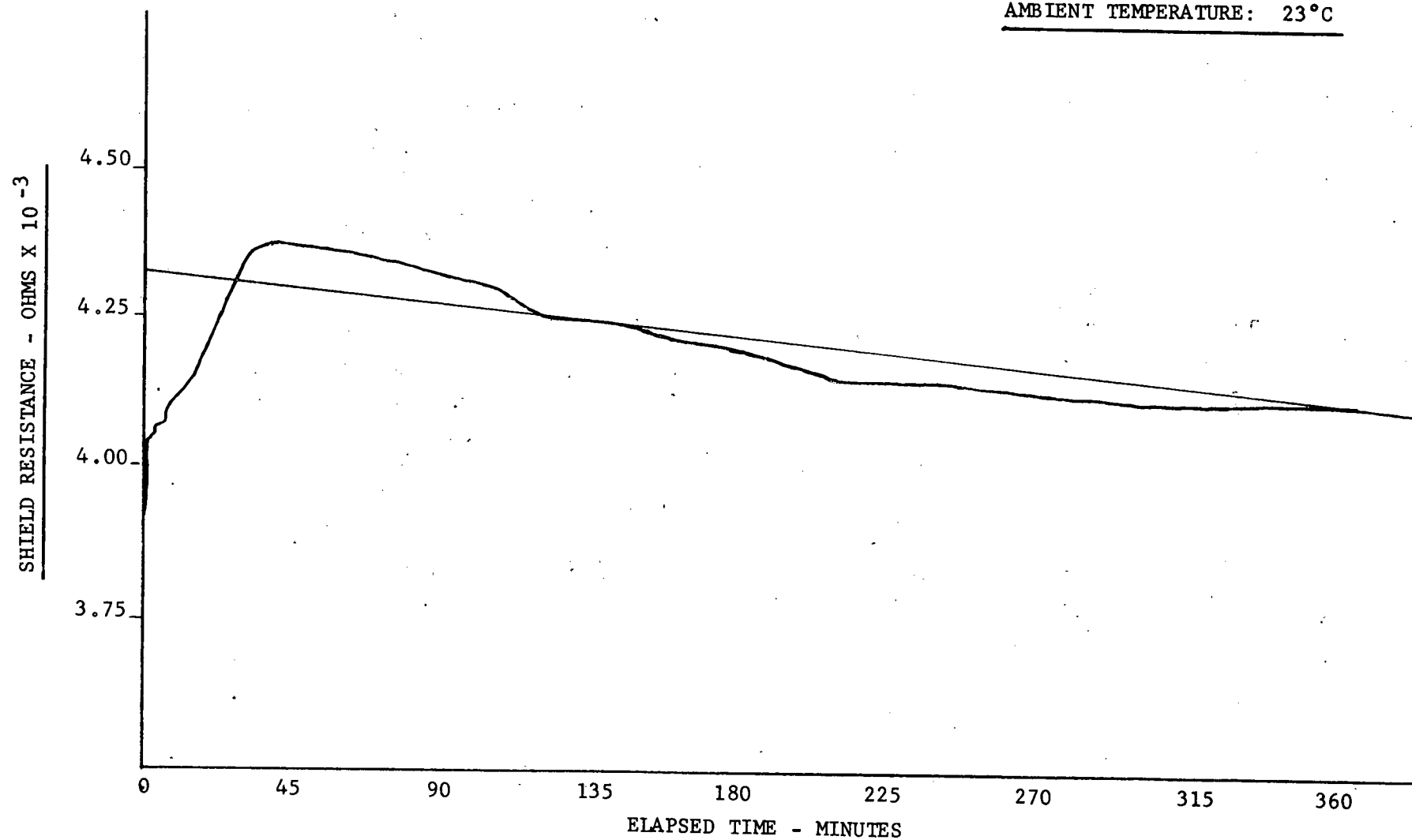
FIGURE 6.2

GRAPH OF CABLE SHIELD RESISTANCE
VS. ELAPSED TIME DURING TRANSITION FROM 130C.

63

7.0 RESEARCH PROGRAM IN 230kV. JOINTING

The objective of the jointing research program was to develop at least one fully reliable jointing technique for use with 230kV solid dielectric cable.

In order to achieve the objective, the program was planned to follow five avenues of research. These divisions of the program were carried on in parallel. They were:

(Category 1)	Taped Joint
(Category 2)	Vulcanized Joint
(Category 3)	Alternate Jointing Concepts
(Category 4)	Computer Programs
(Category 5)	Connector Evaluation

The planned program is included as Appendix 7.1. The following report on total progress on the program will be keyed to Appendix 7.1. A background description will precede the detailed report on each of the 5 categories.

7.1 CATEGORY 1 - TAPED JOINT

7.1.1 BACKGROUND

The use of EPR (ethylene propylene rubber) tapes as the means of insulating solid dielectric cable systems rated 138kV, and lower voltages, was proven to be a sound and reliable approach. In general, all taped joint problems encountered in the industry may be broken down into one or more of the following classes:

(A)   Improper preparation of cable ends including inadequate sanding and shaping of solid dielectric cable layers and a lack of geometric symmetry. The result of such inadequacies in workmanship is generally the creation of sites for abnormally high electrical stress and/or partial discharge eventually resulting in failure. The proper preparation of cable ends does require work, but is not difficult or unreasonable. The use of proper tooling is a great aid in reducing work time.

(B)   Failure to adhere to joint construction directions. Improper tape tensioning, improper application of shielding, inattention to cleanliness, incorrect dimensions, etc., are examples. The obvious result of such deviations from design can be failure. At best the result will be a joint that does not possess the desired design properties.

(C)   Incorrect conductor connection may lead to failure due to mechanical inadequacy or to progressive electrical degradation.

(D)   Failure to prevent ingress of water into the joint during and following construction may lead to joint failure. This is prevented by the use of suitable watertight coverings and proper sealing of all ground leads extending through this covering.

(E)   Unsuitable design can imply a number of factors. For example, electrical stress levels are reduced by dimensional increases. This dimensional increase can result in excessive mechanical forces in the joint in combination with increased mis-matching of the thermal characteristics of the joint in comparison with those of the cable. At the other extreme, electrical stresses may be increased beyond desirable levels, thus minimizing mechanical and thermal problems but making the joint un-reliable due to an inadequate electrical design margin of safety. The design of a reliable EPR taped joint must include electrical, mechanical and thermal considerations. The end result of such an approach will be an engineering "trade-off" yielding the best balance of electrical, thermal and mechanical characteristics.

The five classes of failures listed above may also be grouped in terms of construction considerations (Class A-D) and design considerations (Class E). The factors included in the first 4 classes are simply related to workmanship. Kaiser experience has been that correct workmanship always results in highly reliable joints when laboratory proven designs and materials are used. While mindful of the important construction considerations, developed through considerable labora-tory and field experience, the focus of attention in the research and development of a 230kV solid dielectric cable joint has been on design. In order to study the design of a possible 230kV taped joint the past experience on 138kV taped joint development and laboratory testing was reviewed. This work was done using Bishop Electric, Cedar Grove, N.J. (Reference 7.1) products. In particular, Bishop W-962 EPR splicing tapes and #17 conductive shielding tapes were used. The design of this successful 138kV taped joint is shown in Fig. 7.1. In order to relate the electrical stresses in this design to stresses later used for the 230kV program the various key electrical stresses are shown in Figures 7.2, 7.3, 7.4, 7.5, 7.6, and 7.7. In all of these figures, stress values from actually performed tests are shown as solid lines, while designed but untested design stress values are shown as dashed lines. Table 1 of Appendix 7.1 also shows selected test stress values for 4 different joint designs.

In order to identify the electrical stresses that are design considerations, Fig. 7.8 is a generalized drawing showing the location of each of the key design stresses.

65
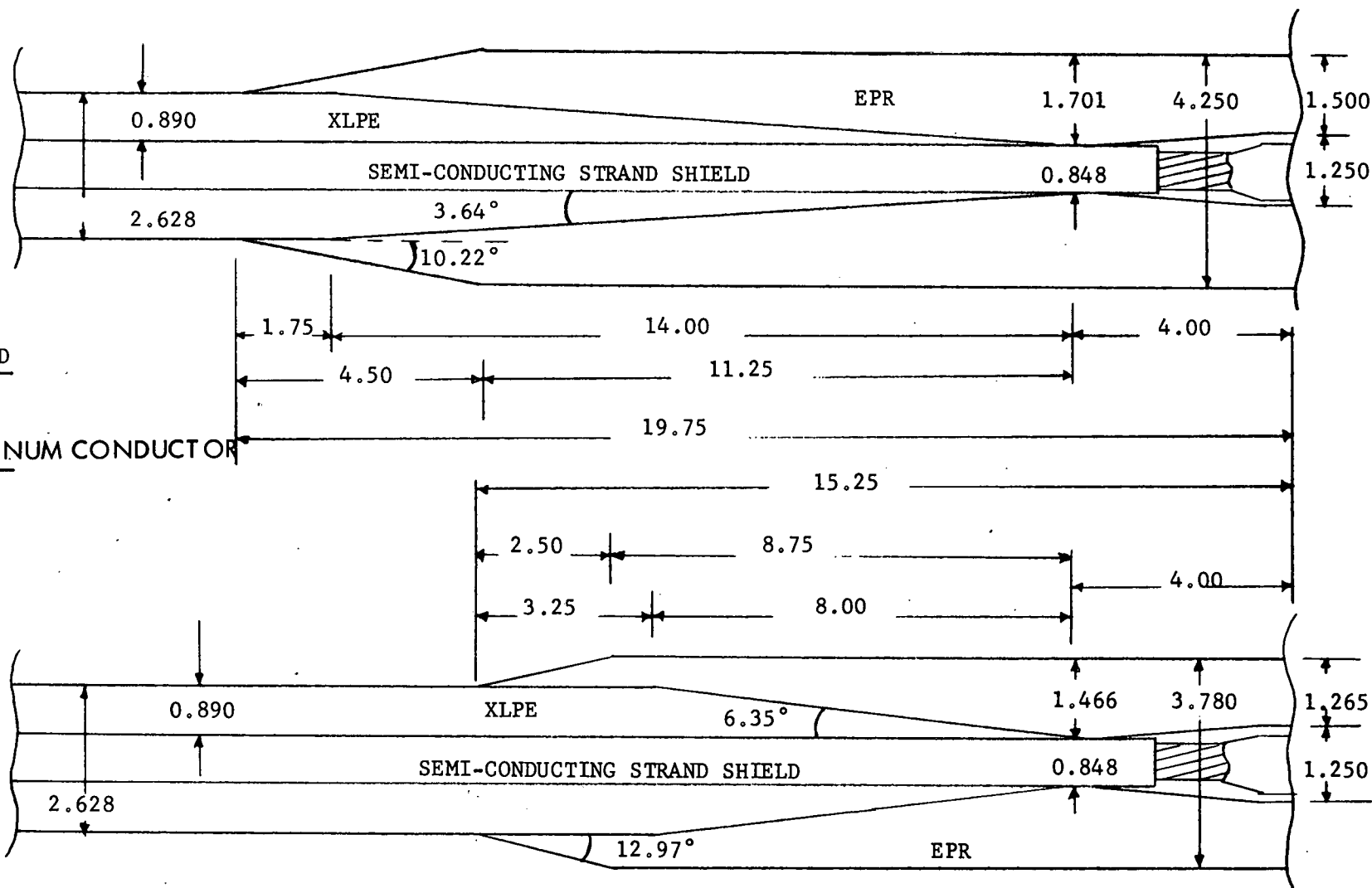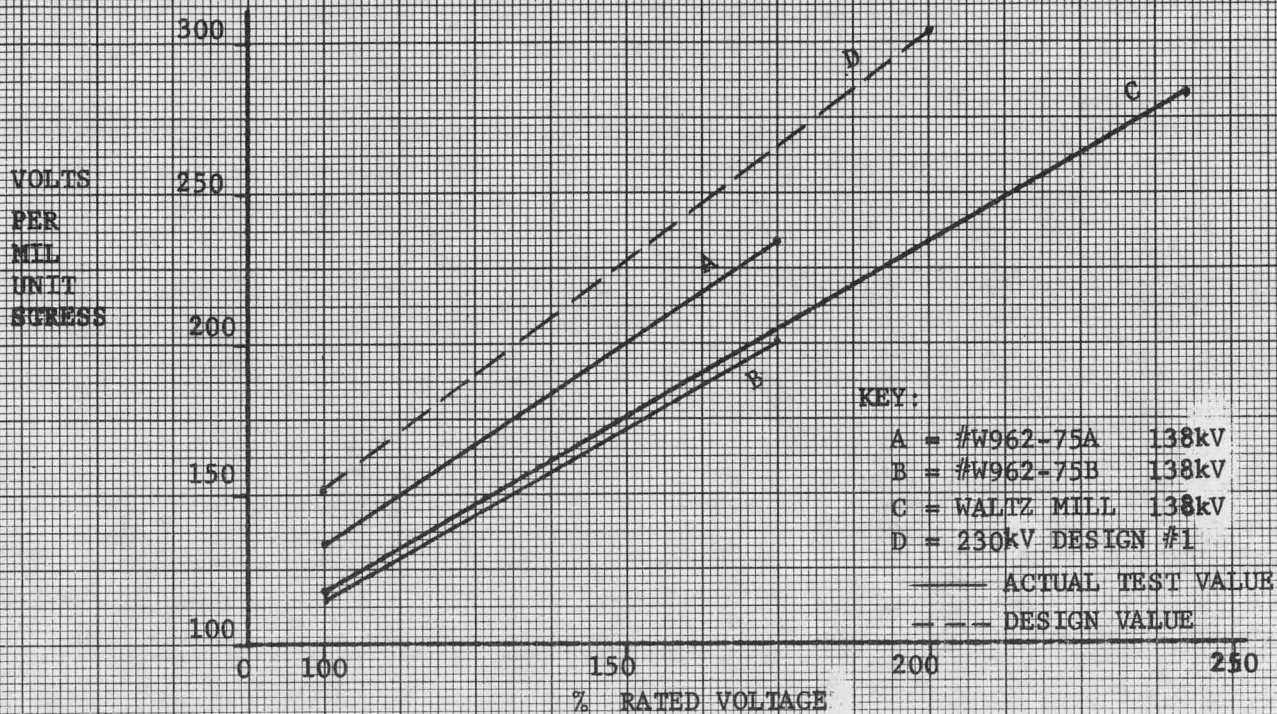
FIGURE 7.1

FIGURE 7.2   MAXIMUM RADIAL 60Hz UNIT STRESS
AS A FUNCTION OF RATED VOLTAGE USING
FOUR HAND-TAPED EPR JOINT DESIGNS

KEY:

A = #W962-75A   138kV
B = #W962-75B   138kV
C = WALTZ MILL   138kV
D = 230kV DESIGN #1
——— ACTUAL TEST VALUE
— — — DESIGN VALUE
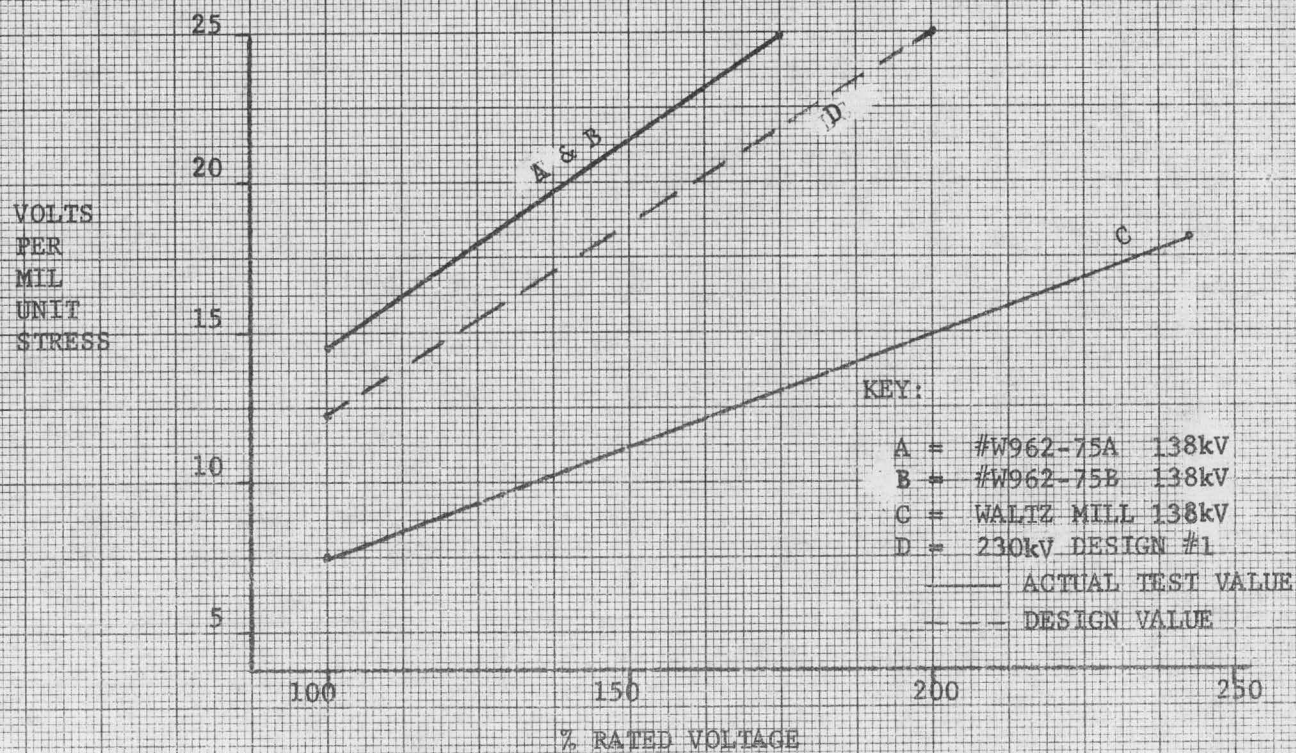
FIGURE 7.3   TANGENTIAL INTERFACIAL 60 Hz UNIT STRESS
AS A FUNCTION OF RATED VOLTAGE USING
FOUR HAND-TAPED EPR JOINT DESIGNS

KEY:

A = #W962-75A   138kV
B = #W962-75B   138kV
C = WALTZ MILL 138kV
D = 230kV DESIGN #1
——— ACTUAL TEST VALUE
— — — DESIGN VALUE

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VOLTS
PER
MIL
UNIT
STRESS

KEY:

A = #W962-75A 138kV
B = #W962-75B 138kV
C = WALTZ MILL 138kV
D = 230kV DESIGN #1
—————— ACTUAL TEST VALUE
— — — DESIGN VALUE
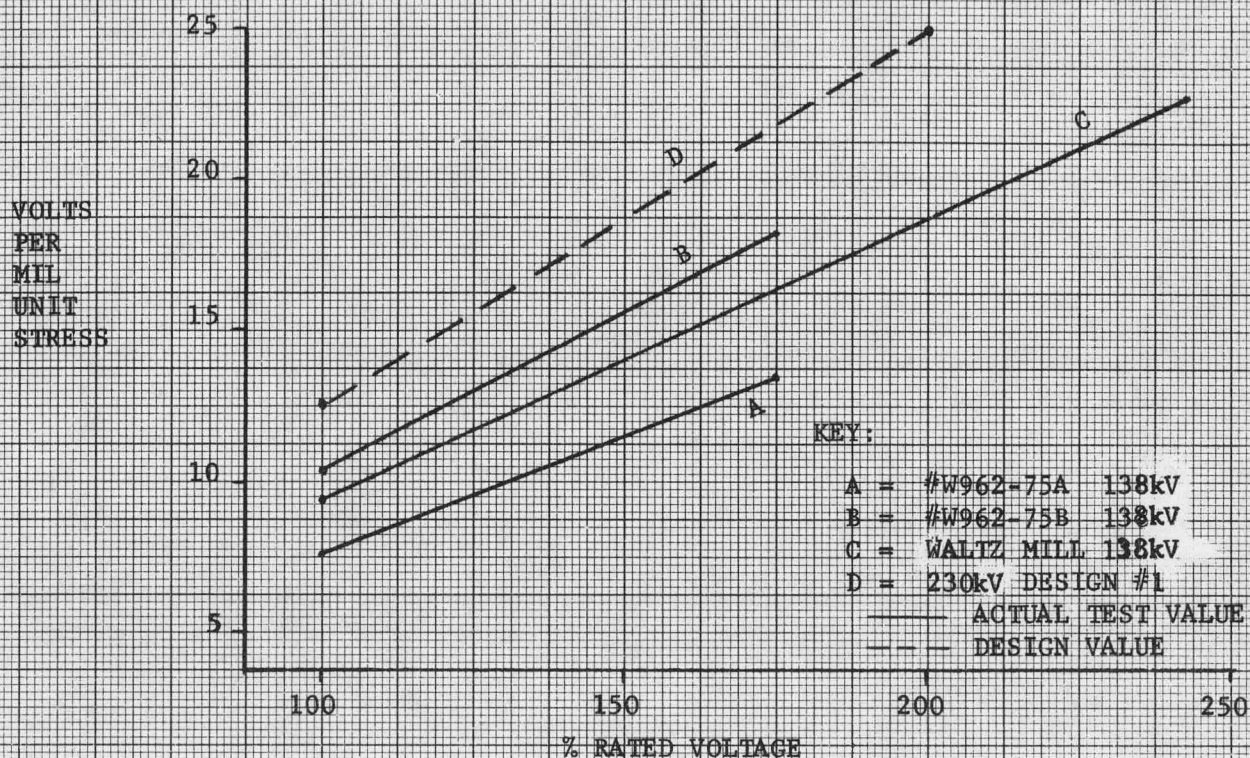
% RATED VOLTAGE

FIGURE 7.4   LONGITUDINAL INTERFACIAL 60 Hz UNIT STRESS
AS A FUNCTION OF RATED VOLTAGE IN FOUR
HAND-TAPED EPR JOINT DESIGNS

VOLTS
PER
MIL
UNIT
STRESS

KEY:

A = #W962-75A 138kV
B = #W962-75B 138kV
C = WALTZ MILL 138kV
—————— ACTUAL TEST VALUE
— — — DESIGN VALUE
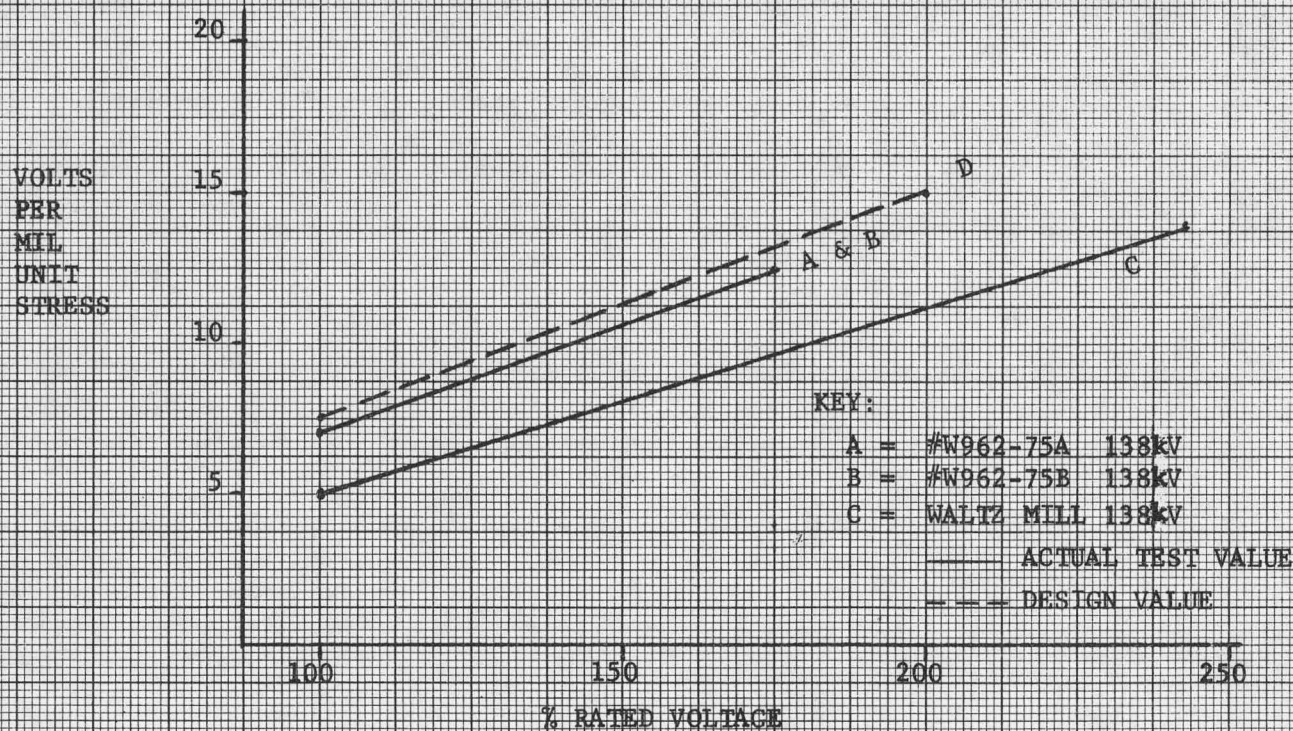
% RATED VOLTAGE

FIGURE 7.5   AVERAGE INTERFACIAL 60 Hz CREEPAGE UNIT STRESS
AS A FUNCTION OF RATED VOLTAGE IN FOUR
HAND-TAPED EPR JOINT DESIGNS
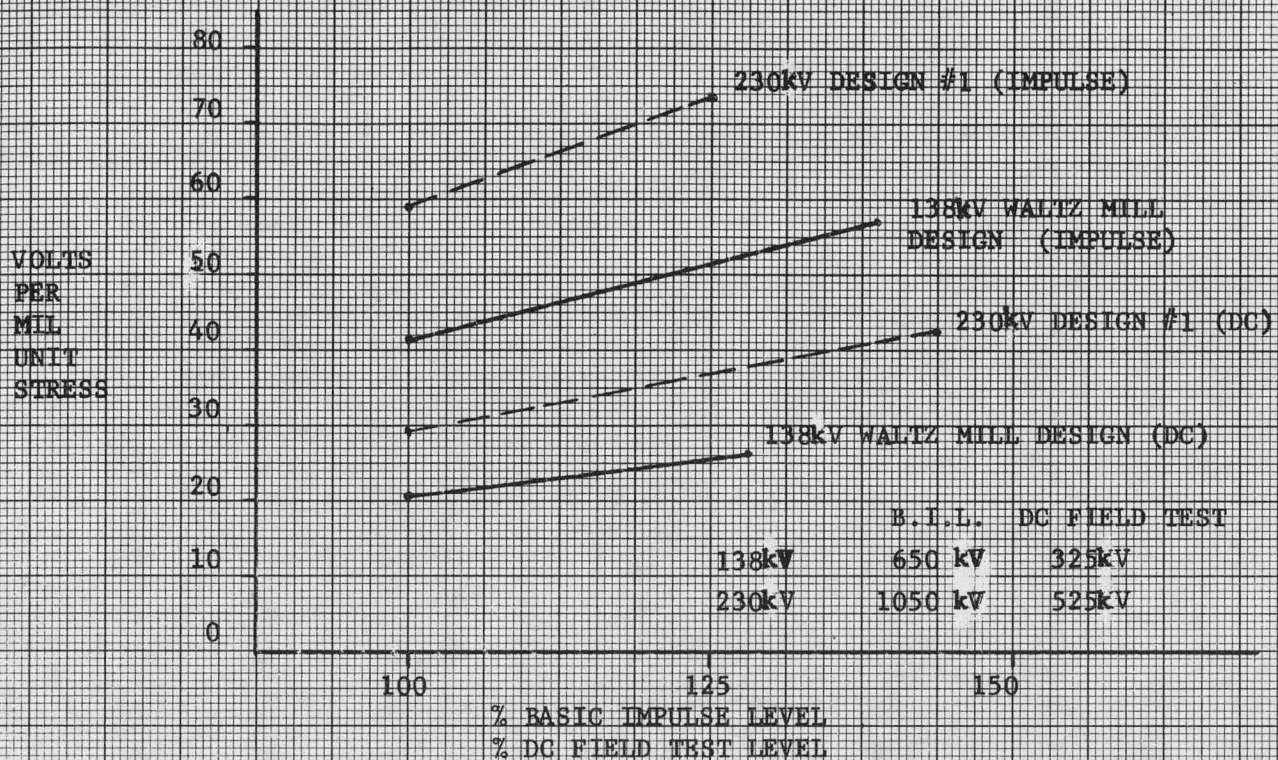
FIGURE 7.6   UNIT DC AND IMPULSE CREEPAGE STRESS AS
A FUNCTION OF TEST LEVEL IN TWO HAND-TAPED
EPR DESIGNS
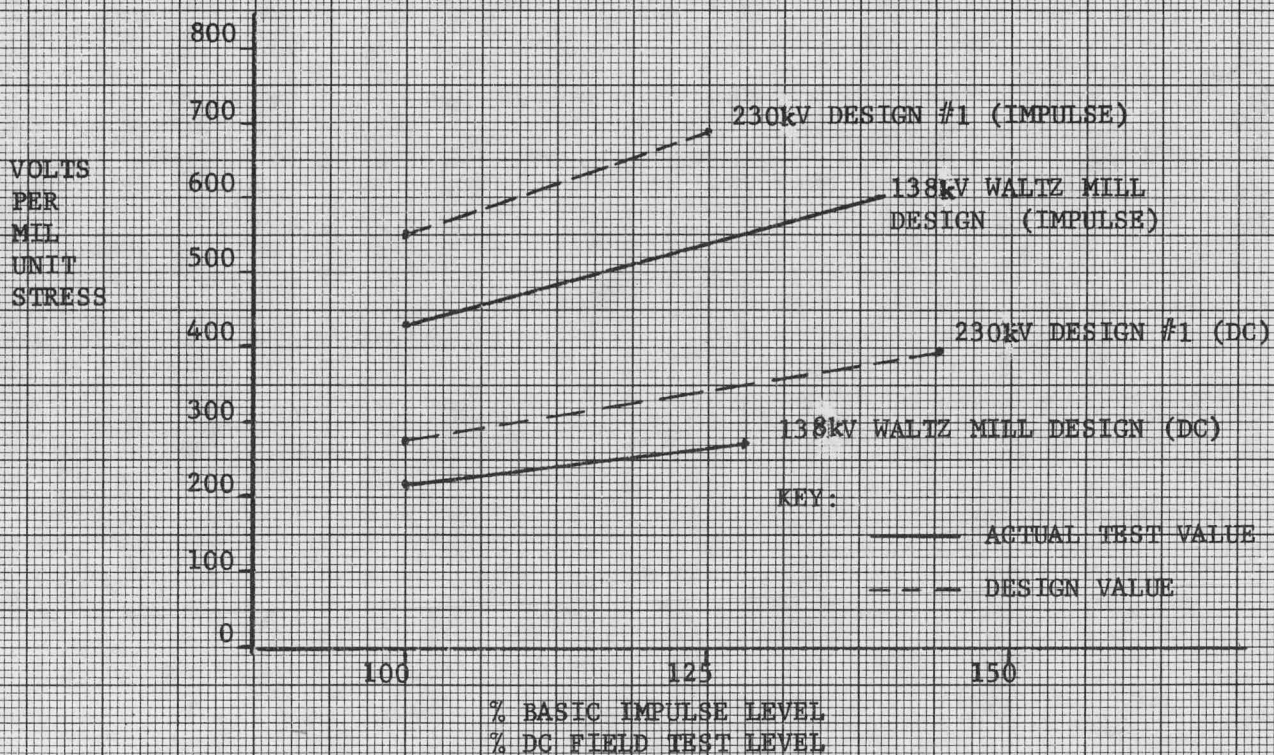
FIGURE 7.7   AVERAGE RADIAL DC AND IMPULSE UNIT STRESS
AS A FUNCTION OF TEST LEVEL IN TWO
HAND-TAPED EPR DESIGNS

FIGURE 7.8

IDENTIFICATION OF ELECTRICAL

STRESS IN JOINT DESIGNS
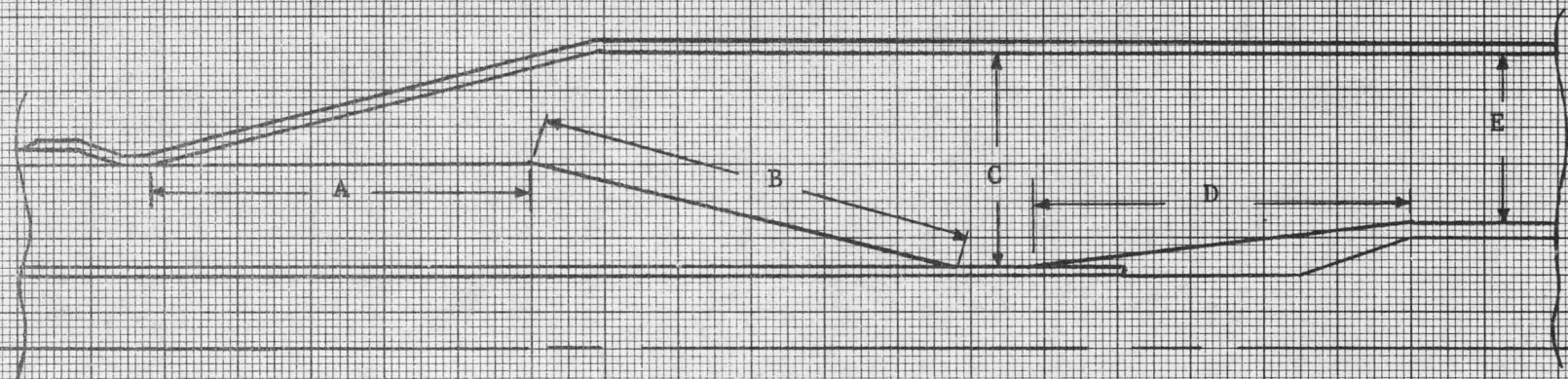
A   =   Interfacial Longitudinal Stress (Calculated at Highest Stress Location).

B   =   Interfacial Tangential Stress (Calculated at Highest Stress Location).

A + B =   Average Interfacial Creepage Stress.

C   =   Average Radial Stress (Maximum Radial Stress Calculated at Center Electrode Shield).

D   =   Longitudinal Connector Area Stress (Calculated at Highest Stress Location).

E   =   Average Radial Stress (Maximum Radial Stress Calculated at Center Electrode Shield).

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Considering that all construction details were properly carried out, the following observations on performance of the 138kV Waltz Mill design were made:

(F)   Electrical interfacial stresses (pencil tangential stress and stress cone longitudinal stress) might be increased for use in a 230kV design while still retaining a reasonable design margin of safety. This was based upon the absence of any interfacial breakdowns in Kaiser's test experience even though interfacial stresses as high as 22.5 volts per mil were experienced (Fig. 7.3 and 7.4).

(G)   The Waltz Mill qualification joint withstood maximum radial 60 Hz stress in excess of 270 volts per mil before eventually failing in the radial mode. It was felt that a designed maximum stress significantly greater than the rated 117 volts per mil value used for the 138kV joint would very likely be workable (Fig. 7.2).

(H)   The creepage stress (60 Hz, DC and Impulse, Fig. 7.5 and 7.6) might be increased to some extent. Since creepage stress is also an interfacial stress it was presumed that this might be done while still retaining a reasonable design margin of safety.

(I)   The welded connector and conductor within the taped joint was found to be operating at about 170C when the cable conductor was at 130C. Although the 130C emergency temperature would be imposed on the cable system for no more than 500 hours in a 40-year life, it was necessary to ensure that the joint could also withstand the emergency rating of 130C without detriment. The higher temperature within the joint (170C) was the result of the poorer heat dissipating properties of the joint layers as compared to cable layers. This is in part effected by the bulk of the joint, hence the shorter and smaller in diameter the joint, the more closely the joint will thermally "match" the cable in ability to dissipate heat.

The problem is partially due to the higher thermal resistivity (thermal rho) of the EPR tapes in comparison to the XLPE cable insulation. The problem condenses to finding the steps that may be taken to reduce the over-temperature that occurs in the joint. Basically, this may be done by: (a) reducing I^2R heating by use of a connector having electrical resistance much lower than the conductor, and/or (b) designing the joint to be as close as possible to the cable in its heat-dissipating properties.

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A formula derived from Neher-Mc Grath (Reference 7.2) for use in the laboratory to calculate ampacities of test cables may be adapted to more clearly observe the importance of comparison between the cable and the joint heat dissipating properties. R_{ca}' is a mathematical factor used in the calculation of cable/joint ampacity. It is derived by calculating the heat − dissipating properties of the cable or joint. Figure 7.9 shows the ratio of R_{ca}' (joint) to R_{ca}' (cable) making the assumptions that cable and joint walls remain the same for all conductor sizes and that conductor size is the only variable. The data are derived from the formulae in Appendix 7.2. For the splice design, any reduction in the factor for heat dissipation (R_{ca}') would cause the joint conductor to run cooler and thus reduce the R_{ca}' joint/cable ratio in the direction of unity. If unity could be achieved than the joint would run at the same temperature as the cable (assuming Rac of the joint is identical to that of the cable). Referring again to the basic formula shown at the beginning of Appendix 7.2, it is also evident that any means by which the denominator product (Rac) (R_{ca}') for the joint calculation may be made equal to the denominator product for the cable calculation, will result in the joint conductor running at the same temperature as the cable conductor. Thus if the joint Rac can be reduced to a value equal to

$$\frac{Rac \ (cable)}{ratio \ R_{ca}' \ \frac{(joint)}{(cable)}}$$

the objective could be achieved. In actual practice a connector having a much lower resistance than this would be required because the connector comprises a relatively small portion of the total axial length of conductor enclosed within the joint.

7.1.2 JOINT DESIGNS, EVALUATIONS AND TESTS

The actual steps which have been taken will now be outlined. Reference Appendix 7.1.

STEP I

A 138kV taped joint using Bishop materials was designed and constructed. The electrical stresses in this joint are tabulated in Table I of Appendix 7.1. Individual electrical stresses are graphed in Figures 7.2, 7.3, 7.4 and 7.5. The joint was identified as W-962-75A and was installed in our laboratory long-term 138kV 400 kcmil test circuit. The joint was tested at 150% rated voltage (120kV phase-to-ground) for 360 hours. Tangential interfacial stress at this test level was 21.4 volts per mil, an increase of 89% over the comparable stress in the Waltz Mill 138kV design. The objective of the test was to evaluate the joint for withstand ability for 360 hours and to dissect and inspect the joint following the test. Although partial discharge measurements were made on this joint, it was not possible to isolate

72
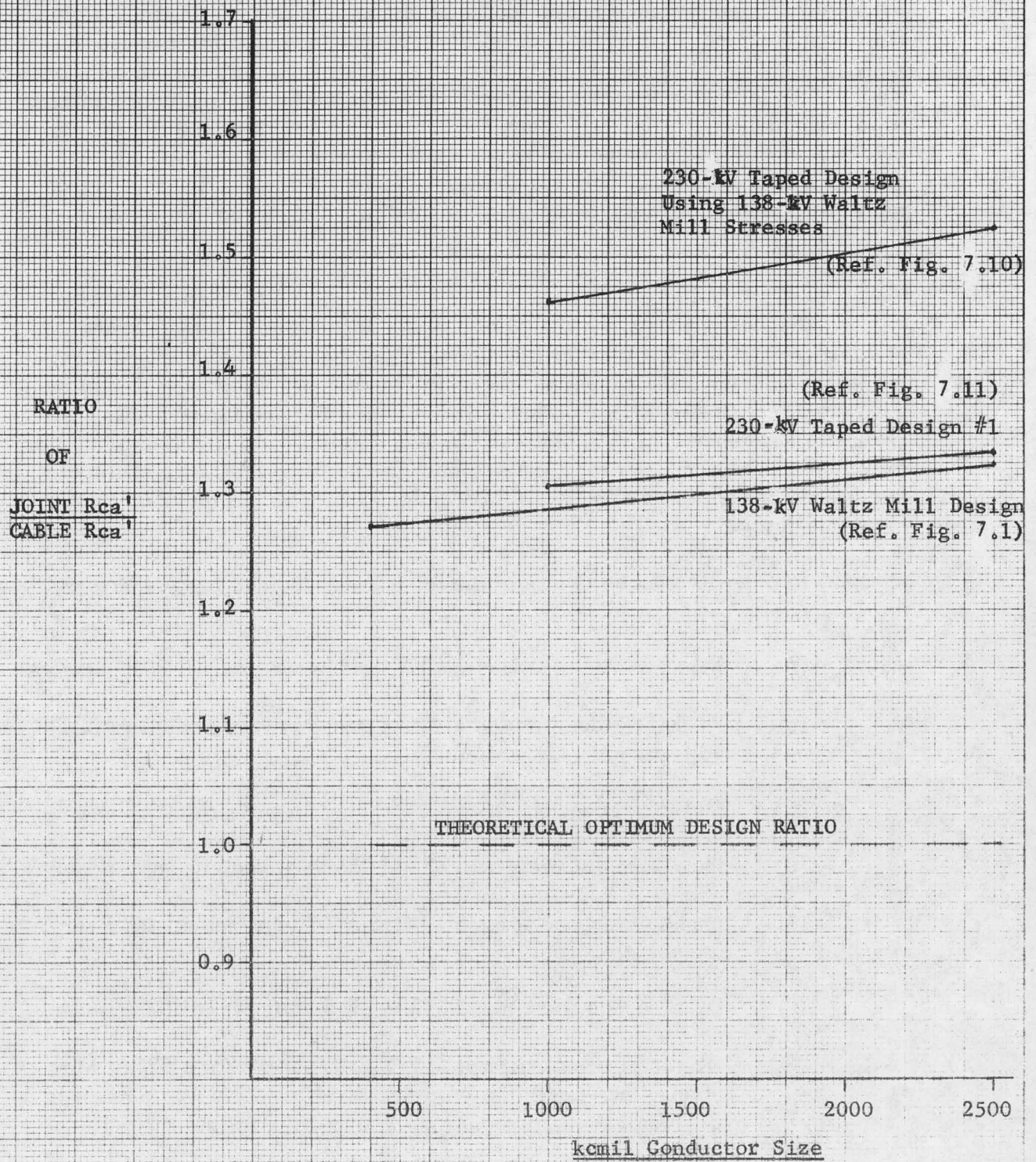
FIGURE 7.9

Joint/Cable Rca' Ratio of
Three Hand-Taped EPR Joint
Designs

the joint sufficiently from a known source of discharge elsewhere in the test circuit. Discharge observed in the joint was 16 picocoulombs (pC) at 120kV and 1.5 pC at 98kV. It could not be determined if this 16 pC was emanating from the joint or the cable. This joint was dissected and carefully inspected for any indication of electrical degradation, particularly along the cable/joint insulation interfaces. No evidence at all was found indicating any electrical breakdown of this interface under 10X magnification. This was considered to be solid indication that higher tangential interfacial stress levels could be used in 230kV taped joint designs.

STEP 2

The next step was the design of a 230kV taped joint. If the stresses used in our successful 138kV Waltz Mill design were simply applied to a 230kV design, the joint would have the dimensions shown in Figure 7.10. While this design would keep electrical stresses at proven levels it would certainly represent a still greater mismatch (Reference Fig. 7.9) between cable and joint heat dissipating properties, resulting in joint conductor temperatures much greater than 170C. Mechanical forces and construction difficulty are also design considerations that might not favor this design.

In order to reduce the size of the joint it was decided to raise stresses in the 230kV joint design as follows:

(A)   Maximum radial stress from 117 to 152 volts per mil (30% increase)

(B)   XLPE/EPR tape interfacial stress from 9.4 volts per mil to 12.5 volts per mil (33% increase)

(C)   60 Hz creepage stress from 5 to 7.5 volts per mil (50% increase)

(D)   Impulse radial stress from 433 to 556 volts per mil (28% increase)

(E)   Impulse creepage stress from 41.3 to 59 volts per mil (43% increase)

(F)   DC creepage stress from 26.3 to 29.5 volts per mil (12% increase)

(G)   DC radial stress was kept at 277 volts per mil for a 525kV test level. Increase in the joint test level to 750kV would result in a DC radial stress increase from 277 to 397 volts per mil (43% increase)

Comparison of the electrical stresses in the 230kV design with past test experience can be seen in Figures 7.2, 7.3, 7.4, 7.5, 7.6 and 7.7. Past test experience includes over 12,000 hours of testing performed in Kaiser's high voltage

NOTE: Only Electrical Stress
Exceeding 138-kV Waltz Mill
Design Value is Interfacial
Longitudinal Stress

Scale 1:3

Dimensions in Inches

BISHOP W-962 EPR

7.611

3.00

1.050

1.271

XLPE

3.17

10.25

16.5

Taper Length

3.5

Stress Cone

13.5

16.75

30.25
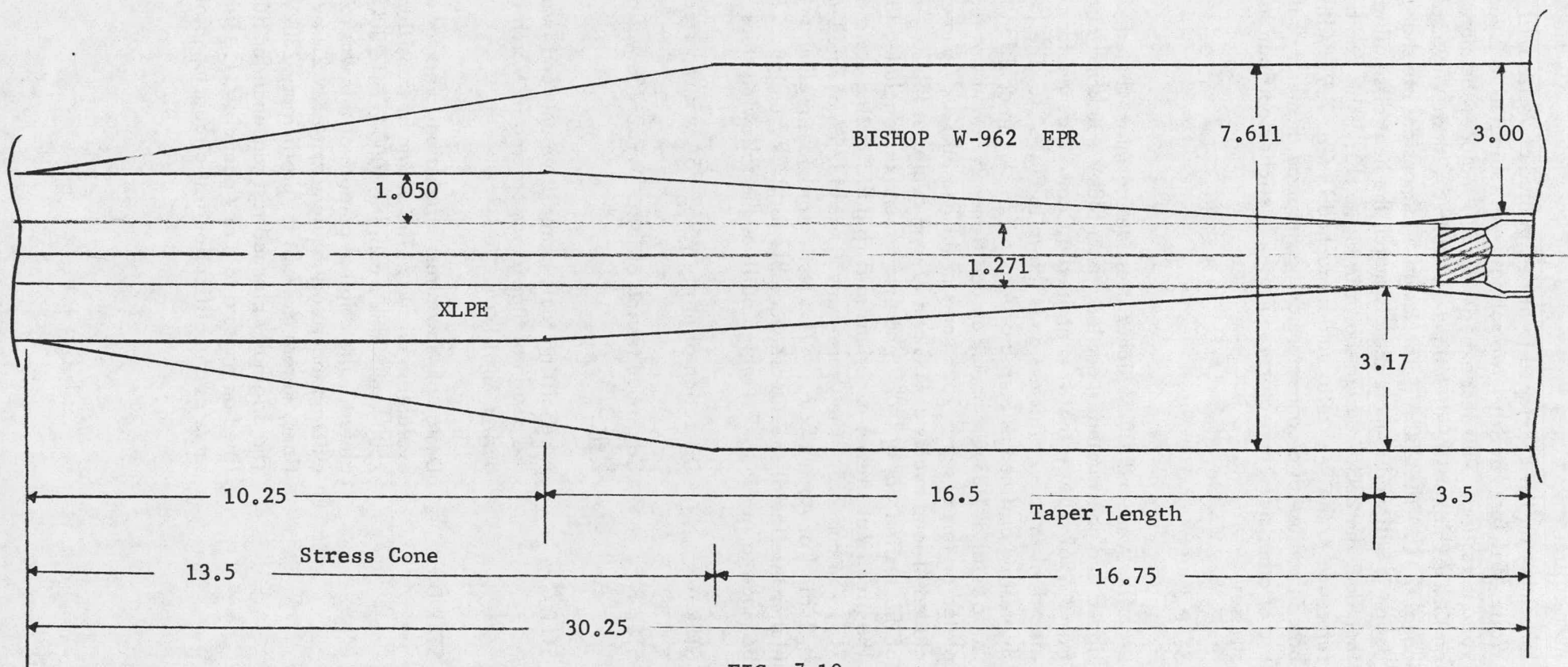
FIG. 7.10

DESIGN OF A 230-kV TAPED EPR JOINT WITH ELECTRICAL STRESSES NOT EXCEEDING
THOSE OF 138-kV WALTZ MILL DESIGN

laboratory on the EPR-taped joint design used at Waltz Mill. In addition, at the Waltz Mill Test Facility, two splices were subjected to 2 years of accelerated voltage testing. Past test experience also includes the more recent work performed on 138kV "higher stress" designs #W-962-75A and #W-962-75B. (Reference page 72). The 230kV joint design #1 dimensions are shown in Fig. 7.11. This design is believed to more closely match the heat dissipating properties of the cable than does the 230kV design shown in Fig. 7.10. This can be seen clearly by reference to the R_{ca}' ratio values graphed in Fig. 7.9. Although the design was based upon use of a connector having the same diameter as the cable conductor, use of other size connectors requires only slight modification of dimensions and stresses.

STEP 3

A second 138kV higher stress design joint labeled #W-962-75B was designed and constructed in our long-term 138kV 400 kcmil circuit. This differed from #W962-75A in that it contained a Cadweld connector and slightly different electrical stresses. This design is shown in Fig. 7.1. The joint was subjected to the testing outlined as Step B of Appendix 7.1. In addition to that testing, which was a total of 1133 test hours, an additional 2972 hours of testing have been completed on this design. 2526 hours of this was at 120kV phase-to-ground and included 41 load cycles at 90C and 10 load cycles at 130C. An additional 446 hours of this testing was at 140kV phase-to-ground and included 15 load cycles at 90C. The electrical stresses experienced during this testing are shown in Figures 7.2, 7.3, 7.4 and 7.5. The stresses at 150% and 175% of rated voltage are also shown in Table 1 of Appendix 7.1. This testing provides preliminary indication that higher interfacial stresses are workable for 230kV designs. Further reference should be made to Appendix 7.1 which outlines the following steps:

STEP A -   Dissection of joint #W962-75A was reported under Step 1.

STEP B -   Continued testing of joint #W962-75B was reported under Step 3.

STEP C -   A pencilling tool, motor drive unit and insulation stripper for the design of Step 2 was ordered in March 1976 and received during April 1976.

STEP D -   Design of "low-stress" transition joints for a 230kV splice evaluation circuit. The design of transition joints to connect 2500 kcmil 138kV cable to 1000 kcmil 230kV cable was completed. The original purpose of this was to enable us to utilize existing laboratory equipment (G&W 230kV paper roll terminations, Reference 7.3) for preliminary 230kV joint evaluation. The originally planned test sequence for this circuit was outlined on pages 6 to 8 of Appendix 7.1. This circuit was to serve as a qualification test circuit for joint designs in order

230-kV KAISER

TAPED SPLICE DESIGN #1

1000 kcmil ALUMINUM

SCALE = 1:3

BISHOP W-962 EPR

1.050   XLPE

1.890   5.051

1.271

SEMI-CONDUCTING STRAND SHIELD

MIG WELD

5.25
STRESS CONE

12.80
CABLE INSULATION TAPER

5.00

23.05

CABLE INSULATION TAPER ANGLE = 4.69°
STRESS CONE ANGLE = 9.09°
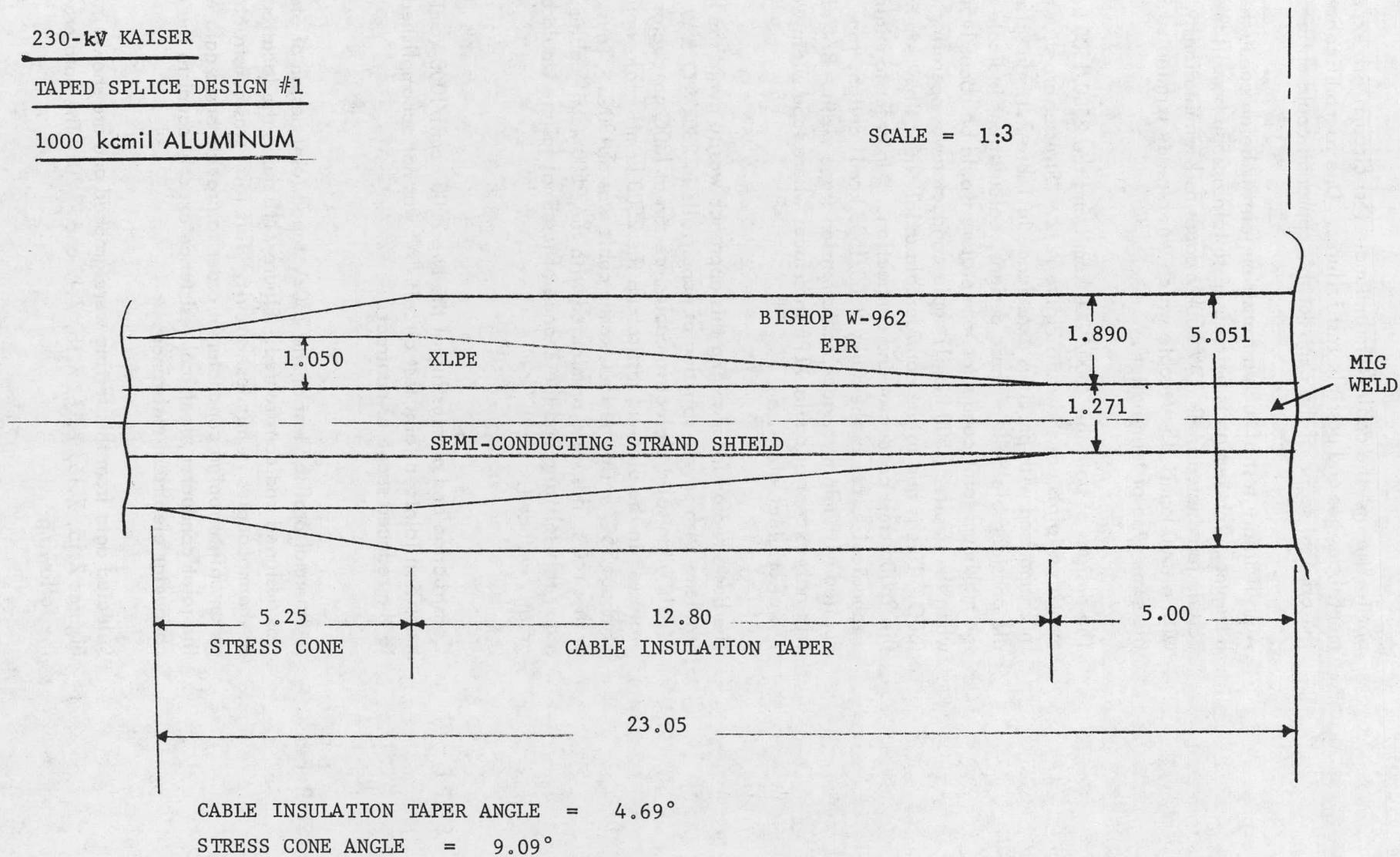
FIGURE 7.11

not to "tie up" the cable/terminal main test circuit with experimental designs and possible test failures. Due to modification of the original scope of the contract this approach could not be used.

A preliminary test of such a transition joint is being conducted, however. This design is being used to join a 2500 kcmil 138kV cable, terminated in G & W 230kV paper roll terminations, with a 1500 kcmil 115kV cable which was already terminated in the same type of termination.

The designs of both the 2500/1000 kcmil and the 2500/1500 kcmil transition joints are shown in Figure 7.12. Stresses are shown in comparison with previous experience in Table 7.1. In spite of the considerable bulk of these designs, calculations indicate that the maximum joint conductor temperature would be about 145C when the smaller (1500 kcmil) cable conductor was operating at 130C. This is due to the considerable axial "heat sink" effect of the 2500 kcmil conductor and connection. In order to minimize mechanical forces in the bulky 2500/1500 kcmil design, tapes were applied with minimum acceptable tension (tape width = 3/4 of original) except at cable XLPE interfaces where tape width was 2/3 of original width.

The basic reason for planning this approach was to avoid the known problems with severe splitting of paper rolls in 230kV G & W terminals when solid dielectric cables are run at 130C conductor temperature. In the planned test set-up the 2500 kcmil cable would run at about 75C while the 1500 kcmil cable was at 130C. Thus, if both circuit ends were terminated with the 2500 kcmil cables, paper roll splitting and the chance of terminal failure would be greatly reduced.

STEP E –   Construction and pre-testing of the two 2500 kcmil/1000 kcmil transition joints in joint test circuit "A" was not accomplished due to the reduced scope of contract.

STEP F –   A "thermal profile" test of the 230kV taped joint design of Step 2 was designed and constructed. Figure 7.13 shows the location of thermocouples in this test circuit. This joint was constructed on an uninterrupted conductor in order to provide basic data with the joint conductor electrical resistance exactly equal to the cable conductor electrical resistance.

Selected data from this testing were graphed and are shown in Figures 7.15, 7.16, 7.17, 7.18, 7.19 and 7.20. The data provides the following:

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9.25   13.0

BISHOP W-962 EPR   8.0

XLPE   XLPE

1"   2.82

20.25   7.0   20.0

138-kV 2500 kcmil   230-kV 1000 kcmil
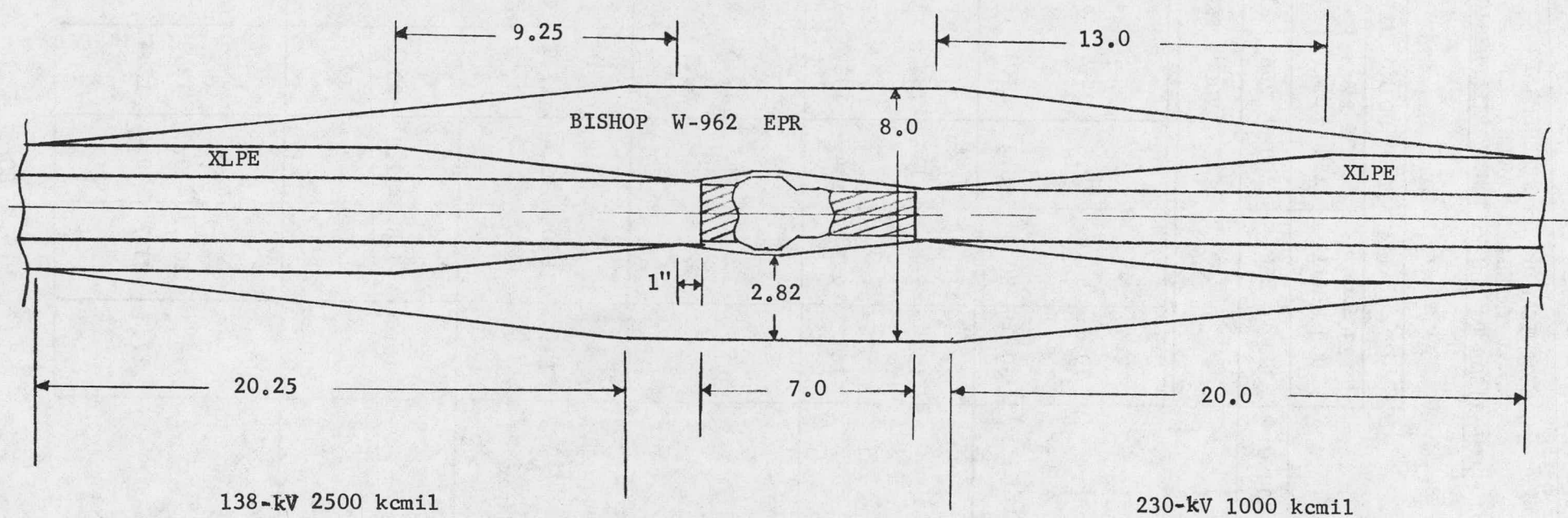
FIG. 7.12

DESIGN OF A HAND-TAPED EPR 230-kV 2500/1000 kcmil
TRANSITION JOINT USING "LOW" ELECTRICAL STRESS

TABLE 7.1

ELECTRICAL 60 Hz STRESSES IN
230-kV TRANSITION JOINTS IN
COMPARISON TO 138-kV WALTZ MILL DESIGN

	TRANSITION JOINT HALF						138-kV WALTZ MILL DESIGN	
	230-kV 1000 kcmil		138-kV 2500 kcmil		115-kV 1500 kcmil			
KILOVOLTS, PHASE-TO-GROUND →	200	266	200	266	200	266	120	160
	VOLTS PER MIL							
60 Hz Stress <u>Average Radial Stress</u>								
At Splice Center	70.8	94.4	70.8	94.4	70.8	94.4	80.0	106.6
At Cable Insulation Taper Edge	60.0	80.0	66.2	88.3	62.0	82.7	70.5	94.0
<u>Maximum Radial Stress</u>								
At Splice Center	139	185	139	185	139	185	157	209
At Cable Insulation Taper Edge	167	222	144	193	156	208	176	235
<u>Average Interfacial</u> <u>Creepage Stress</u>	9.4	12.5	9.4	12.5	9.4	12.5	7.5	10.0
XLPE/EPR Interface Tangential Stress Across First 0.25" of Cable Insulation Taper	13.5	18.0	13.4	17.9	13.5	18.0	10.5	14.0
XLPE/EPR Interface Longitudinal Stress Across First 0.25" At Stress Cone Base	13.4	17.8	17.6	23.5	21.5	28.6	12.5	16.6
Connector Area Longitudinal Stress <u>Across First 0.25"</u>								
At Shield Shoulder	15	20	9.0	12.0	15	20	-	-
At Shield Taper Base	17.8	23.7	9.4	12.5	16.8	22.4	11.3	15.0

PVC/EPOXY/PVC SHELL

CABLE PVC JACKET

CABLE CU TAPES

CABLE S.C.

PVC/EPOXY/PVC SHELL

1/2 LAPPED W-962(SINGLE LAYER)

COPPER MESH

BISHOP S.C.

BISHOP W-962 EPR JOINT INSULATION

XLPE CABLE INSULATION

1000 kcmil ALUMINUM CONDUCTOR
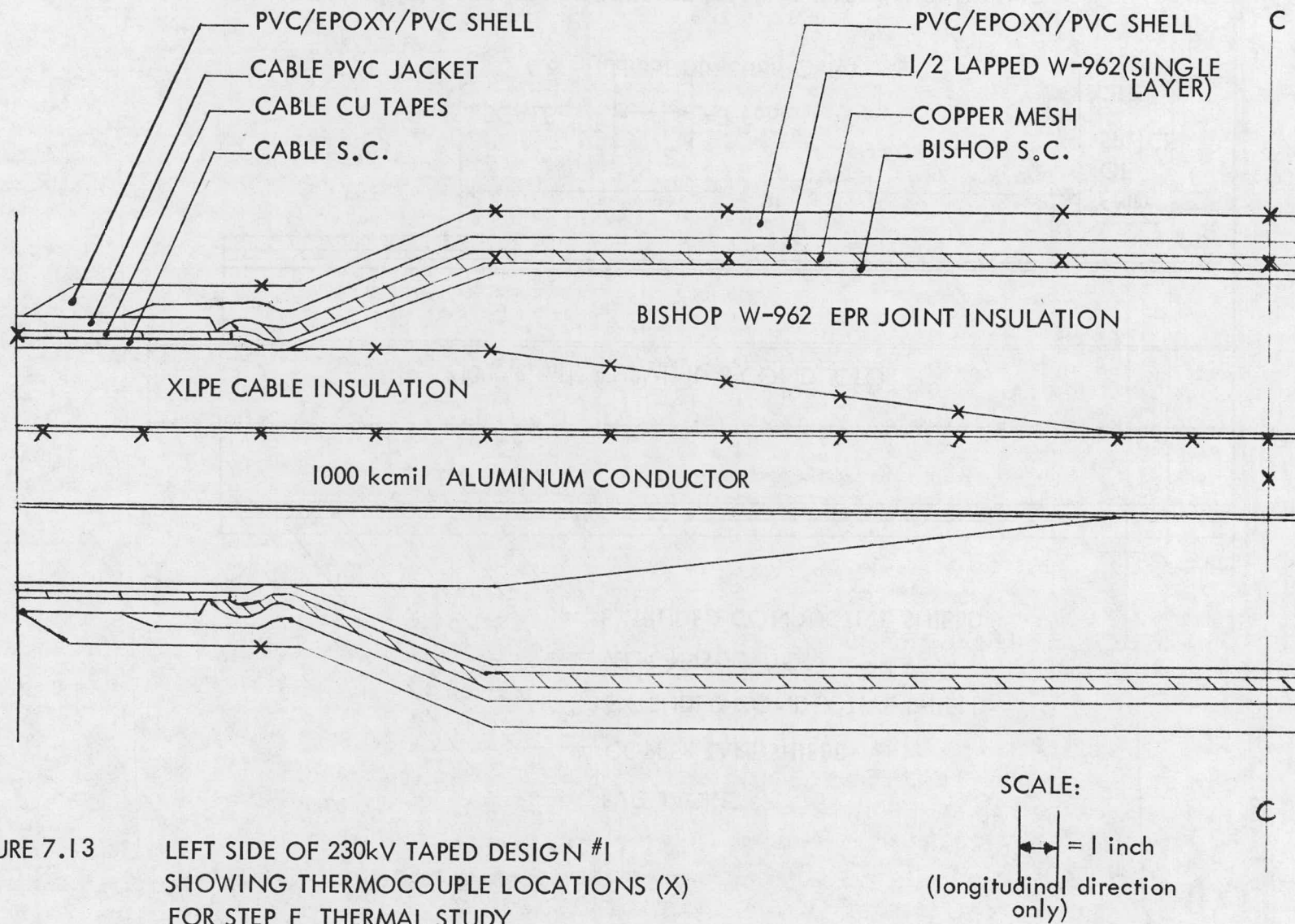
FIGURE 7.13   LEFT SIDE OF 230kV TAPED DESIGN #1
SHOWING THERMOCOUPLE LOCATIONS (X)
FOR STEP F THERMAL STUDY

SCALE:

= 1 inch

(longitudinal direction only)

PVC JACKET

COPPER TAPE SHIELD

EXTRUDED CONDUCTIVE SHIELD

XLPE INSULATION

EXTRUDED CONDUCTIVE SHIELD

1000 kcmil ALUMINUM CONDUCTOR

8'

END
OF
SPLICE

SCALE: |←→| = 1 Foot

(Longitudinal Direction Only)

82
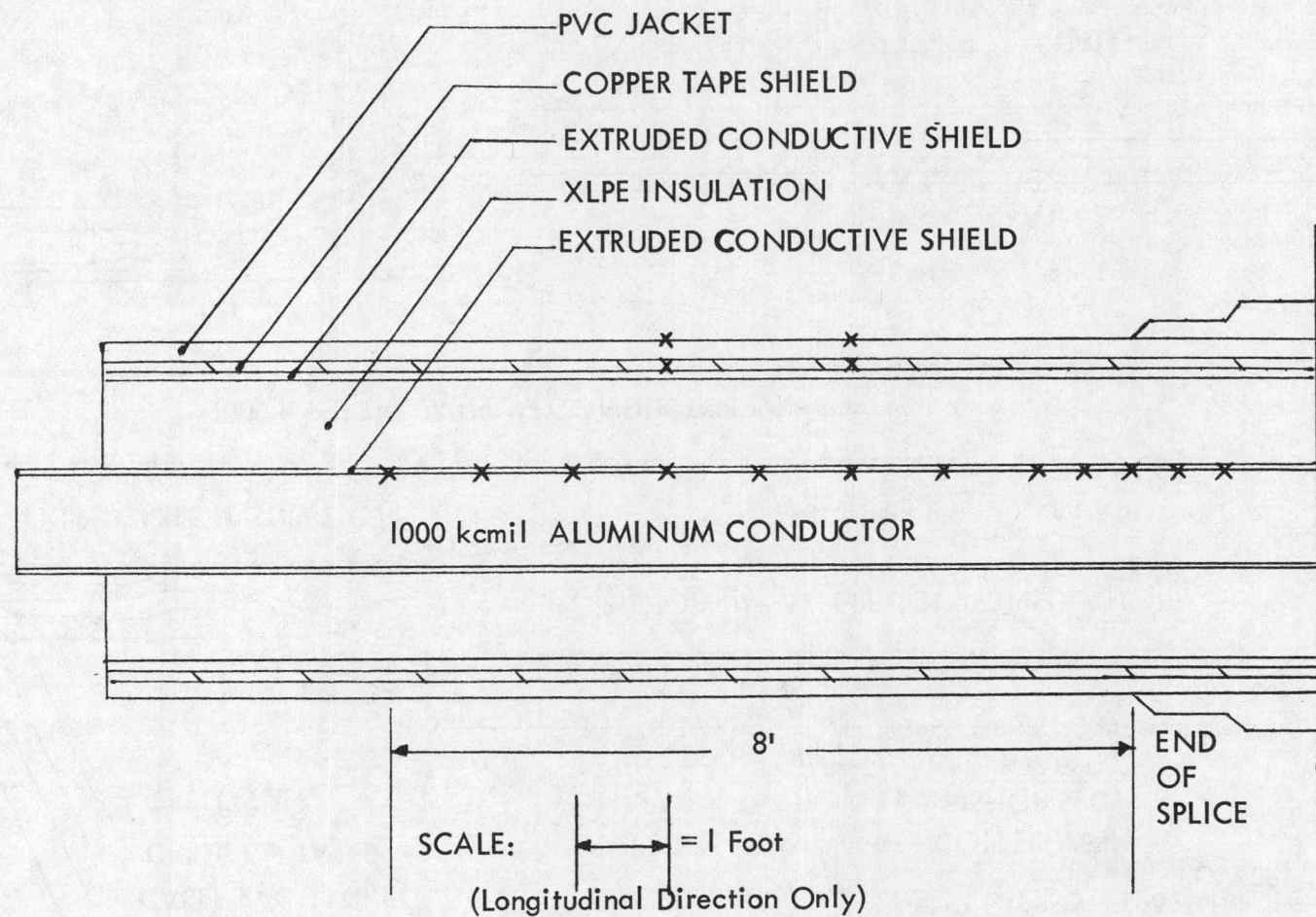
FIGURE 7.14.   230kV CABLE PORTION TO LEFT OF SPLICE DESIGN #1 SHOWING
THERMOCOUPLE LOCATIONS (X)

230-kV CABLE, 1000 kcmil ALUMINUM CONDUCTOR

KEY A = Joint Center Conductor
     B = Cable Conductor
     C = Cable Copper Shield
     D = Joint Copper Shield
     E = Air Ambient

Load
Current
= 945
Amperes

TEMP.
(°C)

TIME (HOURS)
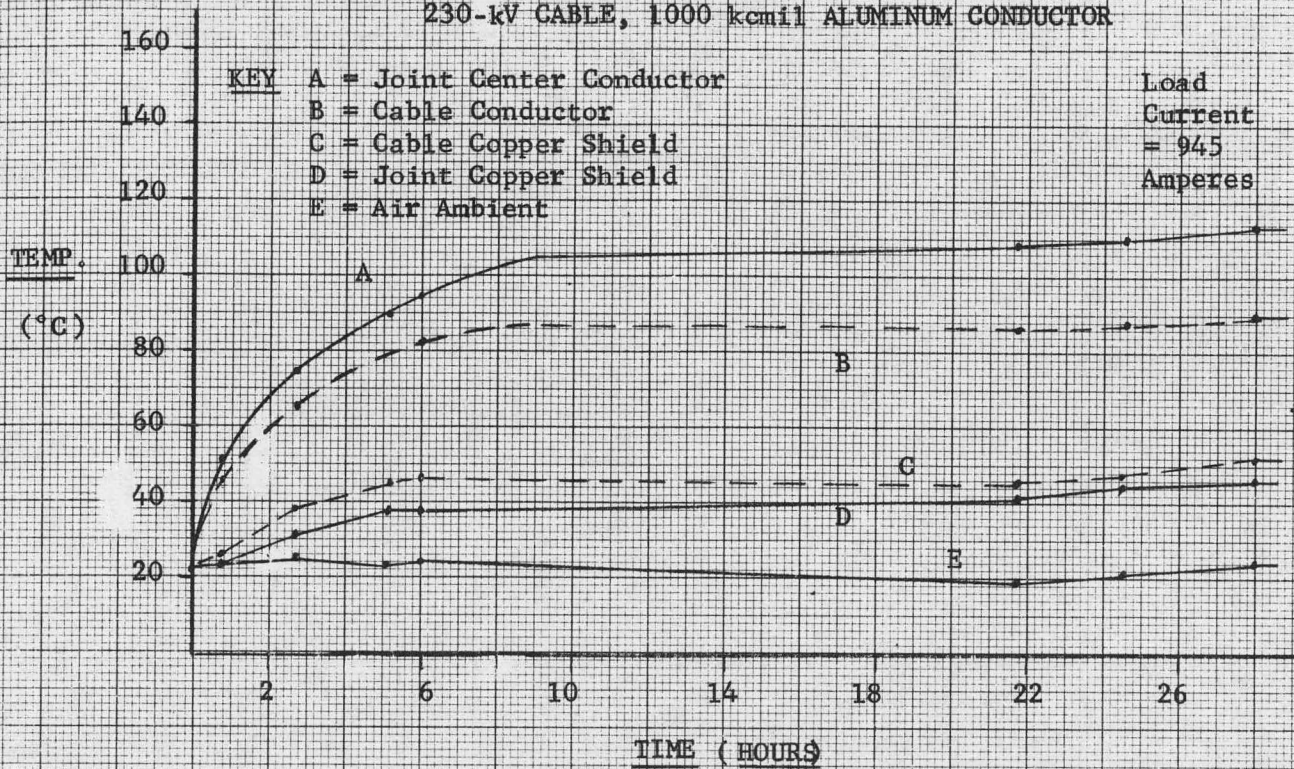
FIGURE 7.15   230-kV TAPED JOINT DESIGN #1
               CABLE CONDUCTOR LOADING TO 90 C

230-kV CABLE, 1000 kcmil ALUMINUM CONDUCTOR
COOLING IN FREE AIR FROM 90 C
CABLE CONDUCTOR TEMPERATURE

KEY A = Joint Center Conductor
     B = Cable Conductor
     C = Cable Copper Shield
     D = Joint Copper Shield
     E = Air Ambient

TEMP.
(°C)

TIME (HOURS)
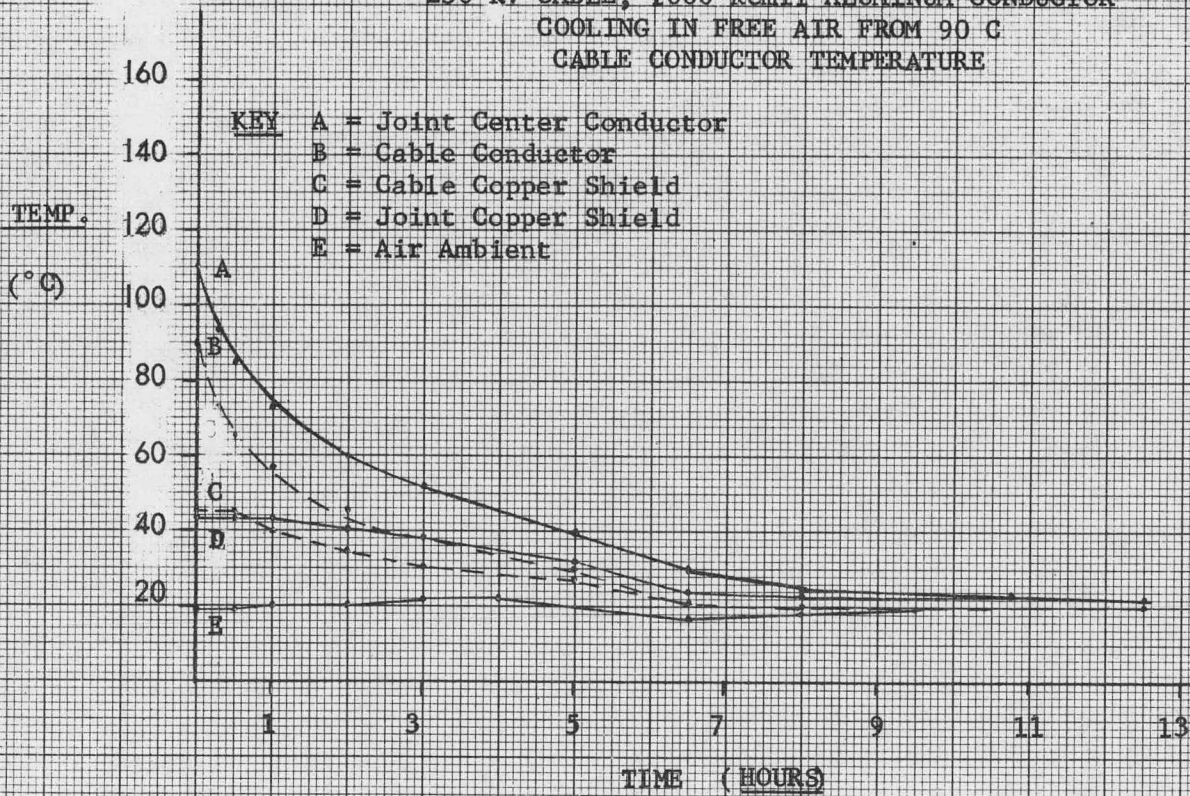
FIGURE 7.16   230-kV TAPED JOINT DESIGN #1
               CABLE CONDUCTOR COOLING FROM 90 C

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230-kV 1000 kcmil
Aluminum Conductor
Load Current
= 1092 Amperes

JOINT CENTER CONDUCTOR

CABLE CONDUCTOR

CABLE COPPER SHIELD

SPLICE COPPER SHIELD

AIR AMBIENT

TEMP.
(°C)

TIME (HOURS)
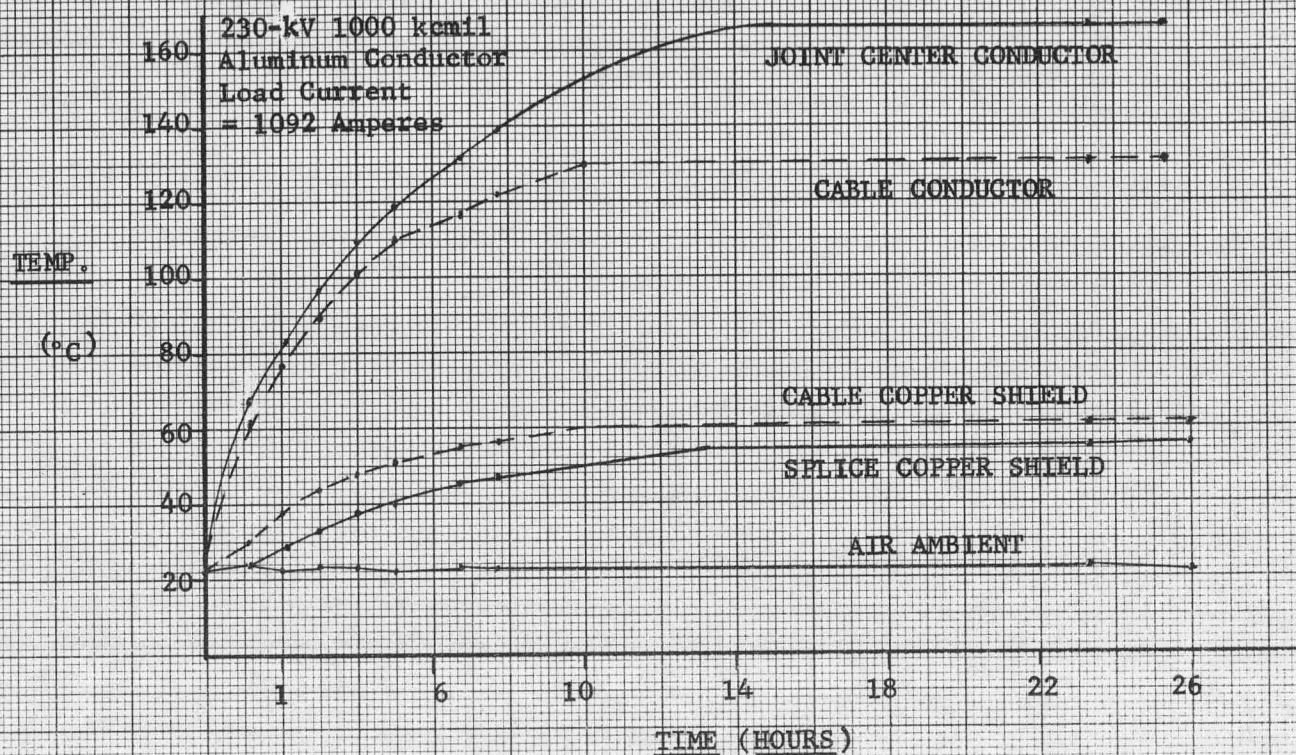
FIGURE 7.17   230-kV TAPED JOINT DESIGN #1
CABLE CONDUCTOR LOADING TO 130 C

230-kV CABLE, 1000 kcmil ALUMINUM CONDUCTOR
COOLING IN FREE AIR FROM 130 C
CABLE CONDUCTOR TEMPERATURE

KEY: A =   Joint Center Conductor
        B =   Cable Conductor
        C =   Cable Copper Shield
        D =   Joint Copper Shield
        E =   Air Ambient

TEMP.
(°C)

TIME (HOURS)
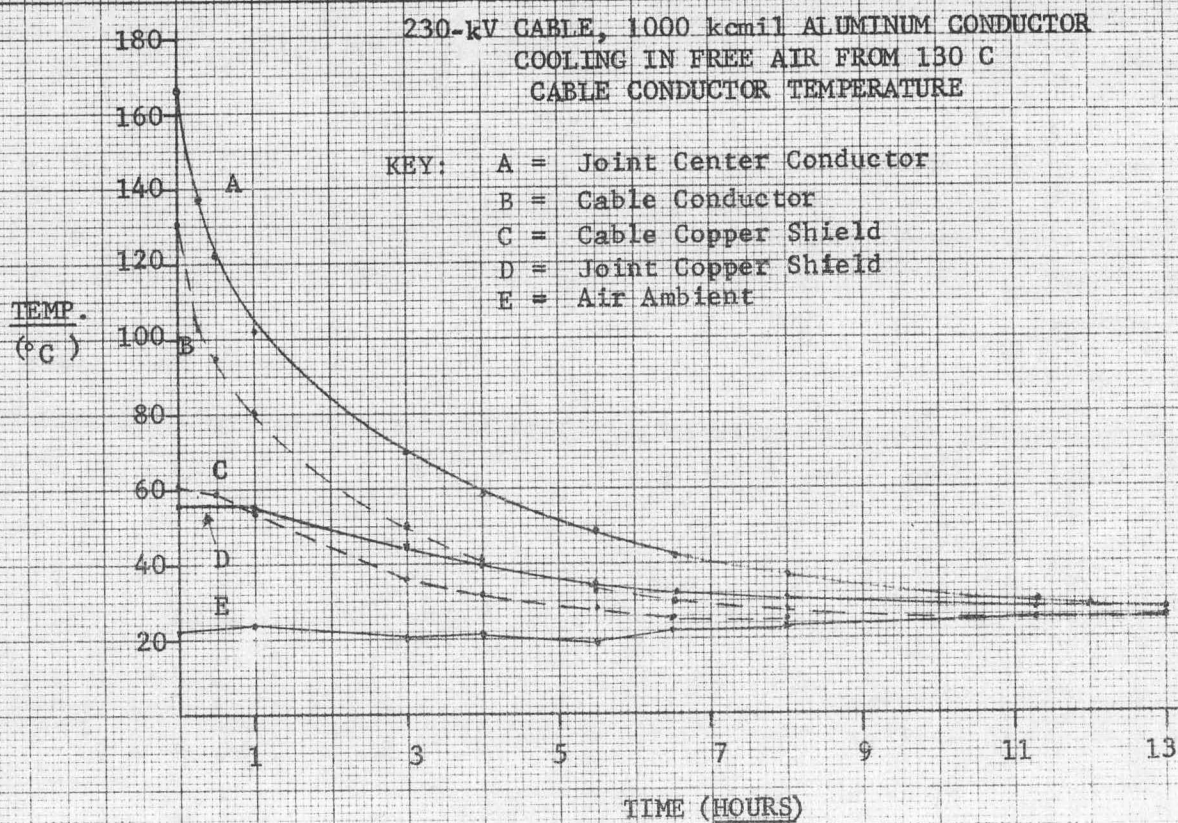
FIGURE 7.18   230-kV TAPED JOINT DESIGN #1
CABLE CONDUCTOR COOLING FROM 130 C

84
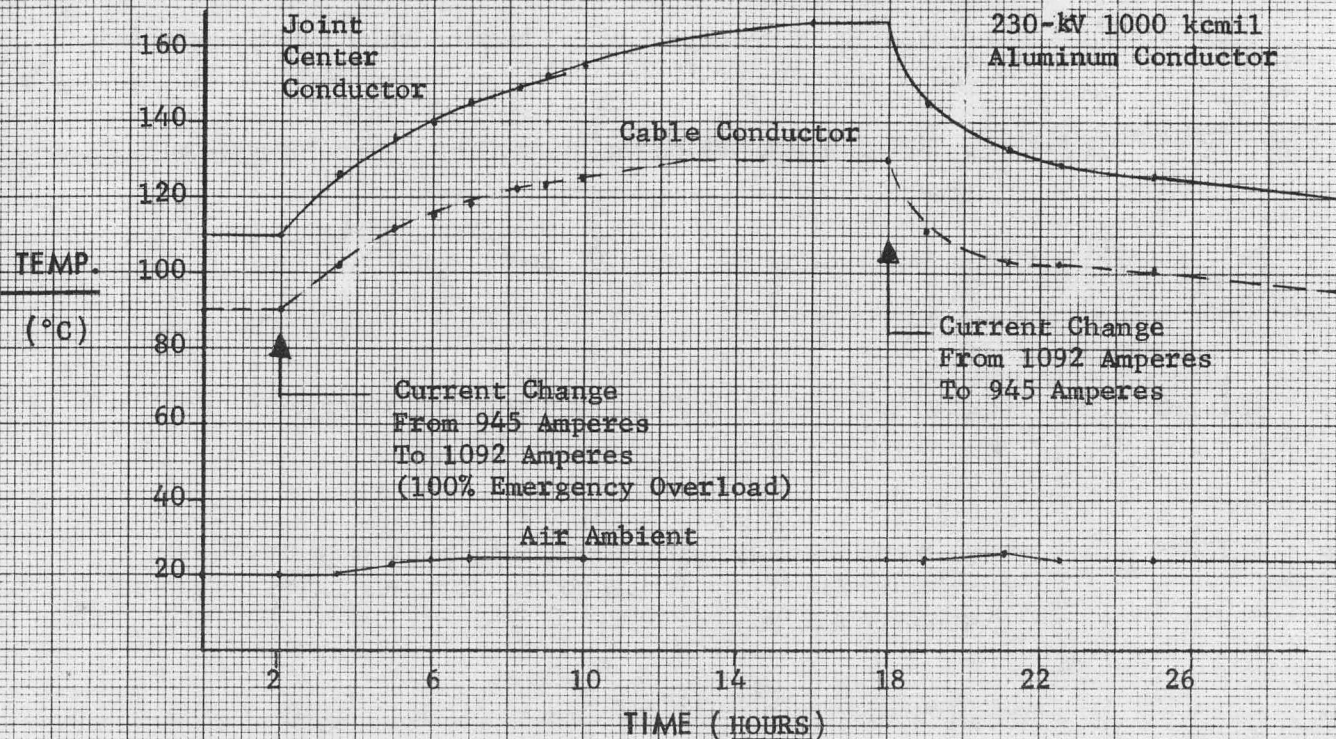
FIGURE 7.19   230-kV TAPED JOINT DESIGN #1
CABLE CONDUCTOR EMERGENCY OVERLOAD
TO 100% LEVEL FROM 90 C EQUILIBRIUM
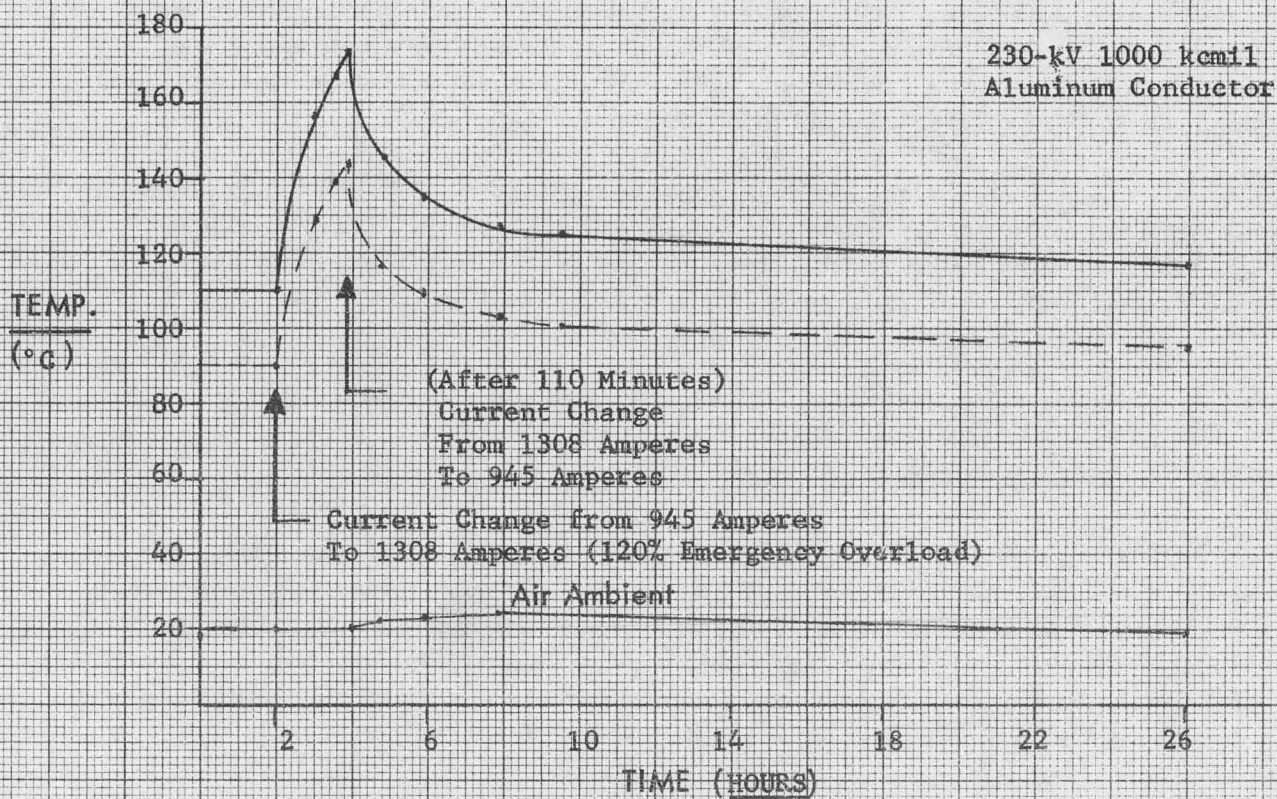
FIGURE 7.20   230-kV TAPED JOINT DESIGN #1
CABLE CONDUCTOR EMERGENCY OVERLOAD
TO 120% LEVEL FROM 90 C EQUILIBRIUM

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(1)   An indication of the degree of overheating which may be expected in 230kV Joint Design #1.

(2)   Data for use in developing the thermal field computer program (Category 4, Part 3).

(3)   Loading curves for 90C and 130C cable operation.

STEP G -   The determination of methods for evaluating taped joint insulation was not pursued due to contract modification.

STEP H -   Working relationships with tape manufacturers were established or re-established with the following manufacturers during the period October 1976 to January 1977:

BISHOP ELECTRIC,	Cedar Grove, N. J.	(REF. 7.1)
PLYMOUTH RUBBER,	Canton, Mass.	(REF. 7.4)
GENERAL ELECTRIC,	Schenectady, N. Y.	(REF. 7.5)
3-M COMPANY,	St. Paul, Minn.	(REF. 7.6)

As stated previously, our development work on 230kV taped joints was done using Bishop Electric materials. Although working relationships with the other three manufacturers were established, work was not brought out beyond the discussion stage due to the expected contract modification.

The planned electrical test sequence outlined in APPENDIX 7.1, pages 138-140 , was not followed due to contract modification. A single 230kV taped joint was installed in the 60 Hz 230kV cable/terminal evaluation circuit and a single 230kV taped joint was installed in an impulse test circuit for a modified test program .

7.1.3   ELECTRICAL TESTING OF 230kV TAPED JOINT DESIGN #1

60 Hz ACCELERATED LOAD CYCLE TESTING

Following 809.5 hours, and 35 load cycles, of accelerated test-ing on the 230kV cable/terminal evaluation circuit, it was decided to install a single 230kV taped joint. Construction of the joint was in accordance with the design shown in FIGURE 7.11 except that an exothermic weld was used. This resulted in an increase of 0.29" in all diameters and a slight decrease in maximum radial 60 Hz stress. Com-plete construction of the joint required 18 hours (36 man-hours).

In order to permit dielectric isolation of the splice insulation from the cable insulation, shield interrupters were installed at each end of the 230kV joint. This permitted individual dissipation factor, capacitance and partial discharge measurements to be made for the splice, cable half length with G & W terminal, and cable half length with Joslyn terminal.

The 230kV taped joint was then subjected to an accelerated (over-voltage) test program. This included 36 load cycles at rated (90 C) cable conductor temperature (Load cycles #36-51 and #68-87). In addition to this, 16 load cycles were completed at emergency (130 C) cable conductor temperature (Load cycles #52-67). These 130 C load cycles were performed with the circuit energized at rated voltage (Load cycles #52-55) and at 125% rated voltage (Load cycles #56-67). Nearly all of the 90 C testing was performed with the circuit energized at 150% rated voltage (200 kV line-to-ground). In total the joint was subjected to 1338.5 hours of high voltage testing. Of this total 116.6 hours were at 100% rated line-to-ground 230kV voltage (133kV), 317.2 hours were at 125% rated voltage (166kV) and 904.7 hours were at 150% rated voltage (200kV).

Measurements of partial discharge characteristics of the 230kV test circuit (including joint) were made initially, at several intervals during the test, and near the end of the testing program. These results are reported in Section 6.0, Tables 6.18 through 6.22. In general, the measurements indicated satisfactory partial discharge levels. When measurements were taken with the circuit at room temperature partial discharge levels were as high as 10 pC at 150% rated voltage but always were below 5 pC at 125% rated voltage. When measurements were taken at the elevated temperatures of 90 C and 130 C results were excellent, with partial discharge levels below the measuring sensitivity of the detection equipment (1 pC). The comparison of measurements over the course of the testing indicates the stability of the partial discharge characteristics of the 230kV evaluation circuit, including joint.

Measurements of capacitance and % dissipation factor were made initially, at several intervals during the test, and near the end of the testing program. These results are reported in Section 6.0, Tables 6.13 through 6.17 In addition, a series of measurement runs were made to determine the effect of load current and continuous applied voltage on the dissipation factor of the joint. These test results are graphed in Figures 7.20A and 7.20B. The dissipation factor of an EPR taped joint is of interest with regards to stability over a period of time with a load current applied. In Figure 7.20A, at a conductor temperature of 90 C the dissipation factor reaches stability when energized continuously at 100% rated (133kV line-to-ground) and at 125% rated (166kV line-to-ground) voltage. At 150% rated voltage the % dissipation factor appears to be rising steadily after 12 hours of current loading. It is believed that had these measurements continued beyond the 12 hour point (length of heating portion of 24 hour load cycle) the % dissipation factor would have reached stability. This was verified by

150% RATED VOLTAGE (200kV)

125% RATED VOLTAGE (166kV)

100% RATED VOLTAGE (133kV)

230kV TAPED JOINT DESIGN #1
% Dissipation Factor As a Function
of Time At Rated Load Current
For 90 C Cable Operation (945 Amperes)
VOLTAGE APPLIED CONTINUOUSLY.
Ambient Range: 20 C - 24 C

PERCENT
DISSIPATION
FACTOR

TIME   (HOURS)

FIGURE 7.20 A

230kV TAPED JOINT DESIGN #1
% Dissipation Factor As a
Function of Time At Emergency
Overload Current For 130 C
Cable Operation
(1092 Amperes)
VOLTAGE APPLIED
CONTINUOUSLY
Ambient Range:
21 C - 24 C

125% RATED
VOLTAGE
(166kV)

100% RATED VOLTAGE (133kV)

PERCENT
DISSIPATION
FACTOR

TIME (HOURS)

FIGURE 7.20 B

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a later test where % dissipation factor was measured at 90 C and with continuous 150% rated voltage applied, with a load current of 945 amperes applied for 18 hours continuously. By the 18 hour point the % dissipation factor was stabilizing at slightly above 0.6%. It is concluded that the joint would be electrically stable at 150% rated voltage and 90 C continuous operation. .

It was noted that % dissipation factor readings for the joint tended to decrease in numerical value over the course of the test. In example, the readings just discussed represented a decrease of about 0.15 (decrease from 0.761% to 0.610%). Also, the initial room temperature readings, compared with the final readings, indicate a decrease from 0.121% to 0.100% (Reference Tables 6.14 and 6.17.   This tendency for the dissipation factor to improve may be due to a gradual increase in the degree of cure of the EPR splice insulation.

Figure 7.20B depicts the increase in % dissipation factor of the 230kV joint when subjected to 12 hour heating periods at emergency (130 C) conductor loading. A 1092 ampere load current was induced while the conductor was continuously energized at 100% and at 125% rated voltage. The 130 C measurements were not carried out beyond the 12 hour point. The 1.1% dissipation factor observed at the 12 hour point (at 125% rated voltage) compares very favorably with the 3.5% dissipation factor observed with our 138kV Waltz Mill design at the 12 hour point of a 125% overvoltage test.

IMPULSE TESTING

In order to test a single joint for impulse withstand, a series of steps were taken. First, a length of 230kV cable was tested (Sample 1). The results of this test at room temperature are shown in Table 6.24 , page 54 . Termination failure occurred. A separate length of 230kV (manufacturing run [#]3) cable (Sample 2) was set up for impulse test and the results of this series of tests are shown in Table 6.25,   page 55 . In brief, the cable passed all tests at room temperature but a failure occurred at BIL while testing at 90 C conductor temperature. The fault was cut out and a 230kV joint constructed that was identical to the 60 Hz test joint (Taped joint design [#]1, Fig. 7.11).   The cable and joint were then impulse tested as shown in Table 6.26 , page 56 . Both cable and joint passed BIL requirements at room temperature. When tested with the cable conductor at 90 C, (joint conductor at about 114 C, reference Figure 7.15) a joint failure occurred on the third impulse at BIL. Examination of the fault revealed that a radial dielectric puncture occurred at a point about 2-3/4" from the center of the connector near the edge of the factory conductor strand shielding. The cause of this fault was uncertain.

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CONCLUSION

The 230kV Taped Joint Design #1 60Hz test results indicate compatability with the 230kV XLPE-insulated cable. Overvoltage testing at 150% rated voltage with the joint carrying rated 90 C load current indicates a substantial margin of safety in the design. Overvoltage testing at 125% rated voltage with the joint carrying emergency overload 130 C load current also indicates a reasonable margin of safety in the design. The design appears to be reliable and satisfactory for normal 60 Hz operation. Measurements indicate electrical stability and freedom from partial discharge at voltages significantly higher than 230kV ratings.

The occurrence of a radial dielectric fault on the third impulse at 90 C and Basic Impulse Level indicates that the joint might require a somewhat thicker insulating wall with consequent lower unit voltage stresses. Verification of this would require the construction and testing of two additional joints based on design #1. Based upon the single test, Taped joint design #1 must be considered marginal on impulse test at 90 C.

7.2   CATEGORY 2 - VULCANIZED JOINT

In order to continue work on this type of joint at the point where it was stopped in 1974, the program outlined in Appendix 7.1 was laid out. The objective was the eventual application of the vulcanized joint at the 230kV level.

Work was begun at the 69kV 500 kcmil level. Steps that were completed between the beginning of the 230kV ERDA contract and 12/31/75 are outlined under Category 2 of Appendix 7.1. The final status of each of the planned program steps referring to Appendix 7.1 will now be reported.

STEP A −   Evaluation of the vulcanized polyethylene joint method at the 69kV level. In order to perform this task, a series of 10 69kV 500 kcmil vulcanized joints were constructed in a cable which had been pre-terminated and tested. Five laboratory people made two joints each. This was done in order to assess the transferability of the method. The joints were made according to the design shown in Figure 7.21. An electrical evaluation test sequence was planned and followed according to the outline shown in Table 7.2.

During the conduct of the test as outlined, a series of 4 failures occurred. Two of these were legitimate joint failures which occurred early in the test program. These

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69-kV KAISER VULCANIZED POLYETHYLENE SPLICE DESIGN

500 kcmil ALUMINUM

SCALE = 1:1
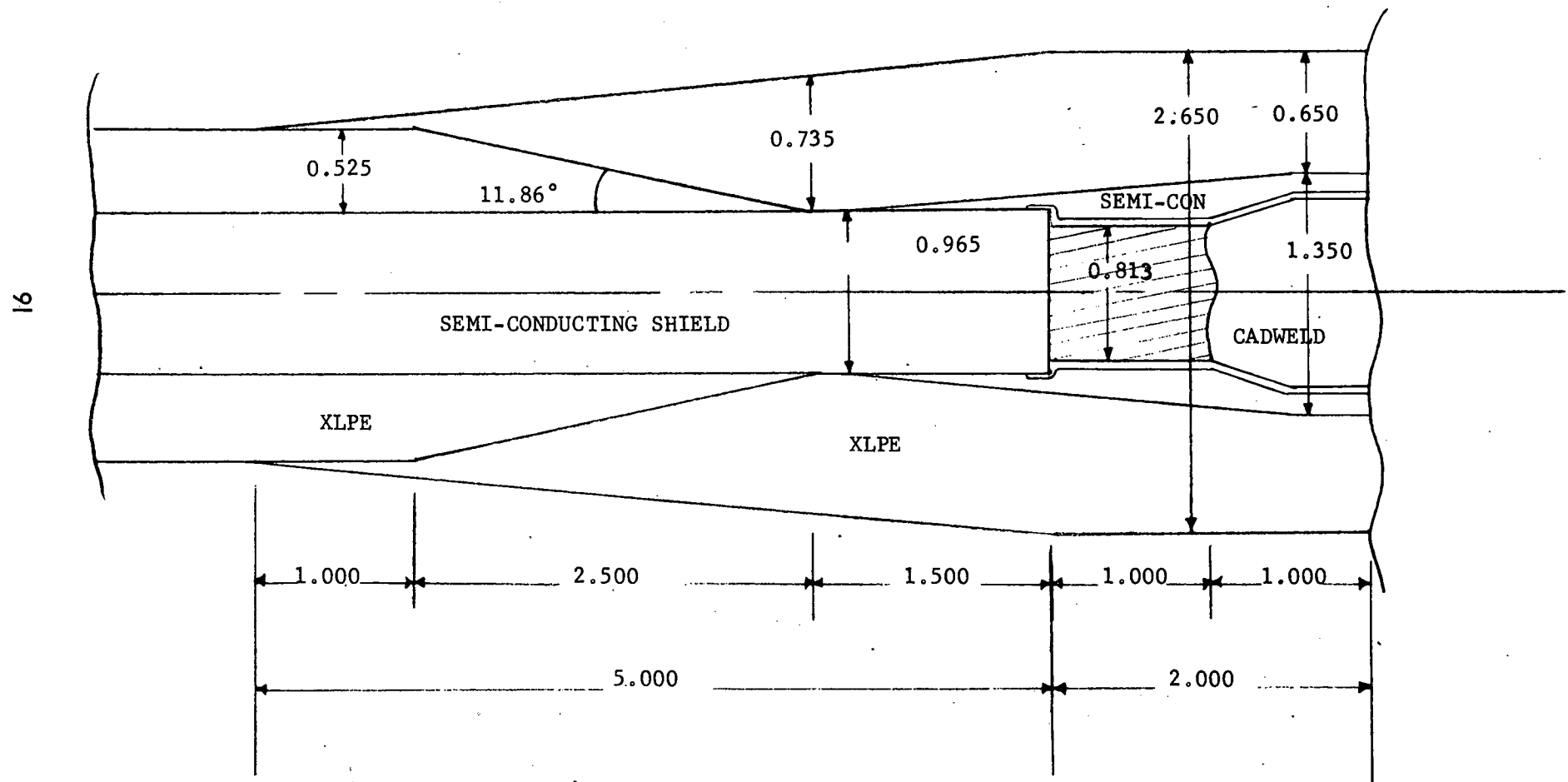
FIGURE 7.21

TABLE 7.2

TEST PROCEDURE FOR EVALUATION OF 69-kV VULCANIZED POLYETHYLENE SPLICES

1. Measure dissipation factor and capacitance of individual splices and terminals at room temperature with 100%, 150%, 200%, and 250% rated voltage.

2. Measure partial discharge characteristics of individual splices and terminals at room temperature with voltage up to the 250% rated level.

3. Energize at 200% rated voltage continuously for 240 hours. Load cycle with 670 amperes for a total of 20 cycles at 90 C conductor temperature (8 hours on/ 4 hours off).

4. During last two hours of Load Cycles #19 or #20, repeat Steps 1 & 2 up to 200% rated voltage with conductor at 90 C.

5. Repeat Steps 1 & 2 at room temperature following completion of Step 3 (20th Load Cycle).

6. Impulse test circuit (terminals short-circuited) at B.I.L. (350kV) 10 impulses with negative polarity. Impulse test circuit at 1.25x B.I.L. (438kV) 10 impulses with negative polarity. All impulsing to be performed with conductor temperature of 90 C. NOTE: Terminals taken out of the effective test circuit during impulse tests to prevent their premature failure.

7. Repeat Steps 1 & 2 at room temperature.

8. Energize at 150% rated voltage continuously for 240 hours. Load cycle with 780 amperes (130 C conductor) 8 hours on/4 hours off for 20 cycles.

9. During last two heating hours of Load Cycles #39 or #40, repeat Steps 1 & 2 up to 150% rated voltage with conductor at 130 C.

10. Repeat Steps 1 & 2 at room temperature.

11. Repeat Step 6.

12. Repeat Steps 1 & 2 at room temperature.

13. Repeat Step 3.

14. During last two heating hours of Load Cycles #59 or #60, repeat Steps 1 & 2, up to 200% rated voltage with conductor at 90 C.

TABLE 7.2 (Cont'd.)

15. Repeat Steps 1 & 2 at room temperature.

16. Repeat Step 6.

17. Repeat Steps 1 & 2 at room temperature.

18. Energize at 250% rated voltage continuously for 240 hours. Load Cycle with 670 amperes for a total of 20 cycles at 90 C conductor temperature (8 hours on/4 hours off).

19. During last two heating hours of Load Cycles #79 or #80, repeat Steps 1 & 2, up to 250% rated voltage with conductor at 90 C.

20. Repeat Steps 1 & 2 at room temperature.

21. Repeat Step 6.

22. Repeat Steps 1 & 2 at room temperature.

23. DC Test at 175kV positive polarity at room temperature.

24. With conductor temperature at 90 C and with terminals in the effective test circuit, apply 10 negative polarity impulses at 80%, 90%, and 100% of B.I.L. Continue in 5% increments of B.I.L. until failure occurs.

25. Remove all shield interrupters.

26. Perform 60 Hz step test at 90 C conductor temperature. Begin at 110kV test level and increase in 10kV increments (30 minute durations) until breakdown occurs.

two failures were determined to be due to a discrete lack of bond between applied and cable insulation. The lack of bond was considered to be due to the use of Teflon tape used to "protect" the cable insulation during connector shield processing. It was believed that adhesive from this tape randomly deposited on the cable surface and the occurrence was noted on only 2 of the original 10 joints. After this observation the use of this Teflon tape was discontinued and no further problems occurred. A third failure occurred due to a defective cable shield interrupter and was not related to joint quality. In the effort to repair this failure a "patch" was attempted using vulcanized polyethylene. Due to close proximity to another joint, the processing of the "patch" resulted in damage to the joint which was not visually obvious. Soon after re-energizing the test circuit, this joint failed. Failure was due to distortion of the joint during patch processing. The joint was remade. Since all these problems occurred early in the test program it was decided to restart the test from the beginning and this was done. The entire test program was completed without further incidents. The considerable test data obtained was condensed into Tables 7.3 and 7.4. Following the test program as outlined, a 60 Hz step test to breakdown was performed with the conductor at 90C. The result was a cable failure at 170kV. Each of the ten test joints was then cut from the circuit and "slinkies" of the total insulation from each of these joints were prepared.

STEP B -   The insulation and connector shielding from each of the ten 69kV tested joints, prepared in slinky form, was inspected according to the inspection format shown as Table 7.5. The detailed visual inspection data, which fills 84 pages of data books, was condensed to show typical insulation quality. This condensation is shown as Table 7.6. These data provide a reference for future work with the polyethylene vulcanized joint. It can be seen that quite a wide range of voids (both size and quantity) occurred, as well as contaminants in considerable quantity. Some of the joints met AEIC 5-75 cable insulation void requirements while others did not. With regard to contaminants, the joint insulations did not meet AEIC 5-75 (Ref. 7.7) requirements. In spite of this, test joints #1, 2, 3A, 4, 5, 6A, 7A, 8A, 9 and 10 completed the test without failure. The results indicated that the next steps in the vulcanized polyethylene joint program should focus upon reduction of voids, contaminants and joint wall eccentricity.

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TABLE 7.3

DISSIPATION FACTOR MEASUREMENTS
OF TEN 500 kcmil 69-kV
VULCANIZED POLYETHYLENE JOINTS

ALL READINGS BELOW AT 200% RATED PHASE-GROUND VOLTAGE (80 kV)

TEST PERIOD**	1	4	10	14	19	22
CONDUCTOR TEMP.	20 C	90 C	22 C	90 C	90 C	23 C
500 kcmil 69-kV Vulcanized Polyethylene Joint #	PERCENT DISSIPATION FACTOR					
1	0.085	0.065	0.065	0.040	0.034	0.045
2	0.193	0.068	0.060	0.033	0.027	0.040
3A	0.107	0.061	0.020	0.034	0.035	0.045
4	0.103	0.049	0.050	0.035	0.035	0.045
5	0.100	0.044	0.051	0.025	0.026	0.034
6A	0.046	0.058	0.051	0.029	0.036	0.042
7A	0.194	0.056	0.050	0.027	0.031	0.040
8A	0.196	0.048	0.048	0.026	0.030	0.040
9	0.107	0.043	0.051	0.025	0.038	0.041
10	0.120	0.036	0.048	0.078*	0.054*	0.065*
Cable & 10 Joints	0.077	0.016	0.029	0.017	0.032	0.019
Reference Cable Only	0.046	0.030	0.033	0.019	0.010	0.025

*Defective Shield Interrupter
**Reference Table 7.2

TABLE 7.4

MEASURED PARTIAL DISCHARGE CHARACTERISTICS OF A 500 kcmil 69kV SOLID DIELECTRIC CABLE TEST CIRCUIT INCLUDING TEN VULCANIZED POLYETHYLENE JOINTS AND TWO RAYCHEM 69kV THERMOFIT TERMINATIONS

TEST* PERIOD	2	4	5	9	12	14	15	17	19	20	22
CONDUCTOR TEMPERATURE	20C	90C	21C	130C	20C	22C	22C	22C	90C	22C	23C
TEST LEVEL 60Hz KILOVOLTS	PICOCOULOMBS – PARTIAL DISCHARGE ***										
40	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
60	NM	NM	NM	2	NM	NM	NM	NM	NM	NM	NM
80	5.7	5	5	–	5	NM	5	5	NM	NM	NM
84	**	–	–	–	–	–	5	–	–	–	–
100	35	–	5	–	12	–	9.5	6.5	NM	5	12
80	5	5	5	–	NM	NM	5	5	NM	NM	NM
60	–	–	–	2	NM	NM	–	–	NM	NM	NM
40	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM

*   Reference TABLE 7.2 for Test Program.

**   Indicates no measurement was taken.

***   The calibration pulse (equal to 5 pico-coulombs per inch) is a reference against which any discernible discharges are compared. Where no visible discharges are evident, the letters NM (not measurable) are shown. Measurable discharges are denoted by an actual numerical value.

TABLE 7.5

FORMAT FOR XLPE SPLICE INSULATION DATA RECORDING

SPLICE # _____

UNAIDED VISUAL INSPECTION

Amount of splice inspected:
No. of slinkies:

No. of apparent voids:

Voids/in.^{3} =

Primary void shape: (spherical, radial disc, axial disc,
(cylindrical, etc.

Secondary void shape:

Remarks:

INSPECTION UNDER MAGNIFICATION

Magnification power:

(Select 20 consecutive slinkies of worst-appearing section of
 splice)

V 1   =   Voids $\geq$ 5 mils   =

                    voids $\geq$ 5 mils/in^3 =

V 2   =   Voids $\geq$ 2 mils $\leq$ 5 mils =

                    V 2/in^3 =

C 1   =   Contaminants $\geq$ 10 mils   =

                    C 1/in.^{3} =

TABLE 7.5   (Cont'd.)

$C\,2 = $ Contaminants ≥ 2 mils ≤ 10 mils $=$

$C\,2/in.^{3} =$

REMARKS: (report any significant or unusual observations)

ECCENTRICITY

Insulation minimum at splice center   =

Insulation maximum at splice center   =

Total minimum at splice center   =

Total maximum at splice center   =

PROCESS DATA

CONNECTOR SHIELD

Shield process temperature & time:

Special measures taken:

Material: (i.e.   UC 0590)
Method of Application:

INSULATION

Insulation process temperature & time:

Special measures taken:

Material: (i.e.   Cooke 521)
Method of Application:

R.H. and air ambient during application:
Cooling Method:

PERCENT EXTRACTABLES (Modified Method   )

Sample location:

% Extractables:

REMARKS: (report any significant or unusual observations)

TABLE 7.6

TYPICAL TEST JOINT DATA- 69kV 500 kcmil VULCANIZED PE JOINT

PROCESS DATA:	0580 - 1.5H @ 370 F	Semi-Con	
	521 - 12 H @330 F	Step-Cooled	Insulation

TEST DATA:	261.3 H	@ 80kV	90 C
	235.5 H	@ 60kV	130 C
	285.5 H	@ 80kV	90 C
	484.0 H	@ 100kV	90 C

BOND:	Insulation/Insulation:	Good
	Insulation/Semi-Con:	Fair
	Semi-Con/Semi-Con:	Good

ECCENTRICITY:	High:	.802
(Splice Center)	Low:	.488

INSULATION:	Avg. High:	.736	Maximum Spread: 223 Mils
	Avg. Low:	.586	Minimum Spread: 31 Mils
	Avg. Spread:	150 Mils	

VOIDS:

	HIGH	LOW	AVG.
> 5 Mils	$46.5/In.^3$	$0/In.^3$	$5.7/In.^3$
> 2 < 5 Mils	$173.5/In.^3$	$2/In.^3$	$26.6/In.^3$
Largest	35 Mils	3 Mils	13 Mils

CONTAMINANTS:

	HIGH	LOW	AVG.
> 10 Mils	$392.5/In.^3$	$259/In.^3$	$311.9/In.^3$
> 2 < 10 Mils	$474.5/In.^3$	$330.5/In.^3$	431.5
Largest	60 Mils	45 Mils	49 Mils

EXTRACTION:

	HIGH	LOW	AVG.
	31.01%	17.36%	22.48%

STEP C – Four additional 69kV 500 kcmil vulcanized polyethylene joints were constructed and processed by the same procedure as used in the 10 test joints except that the final part of the process, cooling, was performed by "rapid cooling", rather than step cooling. Careful microscopic inspection of the insulations from these four joints indicated that the quality was comparable to that obtained using step cooling. This is significant because step cooling required a 6 hour time period, whereas rapid cooling required only a 2 hour time period.

STEP D – As a step before attempting a 230kV vulcanized polyethylene joint, experiments were performed on an intermediate cable size. The size selected was a 1500 kcmil 115kV XLPE-insulated cable construction. The design for this cable joint is shown in FIG. 7.22. First a joint was constructed with a number of thermocouples imbedded at key points. The graphed data obtained for both connector shield processing and for insulation processing is shown in FIGURES 7.23 and 7.24. A comparison of the times and temperatures for this design versus those for the 69kV 500 kcmil design is shown as FIG. 7.25. This graph shows clearly the much greater thermal lag of the former design. This is due largely to the greater axial heat sink effect of the 1500 kcmil conductor.

Next, a series of three 115kV 1500 kcmil joints were constructed and processed for purposes of visual examination. The first of these developed sufficient compound pressure to split the epoxy processing shell thus resulting in destruction of the joint. The second joint did not experience this occurrence but did experience excessive extrusion of compound from one end of the epoxy casting. A third joint experienced little problem and appeared to possess good insulation quality. The main point to be made here is that an obviously high degree of variability of results occurred with these three joints of identical construction and process parameters. It is apparent that the technique which produces suitable joints at the 69kV 500 kcmil level does not at the 115kV 1500 kcmil level. This is related to the greater volume of both joint and cable insulation in the latter design as well as the need to use higher process temperatures to achieve satisfactory compound temperatures. The proposed solution to this problem is discussed under Step F.

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XLPE CABLE
INSULATION
(K-160)

18.55
DEGREES

4.38 DEGREES

K-160 (XLPE) OR
K-146 (EPR)
INSULATION

3.074

2.250

1.564

0.870

2.100

3.840

5.00

2.00

1.50

2.25
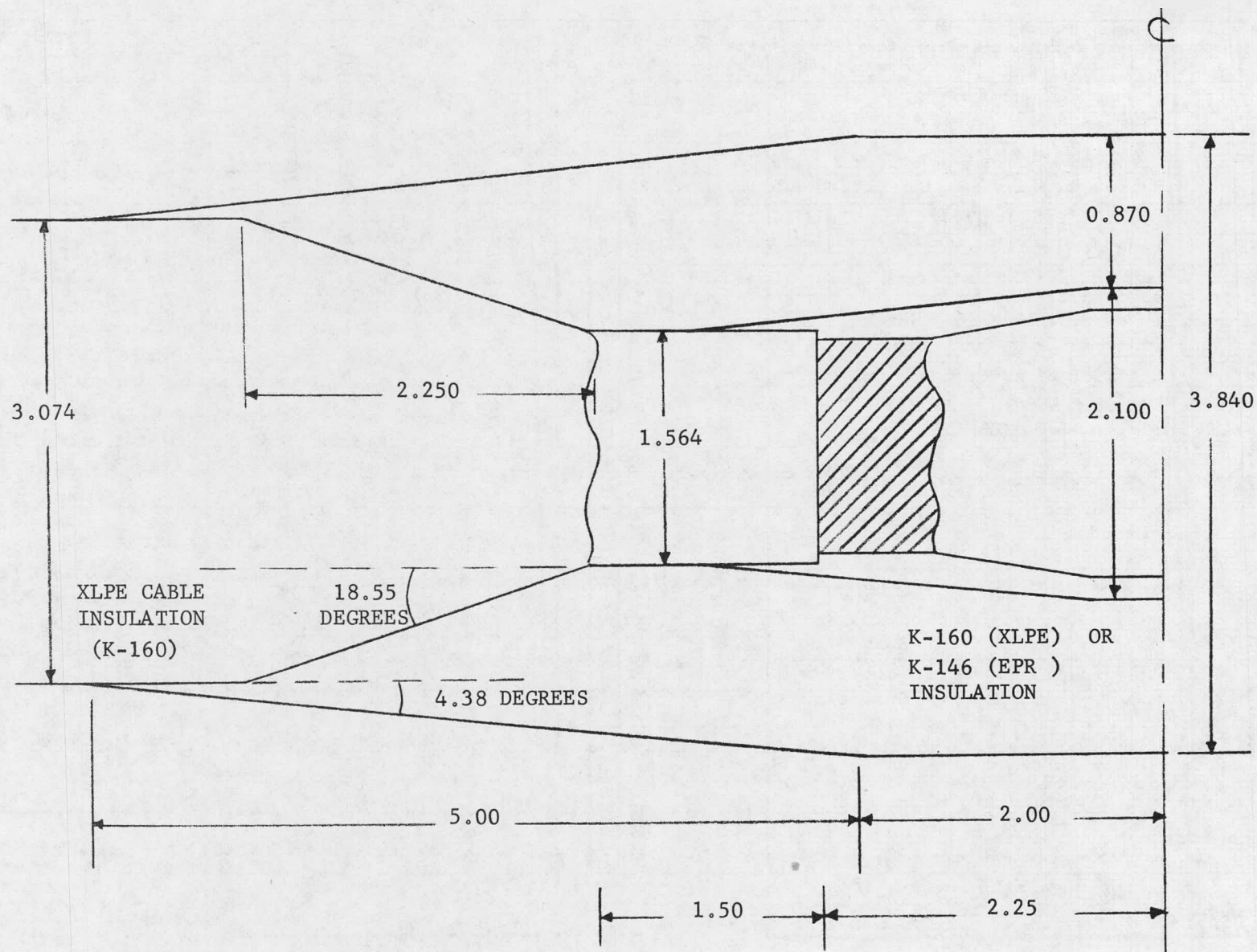
115 kV   1500 kcmil VULCANIZED JOINT DESIGN

FIGURE 7.22

RAPID COOLING

POLYETHYLENE
CRYSTALLINE
MELT POINT

KEY:

A = OVEN TEMPERATURE
B = JOINT INSULATION
    OUTER (HOTTEST) POINT
C = JOINT INSULATION
    INNER (COOLEST) POINT

COOL-DOWN
LOWER
CRITICAL
POINT

TIME (HOURS)
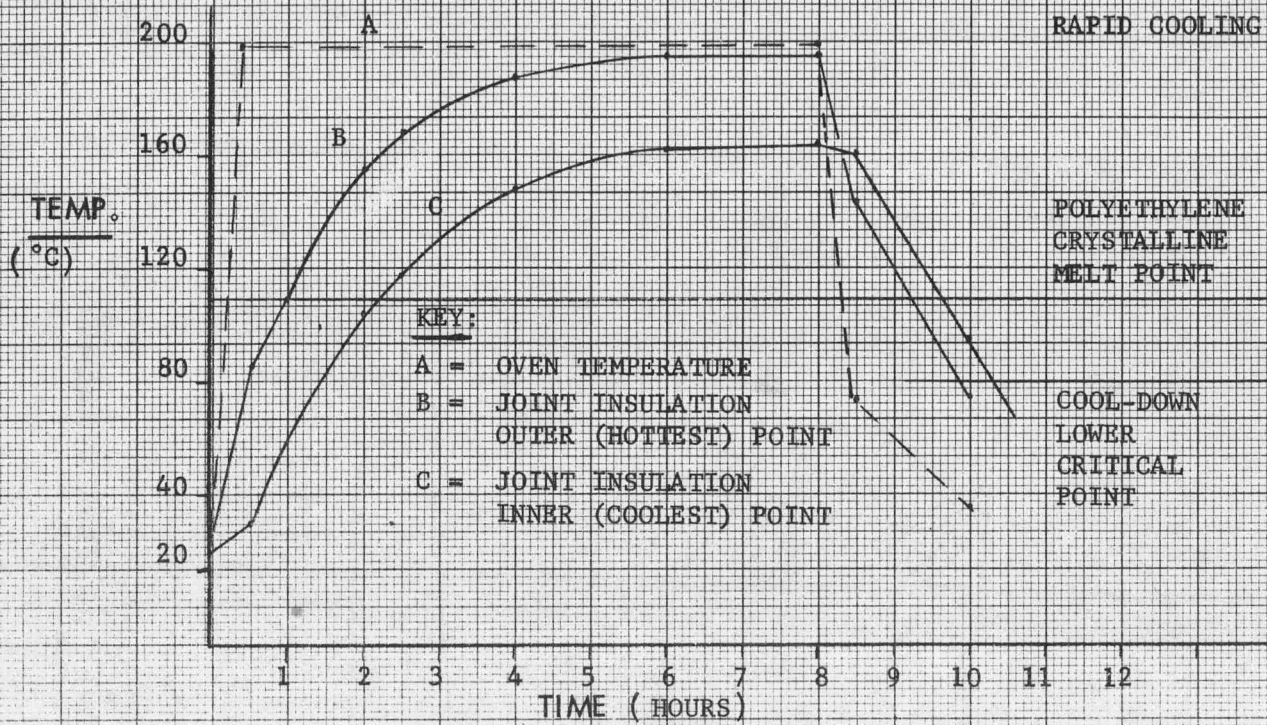
FIGURE 7.23

THERMAL PROCESSING PROFILE OF 115kV 1500 kcmil VULCANIZED
POLYETHYLENE JOINT INSULATION (DESIGN OF FIG. 6.22)

COOLING IN
CLOSED OVEN
(NON-CIRCULATING)

POLYETHYLENE
CRYSTALLINE
MELT POINT

KEY:

A = OVEN TEMPERATURE

B = SHIELDING MOLD TEMPERATURE

C = SHIELDING COMPOUND
    COOLEST POINT

TIME (HOURS)
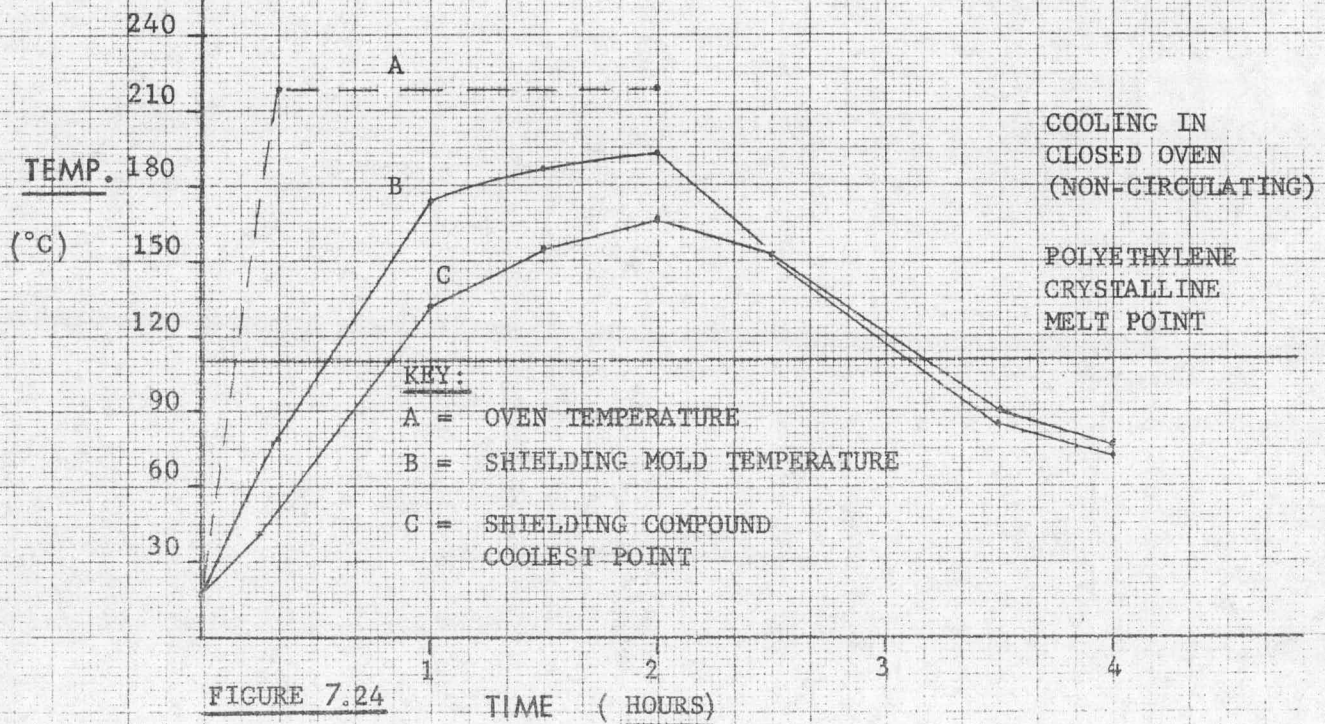
FIGURE 7.24

THERMAL PROCESSING PROFILE OF 115kV 1500 kcmil VULCANIZED
POLYETHYLENE JOINT CONNECTOR SHIELDING

102

COMPARISON OF VULCANIZED POLYETHYLENE JOINT
PROCESSING FOR TWO CABLE SIZES WITH ALUMINUM CONDUCTOR

POLYETHYLENE CRYSTALLINE
MELT POINT

KEY:

A	69 kV	500 kcmil	HOTTEST INSULATION, OVEN = 165C
B	69 kV	500 kcmil	COOLEST INSULATION, OVEN = 165C
C	115 kV	1500 kcmil	HOTTEST INSULATION, OVEN = 188C
D	115 kV	1500 kcmil	COOLEST INSULATION, OVEN = 188C

AIR AMBIENT

TIME (HOURS)
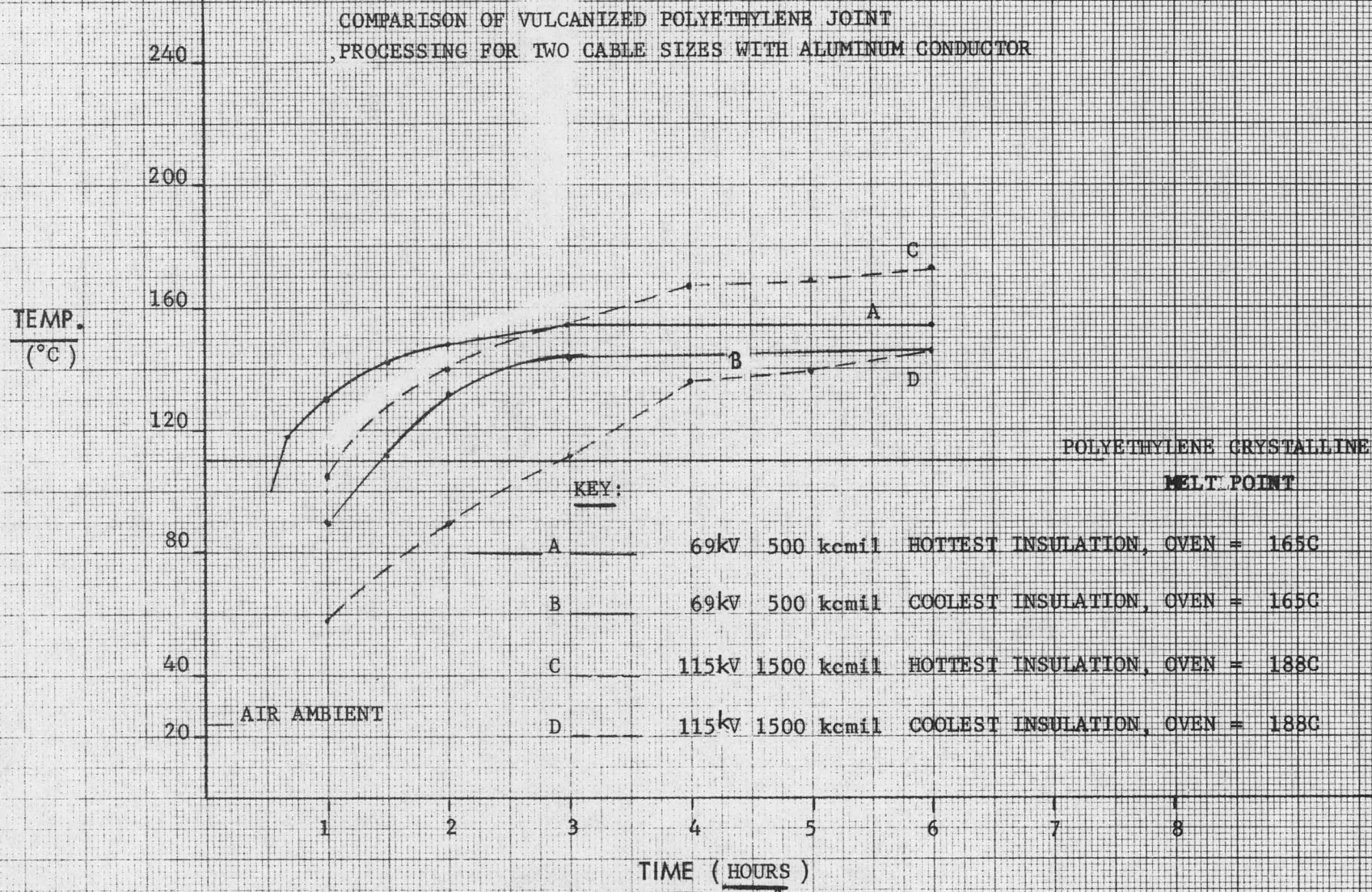
FIGURE 7.25

STEP E –   The design of a 230kV 1000 kcmil vulcanized polyethylene
joint is shown in FIG. 7.26. Although the results of
Step D had indicated that the epoxy containment shell
method was probably not workable in larger cable designs,
a 230kV joint made according to this design was con-
structed with thermocouples at key points. "Thermal
Profile" data were recorded and are graphed in FIG. 7.27
and 7.28. It is of interest to note that despite the greater
wall thickness of this joint, process temperatures and times
are similar to the 115kV, 1500 kcmil processing character-
istics (FIG. 7.24).

STEP F –   The use of induction heating to speed and improve the pro-
cess is considered to be a possible approach. The work up
to this point indicates that for cable sizes much greater than
69kV 500 kcmil, a new means of processing would be re-
quired. It was theorized that the present method utilizing a
heat-shrinkable Teflon sleeve applied over the joint insula-
tion would be retained. The epoxy-saturated polyester used
over this as a pressure shell would be eliminated and re-
placed instead with a porous malleable jacket. The purpose
of this jacket would be the supporting and shaping of the
joint insulation while in the molten process stage. The
underlying separator sleeve (of Teflon or other material)
would provide both separation and a smooth, defect-free
joint insulation surface. This assembly would then be in-
serted in a nitrogen processing chamber equipped with both
induction heating coils (for conductor/connector heating)
and with radiant heaters for heating of the splice insulation
from without. The basic design for such a process chamber
would appear similar to that shown in FIG. 7.29. One of
the persistent problems with the present method is the
occurrence of "sagging" during processing resulting in
joint insulation eccentricity. In order to overcome this
problem a pneumatic joint tensioning device would be
constructed, similar to the design shown in the sketch of
FIG. 7.30.

The use of nitrogen pressure (probably in the range of 50-
150 PSI) would provide a positive means of applying uniform
pressure to the processing joint, particularly during the
critical cooling process. The present method which utilizes
pressure developed by compound expansion while restricted
in a pressure shell provides non-controllable pressure which
may become excessive and result in unsatisfactory joints.

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230-kV KAISER VULCANIZED POLYETHYLENE JOINT DESIGN #1

1000 kcmil ALUMINUM

SCALE = 1:1

1.406

1.050   CABLE INS.
          ANGLE
            = 20.49°

4.300   1.250

SEMI-CON

1.345   1.117   1.800

SEMI-CONDUCTING SHIELD

CADWELD

XLPE

XLPE

2.440   2.810   1.500   1.000   1.250

6.000   3.000

105
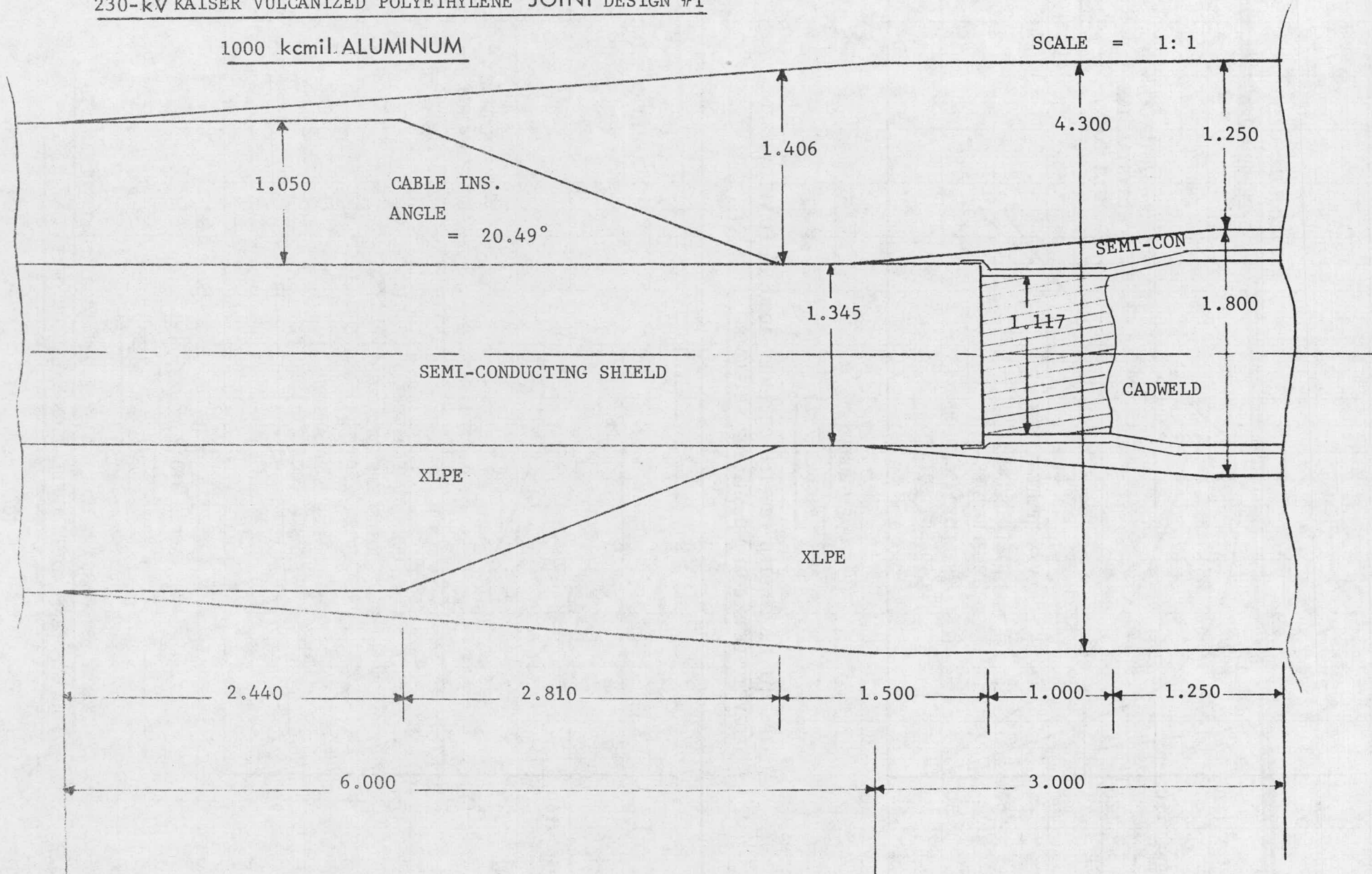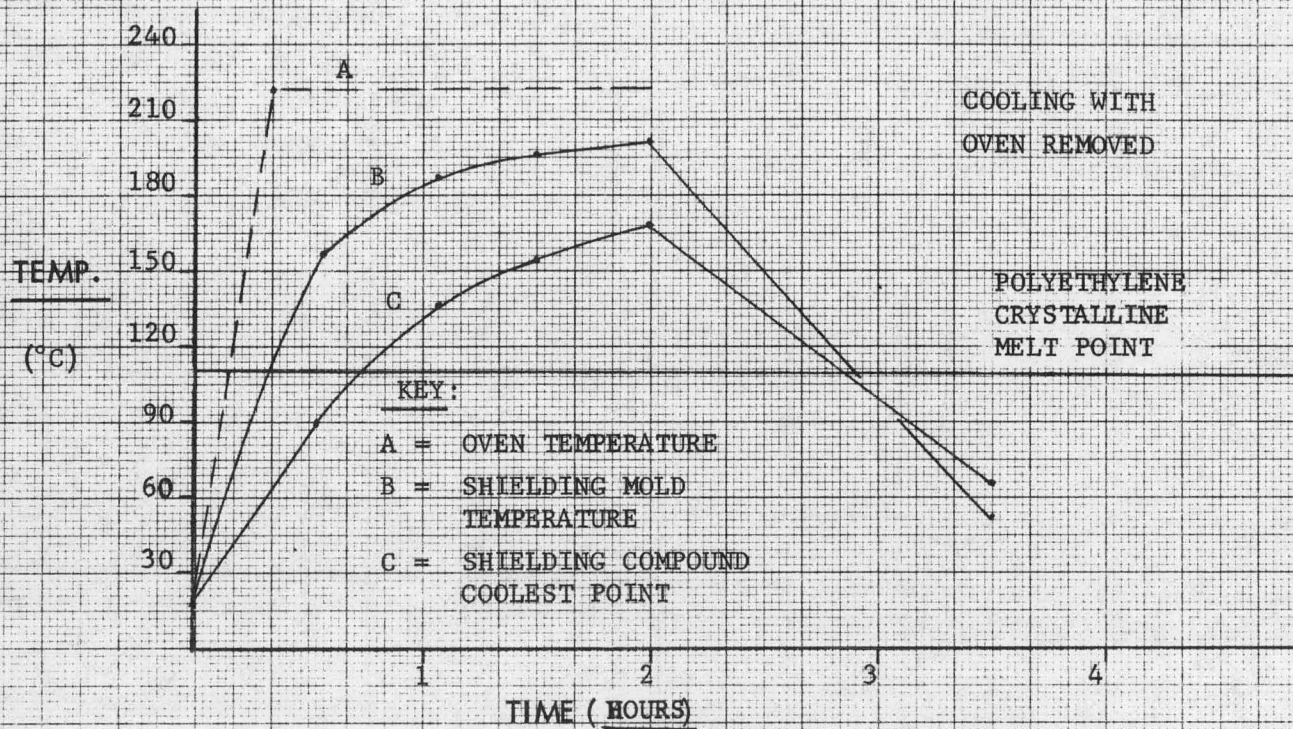
FIGURE 7.26

FIGURE 7.27

THERMAL PROCESSING PROFILE OF 230kV 1000 kcmil VULCANIZED
POLYETHYLENE JOINT CONNECTOR SHIELDING
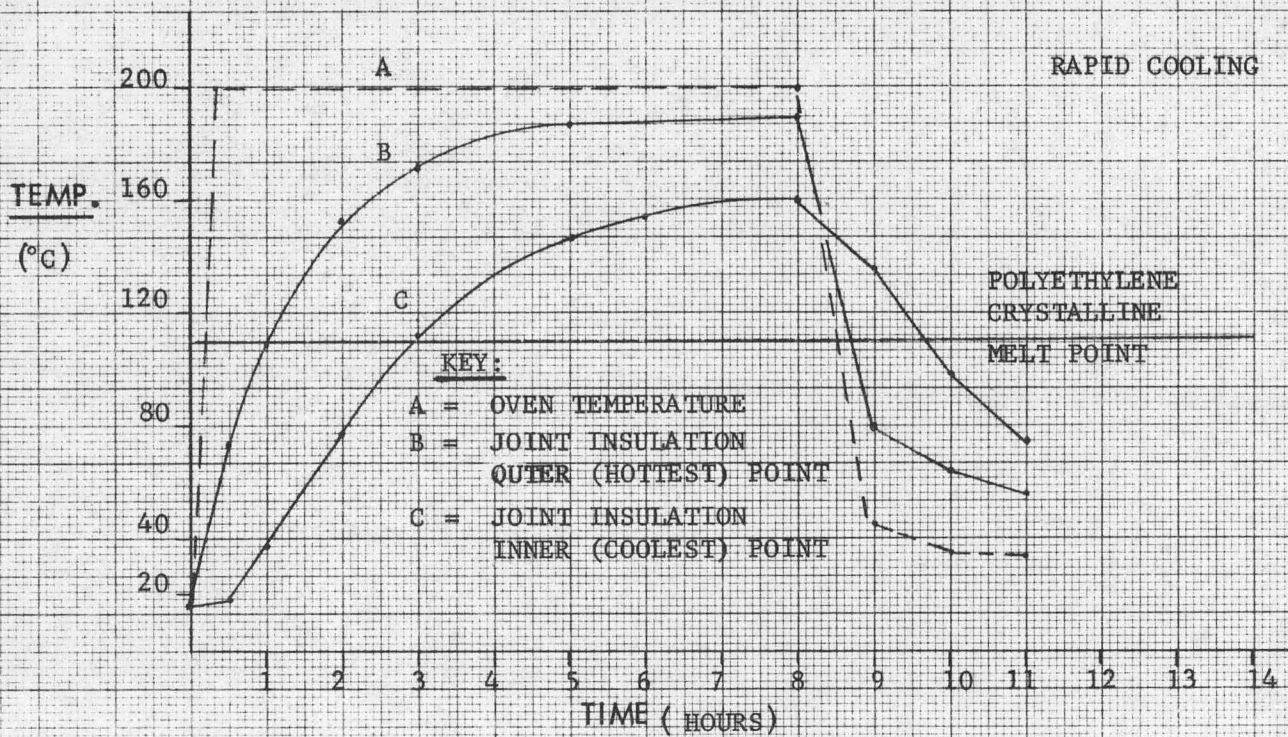
FIGURE 7.28

THERMAL PROCESSING PROFILE OF 230kV 1000 kcmil VULCANIZED
POLYETHYLENE JOINT INSULATION (DESIGN OF FIG. 7.26)

106
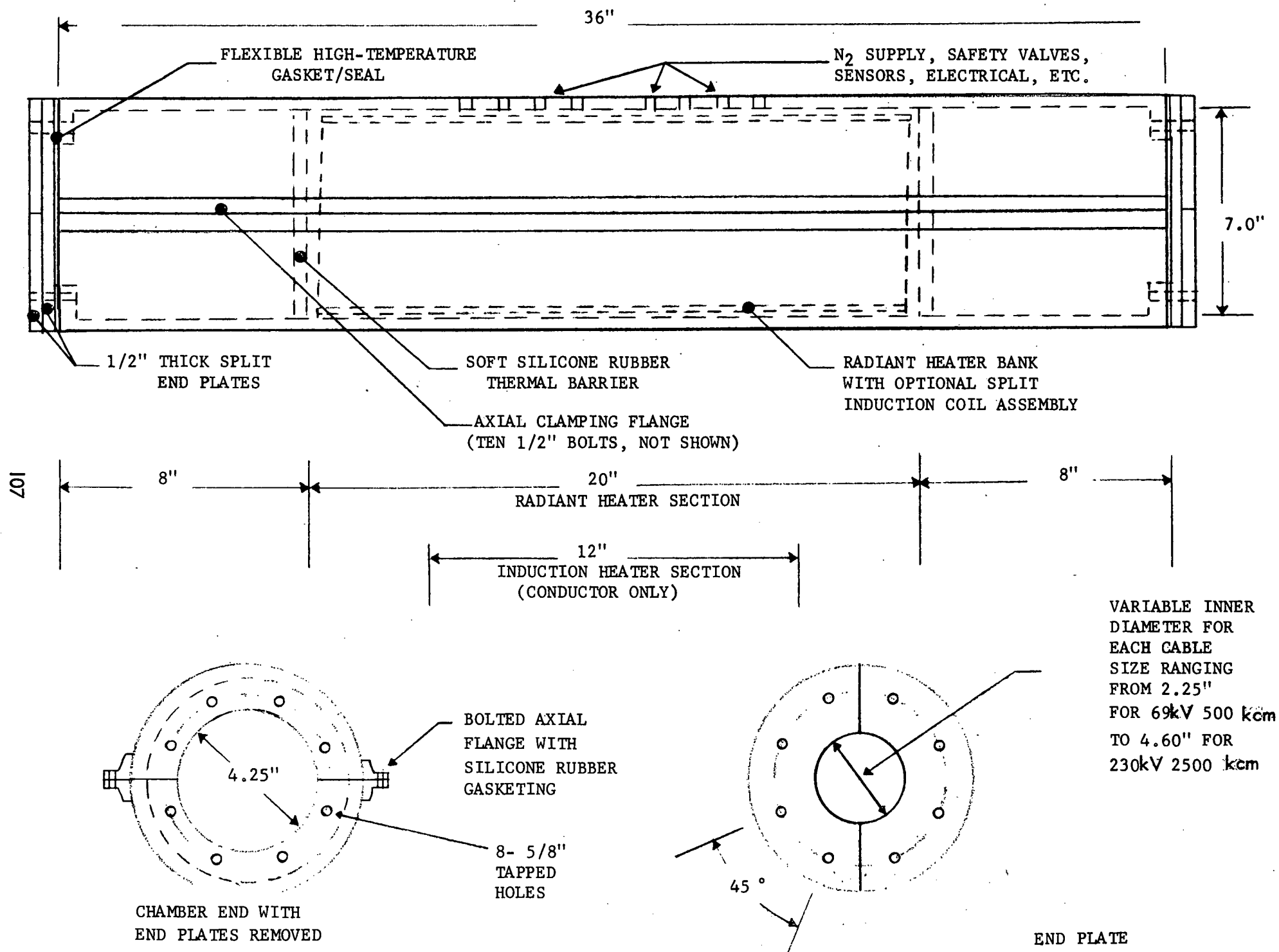
FIGURE 7.29. BASIC DESIGN FOR A NITROGEN PRESSURE PROCESS CHAMBER

SCALE: 1/2

SPLIT END TENSIONING PLATES (2)

CABLE TENSIONING STRAPS (4)

0- 150 LB. THRUST PNEUMATIC CYLINDERS (4)

SPLIT END PLATES

HIGH-TEMPERATURE
SEAL/GASKET

PVC CABLE
JACKET

EXTRUDED INSULATION
SHIELD

HOSE CLAMP

CABLE XLPE INSULATION

108
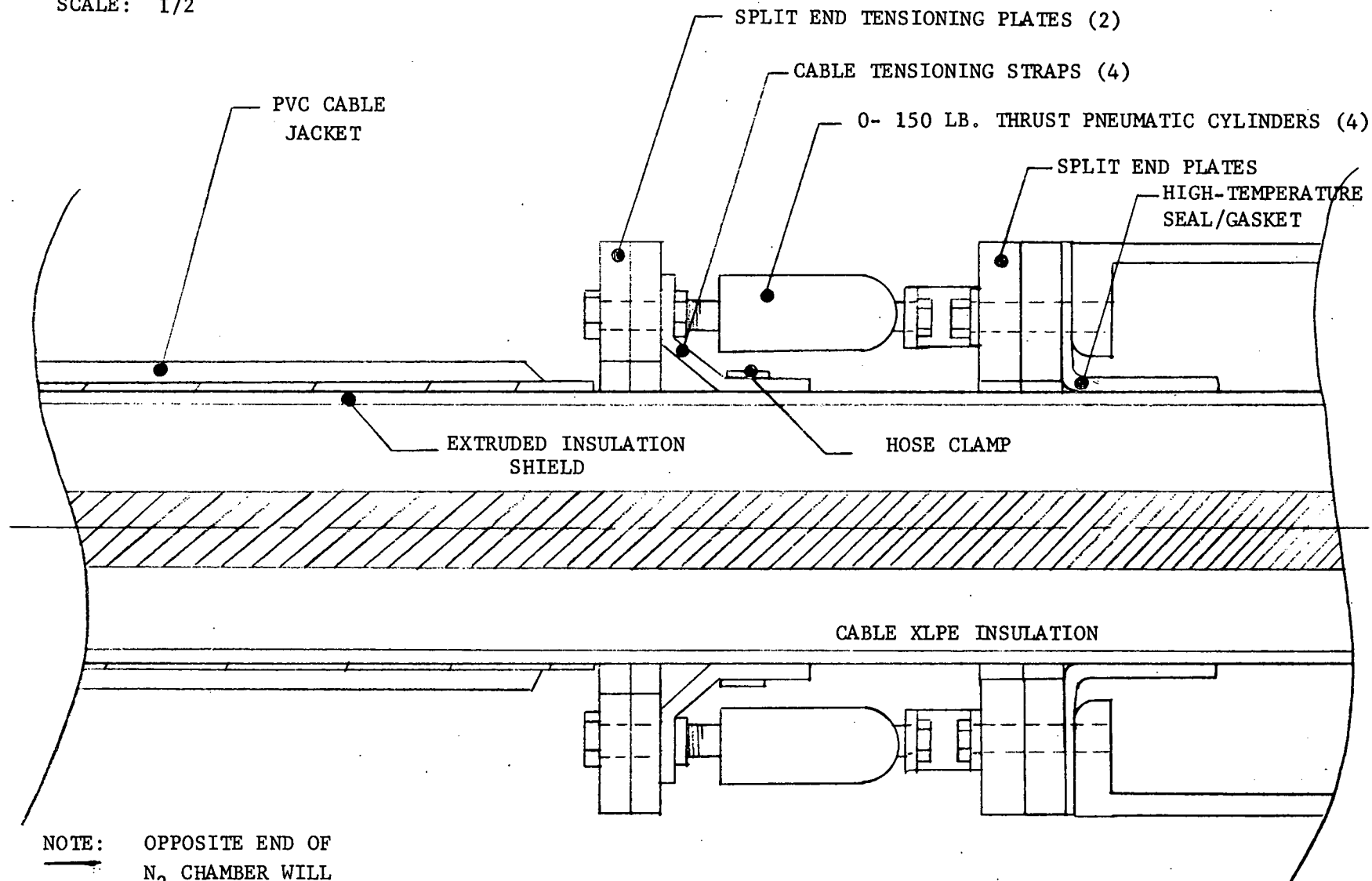
NOTE: OPPOSITE END OF
N$_2$ CHAMBER WILL
USE SAME DEVICE
WITHOUT PNEUMATIC
CYLINDERS.

FIGURE 7.30.

CROSS-SECTION OF A CABLE SPLICE
TENSIONING DEVICE FOR NITROGEN CHAMBER

Also, the present technique may lose adequate process pressure during the critical cool-down process, resulting in unacceptable insulation voids. This appears to be a significant problem at some cable size greater than 69kV 500 kcmil. It is believed that nitrogen pressure with or without induction heating would provide a great advance in the State-of-the Art for vulcanized process jointing. Although basic design work was done, the approach has not been pursued due to modification of the original 230kV ERDA contract.

STEP G — The use of microwave frequency joint compound heating was not pursued.

STEP H — Some steps were taken to assess the use of heat-shrinkable semi-conducting tubing as the means of shielding the connector in the vulcanized joint process. In particular, Gilbreth International (Reference 7.8) manufactures an EPR (ethylene propylene rubber) semi-conductive heat-shrinkable tubing in various sizes. One type is #3621-EPR which has a 2:1 shrink ratio, while another type is #3631-EPR which has a 3:1 shrink ratio. Both appear to have excellent conductive properties.

An experiment was performed in order to check the compatability of such a material, during processing, with cross-linked polyethylene joint insulation. This experiment utilized the same process technique used with the ten 69kV 500 kcmil test joints discussed previously. In brief, the results of this test indicated excellent compatability with XLPE, and insulation voids were reduced below usual levels. Further tests for compatability were made, followed by microscopic inspection of the sleeve/joint insulation interfacial area. Results showed that washing of the EPR sleeving with Inhibisol (trichlorethylene) created a still more satisfactory interface possessing both excellent bond and low void content. No voids greater than 2 mils were found in these "washed" samples. Both #3621 and #3631 EPR sleeving were tested. The conclusion from this work is that XLPE and the EPR sleeving are process-compatible and their use would provide a still higher quality vulcanized joint. In addition to this, construction time for the joint would be reduced by 3 to 4 hours. No further work was performed on this beyond the use of #3631 EPR sleeving in an experimental EPR insulated vulcanized joint reported under Step K.

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STEP I –   Study of the use of transfer molding or extrusion in place of present hand-taped application was not pursued.

STEP J –   The study of alternate (other than dicumyl peroxide) crosslinking agents for use in joint insulation compounds was not pursued.

STEP K –   A 100-pound quantity of Kaiser's K-146 EPR (ethylene propylene rubber) uncured vulcanizable compound was converted to tape. Previously, a small quantity had been converted and used to construct two vulcanized K-146 joints in our 138kV laboratory long-term test circuit. One of these joints withstood 4600 hours of over-voltage testing while the other withstood 4100 hours of test, both without failure. Since these joints were made on a purely experimental basis without any previous work, and since they have performed so well, this approach was considered to warrant some investigation.

An experimental "thermal profile" joint was made using the design shown in FIG. 7.22, substituting K-146 EPR for XLPE joint insulation. Thermocouples were imbedded at key points in the joint. The resulting graphed results are shown as FIG. 7.31, and indicate that the thermal drop through this EPR insulation is slightly higher than through the comparable XLPE insulation. However, the difference is small enough that all previous process data on XLPE joint insulation can be adapted for the use of K-146 EPR.

A second K-146 115kV 1500 kcmil vulcanized EPR joint was constructed for visual inspection. This joint had Gilbreth #3631 heat-shrinkable conductive sleeving as connector shielding. After processing, the joint was dissected and slinkied. Results indicate a high degree of promise for this method. The only problem found was the occurrence of a few circumferential striations and non-bonded tape layers. It is thought that this condition would be corrected by the use of a controllable pressurizing method such as the nitrogen method discussed in Step F. No further work was done.

COMPARISON OF THERMAL PROCESS
CHARACTERISTICS USING TWO
DIFFERENT SPLICE INSULATIONS
IN THE SAME DESIGN FOR
115 kV 1500 kcmil ALUMINUM

KEY:

A = OVEN TEMPERATURE
B = K-146 EPR OUTER SURFACE
C = XLPE OUTER SURFACE
D = K-146 EPR INNER SURFACE
E = XLPE INNER SURFACE
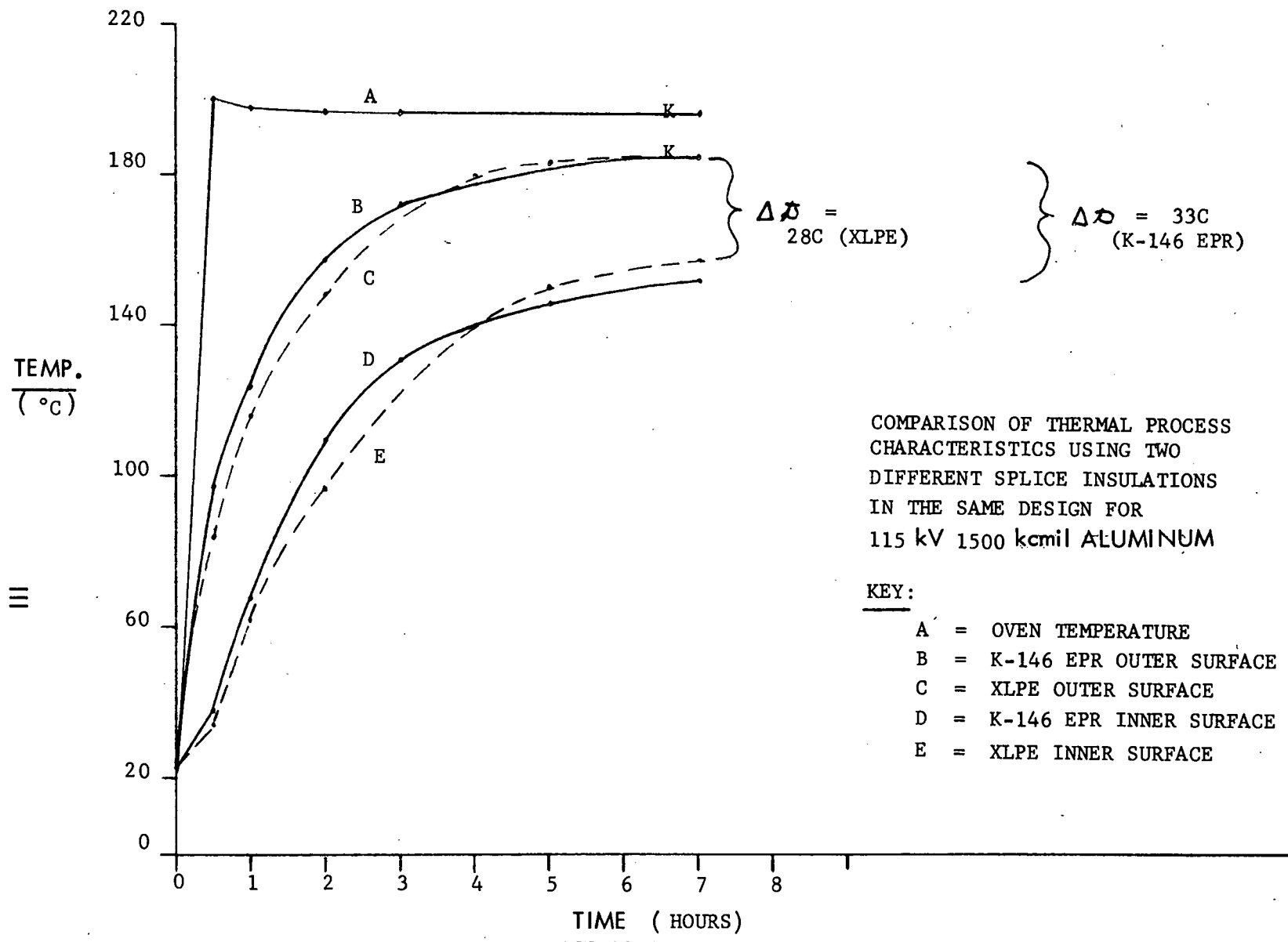
FIGURE 7.31

STEP L -   Other than work done on the use of heat-shrinkable
             connector shielding, no further work was done on reduc-
             tion of process time for 230kV vulcanized joints.

STEP M -   In discussions with Hexcel (Hotsplicer) (REFERENCE 7.9)
             personnel, a mutual interest has been expressed in the
             development of a joint insulation compound for use in a
             230kV Hotsplice. Kaiser has worked with Hotsplicer to
             evaluate their joints at the 35kV, 69kV and 138kV levels.
             Hotsplicer has expressed the interest and need to develop
             a different compound for use at 230kV and Kaiser has ex-
             pressed interest in cooperative evaluation. Due to reduc-
             tion in the 230kV contract scope, further work has not been
             done.

STEPS N, O, & P -

             The final selection, process checks and electrical testing of
             the best practical method for vulcanized joint construction
             has not been carried out.

CONCLUSION

Our work on the vulcanized joint indicates that future work should be directed towards the use of a controllable pressure method, such as the nitrogen method previously described, the use of simplified means of applying connector shielding and the use of EPR as a more easily processed joint insulation. In addition, the use of induction heating may quicken and improve the process. The use of a joint tensioning device would greatly reduce joint insulation eccentricity. Further steps towards improving basic joint insulation compounds and toward improved means of insulation application would tend to improve joint insulation quality.

In general, our work was done starting at the 69kV level. It is known that the joint insulation quality is very important in regards to electrical performance of the vulcanized joint insulation. The work reported on 69kV vulcanized joint electrical performance, and subsequent examination in detail of the tested insulation quality, had the objective of establishing a baseline for "acceptable" insulation defects such as voids and contaminants. In the case of the 230kV vulcanized joint design (shown in FIG. 7.26) the electrical stresses are still higher than previous test experience on 69kV and 138kV joints. The radial stresses are tabulated in Table 7.7. Also, the tangential stresses in various designs are tabulated in Table 7.8 in conjunction with the sketches in FIGURES 7.32 and 7.33. It can be seen that interfacial stresses (which are not a problem in well-bonded interfaces) are significantly higher in the 230kV design than in previous designs. All of this points clearly to the need to exercise every possible means to ensure both the highest possible joint quality, and subsequent reliable trouble-free service.

TABLE 7.7

RADIAL ELECTRICAL STRESSES IN VULCANIZED POLYETHYLENE JOINT DESIGNS

VOLTS PER MIL (60 Hz)

JOINT DESIGN	69 kV 500 kcmil			115 kV 1500 kcmil			138 kV 500 kcmil			230 kV 1000 kcmil		
% RATED VOLTAGE	100	200	250	100	150	200	100	150	175	100	150	200
KILOVOLTS (LINE TO GROUND)	40	80	100	66.4	99.6	132.8	80	120	140	133	200	266
CABLE												
AVERAGE	76	152	191	90	135	179	90	135	157	127	190	253
MAXIMUM	110	221	276	128	191	255	159	238	278	210	315	421
JOINT CENTER												
(PERFECT) (CENTERING)												
AVERAGE	62	123	154	76	115	153	76	114	133	106	160	213
MAXIMUM	89	178	222	105	157	210	128	192	224	170	255	339
(MAXIMUM) (ECCENTRICITY)												
AVERAGE	76	152	191	86	129	173	84	126	147	116	174	231
MAXIMUM	104	208	260	115	173	230	137	205	239	180	269	359
JOINT POINT "X"												
(TIP OF XLPE) (CABLE INSULATION) (TAPER WITH) (PERFECT) (CENTERING)												
AVERAGE	65	130	163	56	99	132	69	104	122	95	142	189
MAXIMUM	90	179	224	103	154	206	136	204	238	175	263	351

TABLE 7.8

TANGENTIAL ELECTRICAL STRESSES IN VULCANIZED POLYETHYLENE JOINT DESIGNS

VOLTS PER MIL (60 Hz)

JOINT DESIGN	69 kV 500 kcmil			115 kV 1500 kcmil			138 kV 500 kcmil			230 kV 1000 kcmil		
% RATED VOLTAGE	100	200	250	100	150	200	100	150	175	100	150	200
KILOVOLTS (LINE TO GROUND)	40	80	100	66.4	99.6	132.8	80	120	140	133	200	266
POINT TO POINT												
X A	17.7	35.4	44.2	28.4	42.6	56.8	41.9	62.8	73.3	57.9	86.8	115.7
A B	16.5	32.9	41.2	26.5	39.8	53.0	36.5	54.7	63.8	52.1	78.1	104.1
B C	15.5	31.0	38.7	24.9	37.3	49.8	32.5	48.7	56.8	47.5	71.3	95.0
C D	14.7	29.4	36.8	23.6	35.4	47.2	29.4	44.2	51.5	43.9	65.8	87.8
D E	14.1	28.2	35.2	22.6	33.8	45.1	27.1	40.6	47.4	40.9	61.4	81.9
E F	13.0	25.9	32.4	21.7	32.5	43.3	20.5	30.8	36.0	34.3	51.4	68.5
X F	14.6	29.3	36.6	23.6	35.4	47.2	28.6	42.9	50.1	40.6	60.9	81.2

FIG. 7.32

SC XLPE
CONNECTOR
SHIELD

69 kV

500 kcmil

ALUMINUM

XLPE CABLE
INSULATION

XLPE JOINT
INSULATION

0.735"

E   D   B
  C   A   X

2.5 2.25   1.25 1.00 0.75 0.50 0.25 0.00

INCHES

F

E
    D   C
        B   A
              X

SC XLPE
CONNECTOR
SHIELD

115 kV

1500 kcmil

ALUMINUM

XLPE CABLE
INSULATION

XLPE JOINT
INSULATION

1.004"

PROFILE OF VULCANIZED JOINT TAPERS SHOWING POINTS FOR CALCULATION
OF TANGENTIAL STRESSES FOR 69 kV AND 115 kV DESIGNS

116
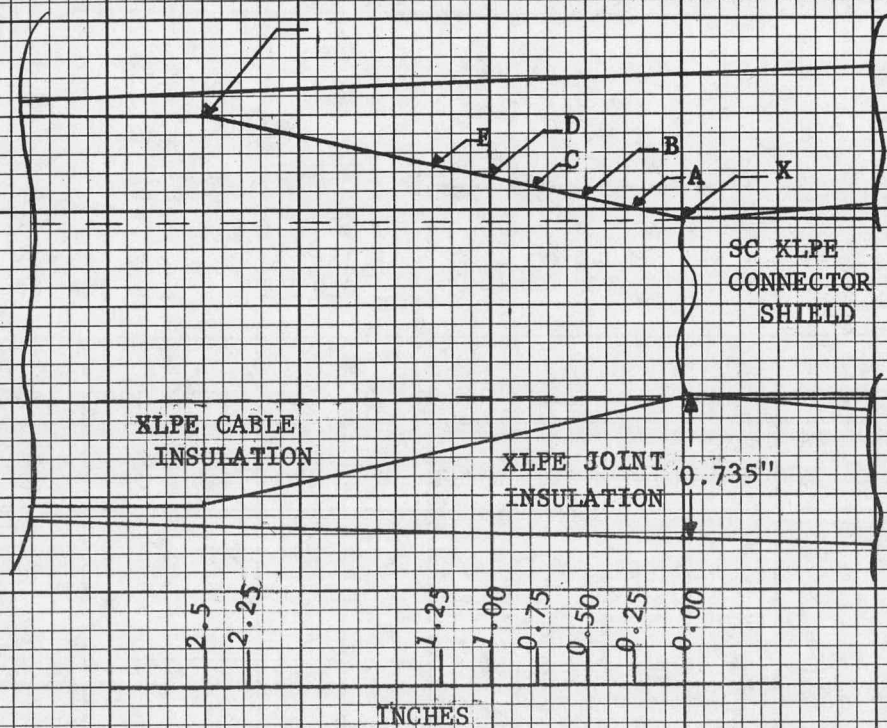
FIG. 7.33
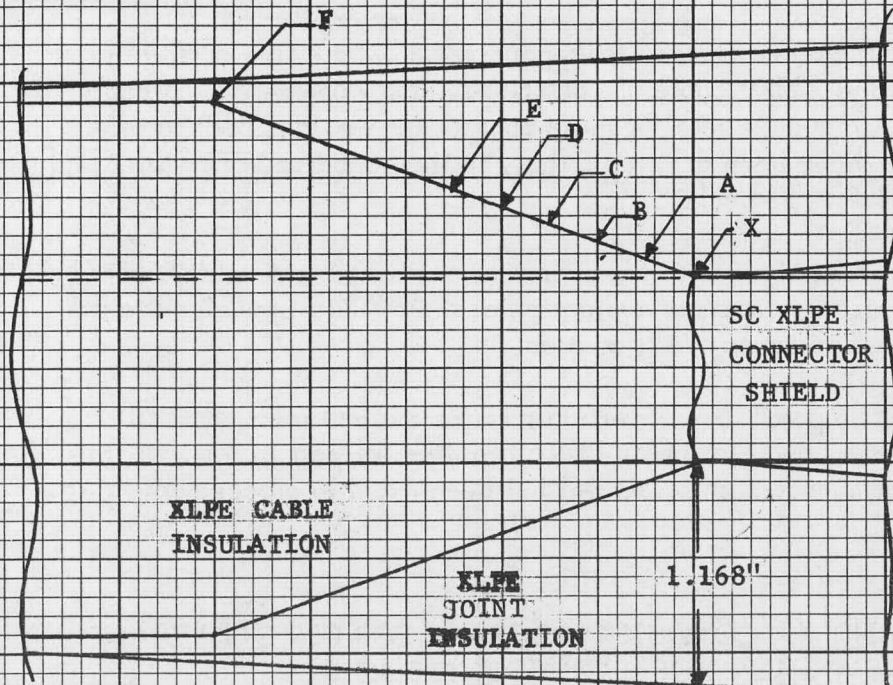
138kV

500 kcmil

ALUMINUM
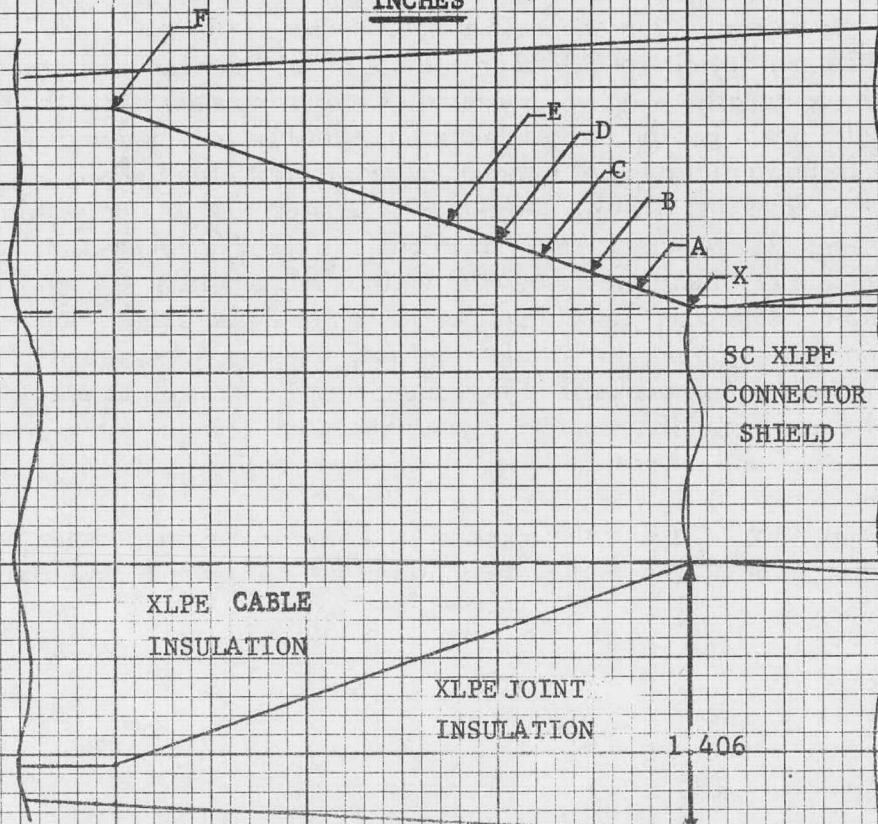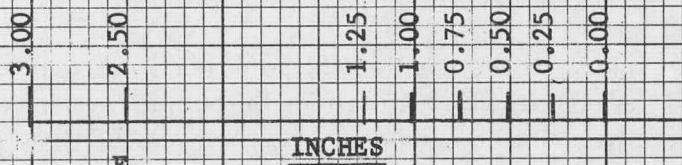
230 kV

1000 kcmil

ALUMINUM

PROFILE OF VULCANIZED JOINT TAPERS SHOWING POINTS FOR CALCULATION OF TANGENTIAL STRESSES FOR 138kV AND 230kV DESIGNS

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7.3   CATEGORY 3 - ALTERNATE CONCEPTS

Reference is made to Appendix 7.1 where five possible alternate means of jointing 230kV cable are described. No work on this category has been performed. Although several of these approaches would appear to offer promise, our efforts have been devoted largely to the hand-taped EPR joint and to the vulcanized joint approaches.

Discussions have been carried out with Elastimold (REFERENCE 7.10) regarding Kaiser testing and evaluation of their 138kV premolded joint which was developed under an EPRI contract.

The possibility of testing this pre-molded joint on a 230kV cable has also been discussed and Elastimold also has active interest in this. At this time, no Kaiser committment or agreement has been made to proceed with this evaluation.

7.4   CATEGORY 4 - COMPUTER PROGRAMS FOR DESIGN AID AND FAILURE ANALYSIS OF HIGH VOLTAGE JOINTS

It was felt that with the wide variation of materials available for manufacturing joints and the number of combinations that could be derived in the use of these different materials, that a computer program could be developed that would assist in the determination of specific requirements to suit the needs of the user. There is a multiplicity of different methods of joining conductor ends that could be used in conjunction with various forms of insulating materials. If the characteristics of a major portion of these materials could be obtained and listed it would form a substantial bank of information available to the industry. The computer aided program first investigated the voltage stress distribution within 230kV taped joint design #1. A second step was to analyze the thermal stress distribution within the same configuration. The next logical step would have been to combine the two into a single computer aid program which could be used to determine joint parameters for use on any installation and with any combination of jointing methods and insulating materials. The reduced scope of this effort prevented the completion of the program. The program stopped at a point preceding the incorporation of the voltage and thermal analyses into a single entity.

Appendix 7.3 shows the approach to both the electrical field and thermal field computer programs. Included are copies of both of these Fortran programs.

     A reliable connector is essential to a reliable high voltage joint. Due to the possibility of inadequacies in the industry testing of aluminum connectors with regard to use in high voltage insulated joints the basic program outlined in Appendix 7.1 was planned. The objective of this was to provide data to indicate reliable connectors for use in 230kV joint designs. Concentration was upon connections for the 1000 kcmil die-sized aluminum conductor. The progress on various steps of this plan will now be outlined.

STEP A -   In general, the sum result of our own knowledge and literature searches indicate that the testing of aluminum connectors in the industry has been particularly limited with regard to conductor sizes of 1000 kcmil and larger and for application within systems rated higher than 35kV. We are not aware of any comprehensive, systematic test which has been done on 1000 kcmil connectors supplied from various manufacturers. In particular we know of no test standard that is comprehensive of the thermal effects which would occur in 138kV and 230kV taped EPR joints. For this reason it was considered essential that these gaps in testing and test procedure should be filled.

STEP B -   The methods of joining insulated aluminum conductors are adequately outlined in Appendix 7.1.

STEP C -   Based upon EEI TDJ-162 (REF. 7.11), a test standard for aluminum connectors was developed. Essentially, this incorporates the basic EEI TDJ-162 500 cycle test at 130 C conductor temperature but goes beyond that test by testing at 160 C, 190 C, 220 C and 250 C conductor temperatures. This is for the purpose of defining the temperature levels which connectors could withstand without experiencing progressive electrical degradation and subsequent overheating followed by thermal runaway. Because it is known that connectors in 138kV taped EPR designs may reach 170 C or more when the cable conductor is at 130 C it is obvious that, for example, a suitable 138kV connector would have to pass the 190 C level to indicate suitability at this level. Our tests have indicated that the 190 C level would also be required for connector suitability at the 230 kV level in taped EPR joint design [#]1.

In particular, the performance of compression connectors on aluminum at temperatures above 140 C is a concern. Data obtained will also be of use to the industry at lower voltage levels where such severe over-temperatures do not occur. Connectors that are not suitable for the 230kV level may be suitable for lower voltages.

STEP D -   A circuit consisting of about 30 feet of bare 1000 kcmil die-sized Class B stranded ECH-19 aluminum was set up in the high current laboratory. Thermocouples were attached to the conductor at various points and current-loading runs were made to determine 60 Hz load current required to raise the conductor to a steady 130 C, 160 C, 190 C, 220 C and 250 C. When the correct current was identified, a total of three separate loading runs were made to verify the data. Cooling curves were also recorded. The composite data for the 15 verifying loading runs is shown in FIG. 7.34. A sample heating and cooling data sheet is shown as TABLE 7.9. From these data it was seen that heating equilibrium for all 5 conductor temperatures was reached within 2 hours. Likewise, all points were within 2 C of ambient temperature at the 2-hour point in time following current shut-off. A 4-hour load cycle time was established, with 2 hours on and 2 hours off.

275 —
250 —
200 —
150 —
100 —
50 —
0 —

TEMP.
(°C)

250C   CURRENT = 1678 AMPERES

220C   CURRENT = 1567 AMPERES

190C   CURRENT ≑ 1446 AMPERES

160C   CURRENT ≠ 1311 AMPERES

130C   CURRENT = 1156 AMPERES

AIR AMBIENT RANGE =

23C - 27C

1   2   3   4   5   6

HOURS

121
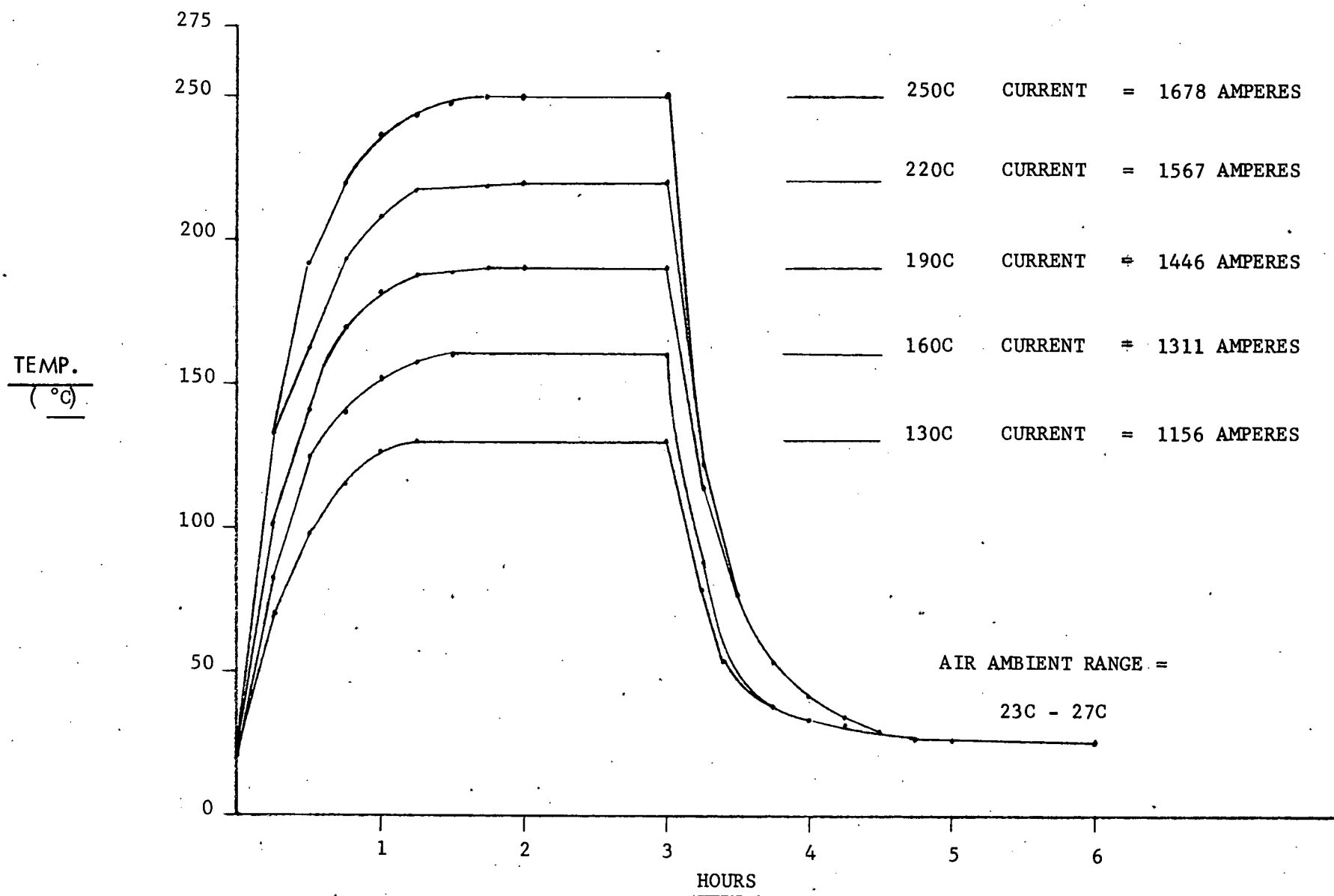
FIGURE 7.34   COMPOSITE GRAPH OF 1000kcmil DIE-SIZED CLASS B
ALUMINUM CONDUCTOR HEATING/COOLING CHARACTERISTICS
IN FREE AIR

MASTER DATA SHEET

THERMAL CHARACTERISTICS -- 230 kV SPLICE CONNECTOR PROGRAM

I = _____1156_____ Amps   AMBIENT = _____25°_____ C

Nominal Conductor Temp. _____130°_____ C

Data Objective: 130°C THERMAL PROFILES

HEATING PROFILE #1

TIME/MIN	15	30	45	60	75	90	105	120	135	150	165	180			
TC#1	56	80	91	99	101	103	104	105	106	106	106	106			
2	70	102	116	126	129	130	131	131	131	131	131	131			
3	70	102	117	127	129	130	131	131	131	131	131	131			
4	67	98	112	120	123	125	126	126	126	126	126	126			
5	70	102	115	124	126	128	129	130	130	130	130	130			
6	70	102	114	124	126	128	129	130	130	130	130	130			
7	70	102	114	124	126	128	129	130	130	130	130	130			
8	56	75	89	98	101	103	104	105	106	106	106	106			
9	56	80	91	99	101	103	104	106	106	106	106	106			
10	56	75	89	98	101	103	104	106	106	106	106	106			
11	25	25	25	25	25	25	25	25	25	25	25	25			

COOLING PROFILE #1

TIME/MIN	15	30	45	60	75	90	105	120	135	150	165	180			
TC #1	67	56	45	37	33	31	28	27	27	27	27	27			
2	75	56	47	38	33	31	28	27	27	27	27	27			
3	75	56	47	38	33	31	28	27	27	27	27	27			
4	75	56	47	38	33	31	28	27	27	27	27	27			
5	75	56	47	38	33	31	28	27	27	27	27	27			
6	75	56	47	38	33	31	28	27	27	27	27	27			
7	75	56	47	38	33	31	28	27	27	27	27	27			
8	67	56	48	39	34	31	28	27	27	27	27	27			
9	67	56	45	37	33	31	28	27	27	27	27	27			
10	67	56	48	40	33	31	29	27	27	27	27	27			
11	26	26	26	26	26	26	26	27	27	27	27	27			

TABLE 7.9

STEP E –   Working relationships with aluminum connector
suppliers were established. The following manufacturers
were contacted:

Mac Products Inc.	Kearny, New Jersey	(REF. 7.12)
Erico Products	Cleveland, Ohio	" 7.13
Thomas & Betts Co.	Elizabeth, New Jersey	" 7.14
Electrical Specialty Products Co.	Montevallo, Al.	" 7.15
Utility Industries	Pennsauken, N. J.	" 7.16
Homac Manufacturing Co.	Ormand Beach, Fla.	" 7.17
Burndy Corporation	Norwalk, Conn.	" 7.18
Frankel Connector Co.	Bronx, New York	" 7.19
AMP Inc.	Harrisburg, Pa.	" 7.20
Teldyne-Penn Union Electric	Edinboro, Pa.	" 7.21
Anderson Electric	Leeds, Ala.	" 7.22
Kearney Company	Atlanta, Ga.	" 7.23

Of these, the first 9 expressed interest in the connector test program.
Connectors from the first three have been purchased, installed and are under test.
Also, connectors from the fourth supplier have been purchased but not placed under
test as of the date of this report. Due to load cycle equipment unavailability, no
further work is anticipated beyond that in progress with these first four suppliers.
As of the date of this report, connectors from the first three suppliers have com-
pleted the 130 C Test Phase (500 load cycles) and the 160 C Test Phase (100 load
cycles).

Work was also pursued to determine sources of inert gas welding equipment, materials and expertise. No further work was performed on this due to shortening of the Contract.

STEP F — Five of each type of connector were installed in a load cycling circuit as depicted in FIG. 7.35. An additional six of each connector type were installed in the center of straight 8-foot sections of bare conductor, for later tensile strength tests. Three of these were to be heat cycled at the temperature step just below the failure level observed in the load cycle test, while three were to be non-heat-cycled connectors.

Thermocouples were permanently attached to the five load cycling connectors and control conductors using porcelainized cement.

Five of each of three types of connectors were load cycled in air according to the connector test standard presented in Appendix 7.4. All connectors were installed on 1000 kcmil ECH-19 Class B compressed die-sized aluminum conductor, the same conductor used in the manufactured 230kV cable. The three types of connectors tested were:

(1)   Mac #MTAP 1000 NE (compression)

(2)   Thomas & Betts (Somerset) #1000 A S 150 (compression)

(3)   Erico (Cadweld) 1000 kcmil Aluminum (exothermic weld)

A total of 15 connectors were tested through the first 600 load cycles of the projected 900 load cycle test program. The first 500 load cycles were with a control conductor temperature of 130 C (1156 ampere load current) while the last 100 load cycles were with a control conductor temperature of 160 C (1311 ampere load current). In all cases the load cycle consisted of 2 hours with load current applied followed by 2 hours cooling to ambient temperature .

Measurements of connector temperature and dc resistance were taken at approximate 25 load-cycle intervals. Temperature measurements were taken during the final 5 minute segment of heating portions of the load cycles, while dc resistance measurements were taken following 2 full hours of cooling. The temperature readings were compared with measurements, concurrently taken, of conductor temperature. DC Resistance measuring equalizers are 1 inch long compression sleeves

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THERMAL PROFILE TEST ASSEMBLY
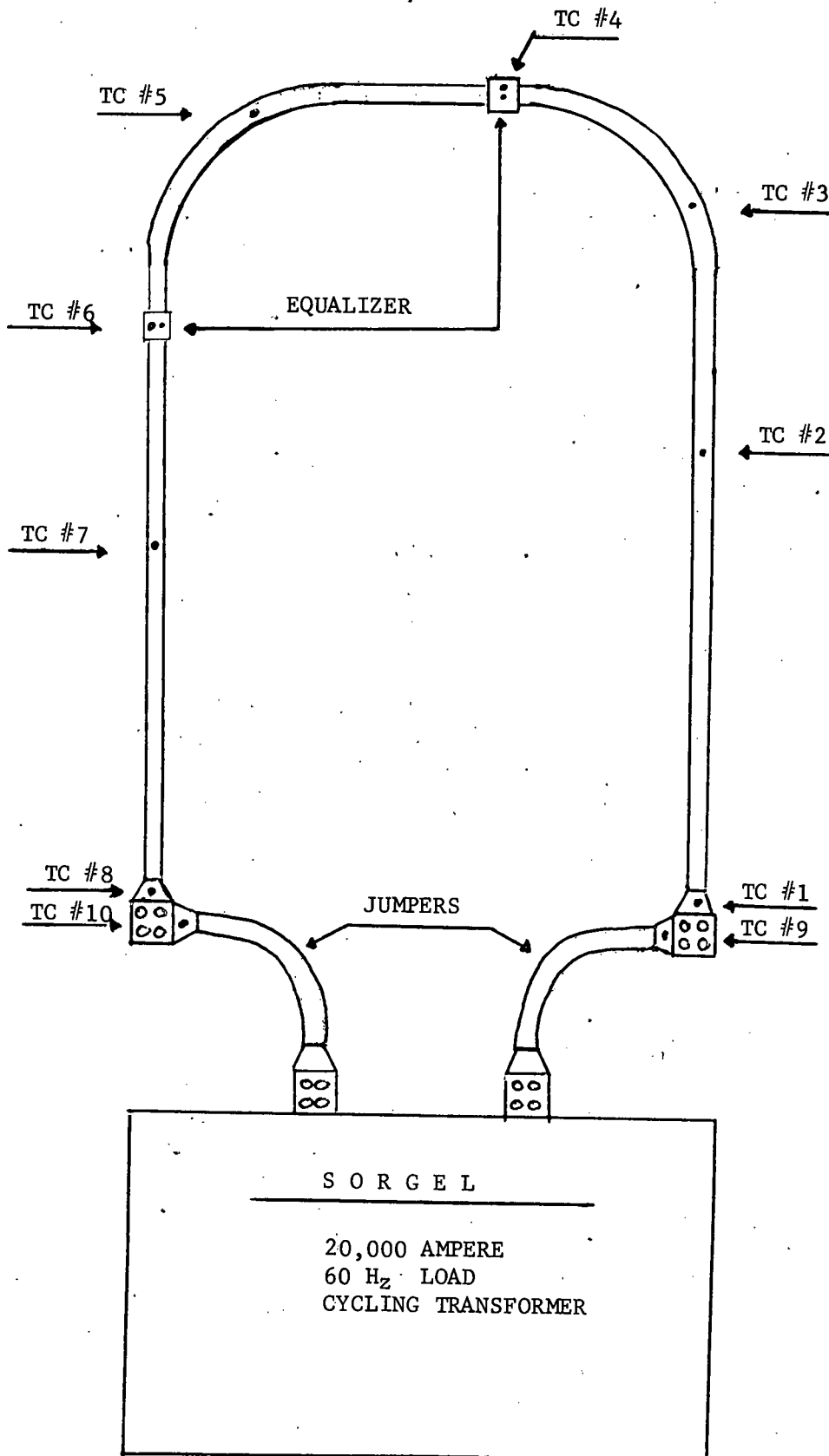
FIGURE 7.35

which were applied to the conductor on either side of the test connector.
The near edge of the equalizer was spaced 1 inch from the end of the
connector. For each connector type, a set of equalizers was also applied
to a length of control conductor. These equalizers were spaced the
same distance apart as those used adjacent to each connector. For
example, equalizer spacing for the Mac connectors was 13.5 inches, for
the T & B connector was 11.5 inches, and for the Cadweld connector
was 5.0 inches. The identical spacing, of dc resistance equalizers,
over connectors and control conductors allowed direct comparison of
connector resistance to the conductor resistance and to calculated
nominal conductor resistance. Calculated dc resistance at 25 C for
various equivalent 1000 kcmil aluminum conductor lengths are:

13.5 inches:	19.90 microhms
11.5 "	16.95 "
5.0 "	7.37 "

Results of the connector load cycling tests are graphed in FIGURES
7.36, 7.37, and 7.38. The following are general conclusions based
upon the graphed data:

MAC CONNECTORS (FIGURE 7.36)

The data indicate that the Mac connectors run significantly
cooler than the control conductor in air. The graphs of both dc resist-
ance and temperature indicate stability over the first 600 load cycles
and no apparent trend toward degradation. Fluctuations in the plotted
data are mainly due to variations in air ambient temperature. At the
end of 600 load cycles all five Mac connectors appear to be intact.

T & B CONNECTORS (FIGURE 7.37)

The data indicate that the dc resistance of the T & B connectors,
as a group of 5, tended to increase over the first 500 load cycles. It
is noteworthy that both temperature and dc resistance of these connectors
tends to be significantly higher than that of the control conductor.
During the final 100 load cycles at 160 C, and particularly during the
last 25 load cycles, substantial increases in both resistance and tempera-
ture are evident. This characteristic is indicative of electrical degrada-
tion of the connectors which would be expected to result in thermal
destruction of one or more of the 5 test connectors. Had the test ex-
tended beyond the 100 load cycles at the 160 C level it is likely that
further increases in temperature and resistance would have occurred.

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DC RESISTANCE MEASURED WITH ASSEMBLY AT TEMPERATURE EQUAL TO AMBIENT AIR

EFFECTIVE DC RESISTANCE MEASUREMENT LENGTH = 13.5 INCHES

CONDUCTOR: ECH-19
CLASS B COMPRESSED DIE-SIZED ALUMINUM
1000 kcmil

CONTROL CONDUCTOR

RANGE OF FIVE MAC 1000 kcmil CONNECTORS

TEMPERATURE MEASURED DURING FINAL 5 MINUTE HEATING PERIOD OF CURRENT LOAD CYCLE

LOAD CYCLE:
2 HOURS WITH CURRENT APPLIED
2 HOURS WITH NO CURRENT

CONTROL CONDUCTOR

TEMPERATURE RANGE OF FIVE MAC 1000 kcmil CONNECTORS

AMBIENT AIR

130 C CONDUCTOR: 1156 AMPERE LOAD CURRENT

NUMBER OF LOAD CYCLES

160 C COND.

FIGURE 7.36   1000 kcmil MAC MTAP
1000 NE CONNECTOR TEST DATA

1311 AMPERE LOAD CURRENT

127
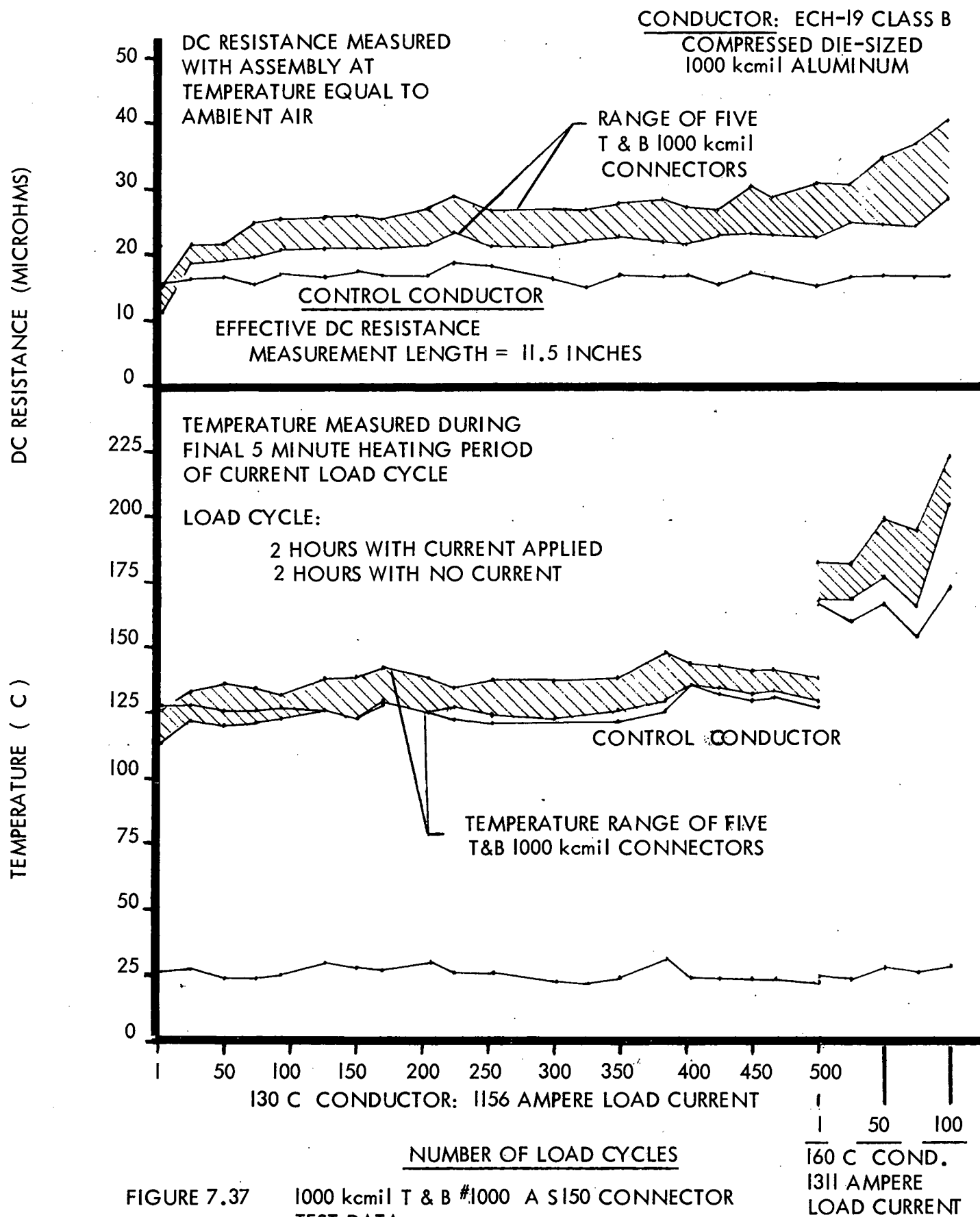
FIGURE 7.37   1000 kcmil T & B #1000 A S150 CONNECTOR
TEST DATA

128
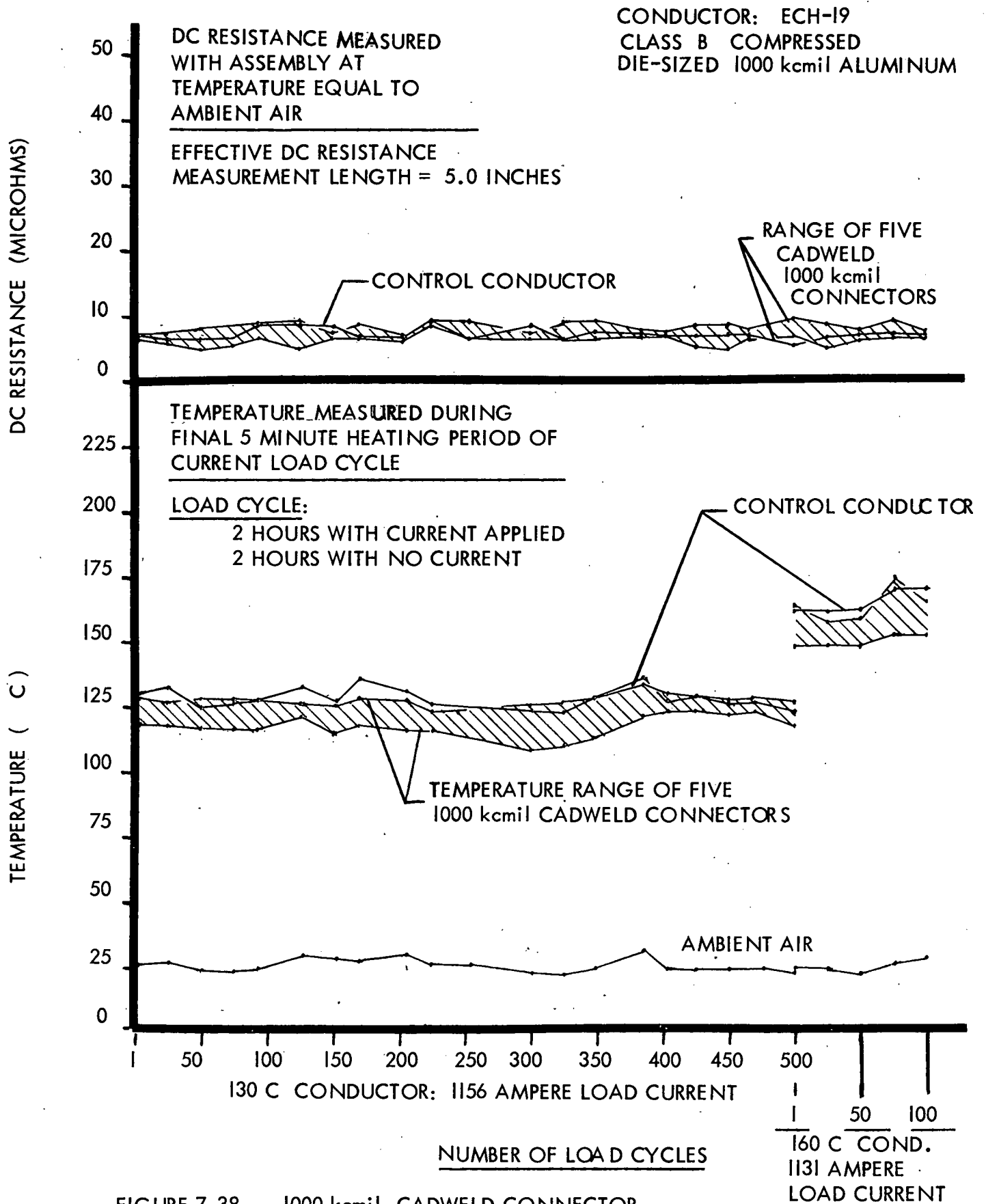
FIGURE 7.38   1000 kcmil CADWELD CONNECTOR
               TEST DATA

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CADWELD CONNECTORS (FIGURE 7.38)

The data indicate that the Cadweld connector resistances tend to closely match the dc resistance of the control conductor. It is noted that the connectors generally tend to run slightly cooler than the conductor. This later occurrence may be due to the slightly better heat-dissipating properties of the Cadweld as compared to the conductor. The data indicate stable temperature and resistance characteristics over the 600 load cycle test with no indication of degradation.

It is evident that the Mac and Cadweld connectors tend to retain satisfactory electrical characteristics, and to operate generally below conductor temperature. The T & B connector does not appear to possess long-term stability beyond the first 500 load cycles and tends to operate above conductor temperature. Final conclusions on all of these connectors cannot be reached, particularly with regard to application in a 230kV joint, due to the need to complete at least the next, 190 C, portion of the load cycle test in order to subject the connectors to temperatures higher than might be encountered in a 230kV taped joint design. Earlier thermal tests (Category I, Step F) indicated that connector temperatures in 230kV taped joint design #1 would be in the vicinity of 170 C when the cable conductor was 130 C. This indicates that, in order to test with a reasonable margin of design safety, the connectors should exhibit stability at the 190 C, or higher, test level.

STEP G - The mechanical test requirements for connectors were covered in Appendix 7.4. A means of measuring actual mechanical forces within 230kV splices was not devised.

STEP H - A bibliography on aluminum connector design, use and research was not compiled.

STEP I - Due to the contract modification, the tests that were underway could not be completed through the 900 load cycles required to evaluate suitability for use in 230kV splice designs. Therefore, it was considered best to use the Erico (Cadweld) connector for the actual construction of 230kV taped EPR joint design #1 in the electrical test circuit. This was based upon past favorable experience with this connector type at the 138kV level.

1   BISHOP ELECTRIC
     10 Canfield Rd.
     Cedar Grove, N. J., 07009

2   J. H. Neher and M. H. McGrath
     "The Calculation of the Temperature Rise and
     Load Capability of Cable Systems"
     Transactions of AIEE, pp 752-72, October 1957

3   ERICO PRODUCTS, INC.
     34600 Solon Rd.
     Cleveland, Ohio, 44139

4   PLYMOUTH RUBBER COMPANY, INC.
     Canton, Mass., 02021

5   GENERAL ELECTRIC COMPANY
     One Campbell Rd.
     Schenectady, New York, 12306

6   3M Company
     3M Center, Bldg. 223-4N
     St. Paul, Minnesota, 55101

7   Association of Edison Illuminating Companies
     (AEIC) No. 5-75 "Specifications For Polyethy-
     lene and Crosslinked Polyethylene Insulated
     Poer Cables Rated 5 Through 69kV" 5th Edition,
     December, 1975

8   GILBRETH INTERNATIONAL CORP.
     3300 State Road
     Cornwells Heights, Pa., 19020

9   HEXCEL CORPORATION
     Electrical Products Dept.
     San Diego, Calif., 92109

10   ELASTIMOLD DIVISION
     Amerace Corporation, ESNA Park
     Hackettstown, N. J., 07840

7.6   REFERENCES (Cont'd.)

11   EEI-NEMA "Standards For Overhead Distribution
          Connectors For Aluminum Conductors, NEMA Pub.
          No. SG 14.10-1962, EEI Pub. No. TDJ-162

12   MAC PRODUCTS, INC.
          60 Pennsylvania Ave.
          Kearny, N. J., 07032

13   Same as REFERENCE 7.3

14   THOMAS & BETTS COMPANY
          8838 Butler Street
          Elizabeth, N. J., 07207

15   ELECTRICAL SPECIALTY PRODUCTS CO.
          P. O. Box 21
          Montevallo, Alabama, 35115

16   UTILITY INDUSTRIES, INC.
          5075 Central Highway
          Pennsauken, N. J., 08109

17   HOMAC MANUFACTURING COMPANY
          P. O. Box 1118
          Ormond Beach, Florida, 32074

18   BURNDY CORPORATION
          Norwalk, Conn., 06856

19   FRANKEL CONNECTOR CO.
          1733 East chester Blvd.
          Bronx, N. Y., 10461

20   AMP INCORPORATED
          Harrisburg, Pa., 17105

21   TELEDYNE-PENN UNION ELECTRIC
          229 Waterford Street
          Edinboro, Pa., 16412

22   ANDERSON ELECTRIC CORP.
          P. O. Box 455
          Leeds, Alabama, 35094

23   KEARNEY COMPANY
          P. O. Box 49167
          Atlanta, Ga., 30329

The objective of the jointing research program is to develop at least one fully reliable jointing technique at the 230kV level.

In order to achieve the objective, the program is planned to follow five avenues of research. These divisions of the program are being carried on in parallel. They are:

(1)   Taped Joint   (Category 1)

(2)   Vulcanized Joint   (Category 2)

(3)   Alternate Jointing Concepts   (Category 3)

(4)   Computer Programs   (Category 4)

(5)   Connector Evaluation   (Category 5)

CATEGORY 1 - TAPED JOINT

Steps completed as of 12/31/75:

(1)   Designed, constructed and tested a higher stress taped joint design in the 138kV 400 kcmil joint test circuit (#W-962 75A). This was tested at 150% rated voltage for 360 hours.

(2)   Designed a 230kV taped joint for the 1000 kcmil 230kV cable using the higher stress design concepts. This is designated 230kV taped design #1.

(3)   Designed and constructed a second higher stress taped joint in the 138kV 400 kcmil joint test circuit (#W-962 75B).

CATEGORY I (Cont'd.)

Future Plans As of January, 1976:

(A)   Dissect higher stress design joint #W962-75A (which had to be removed due to a defective cable section in the 138kV test circuit). Examine for evidence of any electrical degradation due to the testing completed. This will provide an indication of the feasibility of the higher stress concept.

(B)   Continue testing the 138kV joint evaluation circuit (with emphasis on higher stress design taped joint #W-962-75B) as follows:

(1)   10   90 C load cycles at 100 kV
(2)   10   90 C load cycles at 110 kV
(3)   10   90 C load cycles at 120 kV
(4)   10   90 C load cycles at 130 kV
(5)   10   90 C load cycles at 140 kV
(6)   10   130 C load cycles at 100 kV

A comparison of joint design stresses is tabulated here (Table I).

Completion of Test Step B3 provides a strong indication that 230kV design #1 will be workable. Completion of Test Step B5 would indicate that the 230kV design #1 would perform at 150% rated voltage (200kV, phase-to-ground).

(C)   Based upon successful completion of Step B3 order pencilling tool for 230kV joint Design #1.

(D)   Design "low stress" transition joints for connection of a length of 1000 kcmil 230kV cable to an existing 2500 kcmil 138kV cable which is terminated in 230kV terminals. These joints will be designed to avoid the likelihood of their failure at voltages up to 266kV, phase-to-ground. This will provide a full scale test circuit with capacity for electrically evaluating 230kV splice designs.

(E)   Construct and pre-test the two joints of Step D, "jointing in" about 50-feet of 230kV cable.

(F)   Design and construct a "thermal profile" test on 230kV Joint Design #1. This joint will be constructed in the center of a 24-foot length of 1000 kcmil 230kV cable. Thermocouples will measure temperature occurring at numerous locations in the joint and cable. In order to avoid the

TABLE I

ELECTRICAL STRESSES IN TAPED JOINT DESIGNS

	Waltz Mill 138kV ERC Design		138kV Higher Stress Design				230kV Design #1	
			W-962-75A		W-962-75B			
% RATED VOLTAGE	150	175	150	175	150	175	100	150
KILOVOLTS	120	140	120	140	120	140	133	200
60Hz UNIT STRESS (V/M)								
Maximum Radial	176	205	201	234	173	202	152	228
Average Radial	80	93	95	111	95	111	70.4	105.6
Pencil Tangential	11.3	13.1	21.4	25	21.4	25	12.3	18.4
Stress Cone Longitudinal	14.1	16.5	11.6	13.5	15.6	18.2	12.5	18.8
Average Creepage	7.5	8.8	10.7	12.5	10.7	12.5	7.5	11.3
Connector Longitudinal	11.3	13.1	--	--	20.1	23.5	--	--
IMPULSE UNIT STRESS (V/M)								
B.I.L. KILOVOLTS	650		650		650		1050	
Average Radial	433		514		514		556	
Average Creepage	41.3		58		58		59	
125% B.I.L. KILOVOLTS	813		813		813		1313	
Average Radial	541		643		643		695	
Average Creepage	51.6		73		73		73.8	
DC UNIT STRESS (V/M)								
KILOVOLTS	415		415		415		525	750
Average Radial	277		328		328		277	397
Average Creepage	26.3		37		37		29.5	42.3

effects of a connector, in this initial test, the splice will be constructed on an uninterrupted conductor. This test will yield:

     (1)   An indication of the degree of overheating which may be expected in 230kV Joint Design #1.

     (2)   Data for use in developing the thermal field computer program (Category 4, Part 3).

     (3)   Loading curves for 90 C and 130 C cable operation.

(G)   Determine methods for evaluating taped joint insulation. In order to develop the best taped joint design a thorough knowledge of the characteristics of each jointing tape must be obtained. To the greatest extent possible this data will be obtained using standard industry tests, ASTM methods, etc. In cases where no method exists, we will develop techniques for measurement. The characteristics to be measured are listed below.

Each of these characteristics will be determined with the sample at 25C, 60C, 90C, 130C, 150C, 175C, and 200C.

     (1)   60 Hz dielectric withstand and breakdown as a function of thickness and temperature.

     (2)   DC dielectric withstand and breakdown as a function of thickness and temperature.

     (3)   Impulse dielectric withstand and breakdown as a function of thickness and temperature.

     (4)   Dielectric constant and dissipation factor as a function of electrical stress and temperature.

     (5)   Tendency toward dielectric heating (through measurements of dissipation factor) as a function of electrical stress, temperature and time.

     (6)   Joint insulation modulus (tensile & elongation) as a function of temperature.

     (7)   Insulation thermal conductivity as a function of temperature.

CATEGORY 1 (Cont'd.)

(8)   Joint insulation/cable insulation 60 Hz interfacial
          dielectric withstand as a function of temperature.

(9)   Same as 8, except on DC.

(10)   Same as 8, except on Impulse.

(11)   Joint insulation/cable insulation interfacial adhesion as a
          function of temperature and pressure.

The determination of these characteristics may be performed by the
R & D group in conjunction with tape manufacturers and independent research and
development laboratories.

(H)   Develop working relationships with tape manufacturers for cooperative
          efforts in evaluating tape insulations and designs for use at 230kV levels.
          Bishop, General Electric, 3M , Plymouth, etc., are companies in this
          category.

A test procedure will be outlined for evaluation of joints developed from
Categories 1, 2 & 3. The tests will be performed by installing test joints in two
separate test circuits:

(1)   60 Hz testing - Using the circuit described in Steps D & E
          of Category 1 (Joint Test Circuit A).

(2)   DC & Impulse Testing- A circuit will be set up which will
          allow DC tests and impulse tests to be done on the same cir-
          cuit. With a total circuit length of 80', the effective test
          length for DC testing will be 60' and the effective test
          length for impulse testing will be 30' (Joint Test Circuit B).

As joint designs are developed and evaluated, some designs may not merit
consideration beyond the design stage while others will appear to be acceptable.
The first step in evaluating the designs that hold promise is a relatively short-term
electrical test. Following are the steps involved in evaluating a given joint design:

(A)   Construct one joint in Test Circuit A.

CATEGORY I   (Cont'd.)

(B)   Subject joint to following 60 Hz tests:

(1)   Pre-test @ 166 kV for 5 minutes
         "   @ 200kV for 5   "
         "   @ 233kV for 5   "
         "   @ 266kV for 5   "

(2)   Measure dissipation factor and capacitance of splice
         @ 133kV, 166kV, 200kV, 233kV, and 266kV.

(3)   Measure partial discharge characteristics of joint at
         voltages up to 200kV.

(4)   Load cycle 8 hours on/4 off at 90C cable conductor
         temperature.

         Load Cycle 1 - voltage 166 kV
             "   "   2 - voltage 200 kV

         During final hour of Load Cycle 2, repeat Steps 2 & 3.

(5)   Allow circuit to cool to room temperature and repeat
         Steps 2 & 3.

(6)   Current load cable for 130 C conductor temperature
         for a period of at least 8 hours with circuit energized
         at 166kV. Monitor and record dissipation factor meas-
         urements at one-hour intervals. Continue test until
         three hour-interval readings show no significant change.

(7)   Repeat Step 5.

(8)   Load cycle 12 hours on/4 off at 90 C cable conductor
         temperature for a total of 8 additional load cycles
         at 200kV.

         The short-term test outlined above would require 12 days
         for completion (after joint construction).

(C)   When Part B is successful, install three joints of the same design
         in joint test circuit B.   DC test as follows:

(1)   15 minutes at 525kV (0.5 x B.I.L.)
(2)   15 minutes at 655kV (0.624xB.I.L.)

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CATEGORY I   (Cont'd.)

Impulse test as follows:

(1)   10 shots Positive at B.I.L.   (1050 kV)
(2)   10 shots Negative at B.I.L.
(3)   3 shots Negative at 1.05 B.I.L.   (1103 kV)
(4)   3 shots Negative at 1.10 B.I.L.   (1155 kV)
(5)   3   "   "   at 1.15 B.I.L.   (1208kV)
(6)   3   "   "   at 1.20 B.I.L.   (1260kV)
(7)   3   "   "   at 1.25 B.I.L.   (1313kV)

Heat circuit overnight to 90 C conductor temperature and repeat
impulse tests.

(D)   Install additional two joints in Splice Test Circuit A for long-term tests.
The steps in this test are:

(1)   Pre-test at 166 kV for 5 minutes
       "   at 200kV for 5   "
       "   at 233kV for 5   "
       "   at 266kV for 5   "

(2)   Measure dissipation factor and capacitance of each
splice at 133kV, 166kV, 200kV, 233kV and 266kV.

(3)   Measure partial discharge characteristics of splices
at voltages up to 200kV.

(4)   Load cycle 12 hours on/4 off as follows:

(a) 10 load cycles at 90C and 200kV
(b) Repeat Steps 2 & 3 at room temperature
(c) 10 load cycles at 130C and 166kV
(d) Repeat (b)
(e) 10 load cycles at 90C and 233kV
(f) Repeat (b)
(g) 10 load cycles at 90C and 266kV
(h) Repeat (b)

(E)   Upon completion of Step D, subject three joints (from joint test
circuits A or B) to mechanical tests and tests to assure watertight con-
struction.

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CATEGORY I   (Cont'd.)

(F)   Evaluate test results and select best joint design(s) for use in complete
           230kV test circuit.

(G)   Install three joints of each acceptable design in the complete 230kV test
           circuit. Following completion of tests on this circuit, a total of at least
           9 joints for each given design which is accepted will have been tested
           (3 on Joint Circuit A 60 Hz tests, 3 on Joint Circuit B Impulse & DC
           tests, and 3 on the complete 230kV Test Circuit).

CATEGORY 2 -   VULCANIZED JOINT

           Steps Completed as of 12/31/75:

(1)   69kV level evaluation of vulcanized joint using present methods.

           (A)   Thermal profile tests were completed on process temperatures
                      for shielding and insulating the 69kV 500 kcmil joint.

           (B)   Twelve experimental joints were made, using various process
                      parameters, for visual inspection.

           (C)   Seven of the twelve joints were very closely examined after
                      being slinkied. Data on void and contaminant quantity, size,
                      and location were obtained and recorded under microscopic
                      inspection.

           (D)   A 69kV 500 kcmil test cable was terminated and pre-tested.

           (E)   Ten- 69kV 500 kcmil vulcanized joints were constructed by five
                      R & D people in the test circuit of Step D.

           (F)   X-rays of each of the 10 test joints were made.

(2)   A sample order was placed with a small company specializing in custom
           tape extrusions. Steps have been taken to reduce contamination of the
           tape through use of clean packaging methods.

           It is expected that this supplier will be able to produce the small experi-
           mental tape quantities that are required for this development.

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CATEGORY 2 - (Cont'd.)

(3)   A vulcanized EPR (K-146) 138kV 400 kcmil joint was built in the 138kV long-term test circuit. Testing continues on this joint, one other vulcanized EPR joint, seven vulcanized polyethylene joints, and three taped joints. A total of 7500 test hours have now been completed on the original components of this circuit.

(4)   A search has begun to find suitable heat-shrinkable semi-conductive tubing as a possible improvement over the present connector shielding method.

Future Steps: (As of January, 1976)

(A)   Evaluation at 69kV level. Perform accelerated load cycling program on 10 test joints and evaluate electrical test results.

(B)   Following Step A, dissect and slinky insulations from 10 test joints. Correlate microscopic inspection of joint insulations with X-rays. Compare insulation quality and repeatability with that of earlier visual evaluation joints. Determine effect of accelerated load cycle testing on joint insulation.

(C)   Use an additional sequence of experimental joint constructions on the 69kV 500 kcmil cable for the purpose of additional experiments to shorten process time and improve quality.

(D)   As an intermediate step, design and construct four vulcanized joints on a length of either 750 kcmil or 1000 kcmil 69kV cable. The first of these will be used for a thermal profile of the process, while the last three will be used for visual examination of joint insulation helixes.

(E)   Design and construct a vulcanized XLPE joint for the 230kV 1000 kcmil cable for the purpose of determining the processing thermal profile using present technique (oven heating). As a second step use auxiliary heating tapes along cable adjacent to oven ends to determine their effect on the thermal profile (expected reduction of axial heat loss).

(F)   Pursue means of heating the conductor/connector within the joint using radio frequency induction heating. Determine suitability of this technique, and possible improvements resulting, in the process.

(G)   Pursue study of means of heating the joint insulation through use of higher (microwave) frequency. Determine feasibility of this approach.

CATEGORY 2 - (Cont'd.)

(H)   Pursue use of semi-conducting heat-shrinkable tubing as connector shielding (in place of present molded shielding).

(I)   Pursue study of use of transfer molding or extrusion in place of present taped joint insulation application. Determine feasibility.

(J)   Pursue study of alternate (other than dicumyl peroxide) crosslinking agents for use in joint insulation compounds. Convert small quantities of such compounds to tape form for experiment.

(K)   Convert a quantity of EPR uncured compound (such as K-146) to tape form. Design and construct experimental joints for thermal profile and visual evaluation.

(L)   Study means of reducing process time required. Design and construct experimental 230kV joints for evaluation of these means.

(M)   Pursue development with Hotsplicer of a 230kV Hotsplice.

(N)   Based upon results of Steps E through L, determine best practical method for vulcanized joint construction.

(O)   Design and construct one thermal profile 230kV joint and three visual inspection joints based upon Step N.

(P)   If results of Step (0) are favorable, proceed into electrical test sequence.

CATEGORY 3 - ALTERNATE JOINTING CONCEPTS

There are several possible methods of joining 230kV cable besides the taped and vulcanized approaches. There are also concepts which might use taped or vulcanized joint insulation but which would employ significantly different approaches to joint design. Alternate approaches which may hold promise appear to be the following:

(A)   Use of a design approach which would eliminate the necessity to taper the cable insulation. This would use a concept presently used in premolded 35kV joints where no insulation tapering is required. The basic feasibility of the concept as applied to 230kV jointing would depend upon whether or not the inner electrode of the joint could be shaped in such a way as to reduce localized electrical stresses to acceptable levels.

(1)   Run an analog field plot on a preliminary design to determine if electrical stresses appear to be within an acceptable range.

(2)   Based upon A(1) run additional field plots as necessary on additional designs.

(3)   If the basic concept appears workable, study possible methods for practical construction of such a joint.

(4)   Design a practical connector for use in the design.

(5)   Study possible means (i.e., taped, vulcanized PE or EPR, poured elastomer, premolded elastomer, partially pre-molded insulation, etc.) of constructing such a joint.

(6)   In order to actually test the concept, determine the most promising approach. Design and construct the joint for thermal analysis.

(7)   Based upon the successful completion of Step 6, proceed into electrical test sequence.

(B)   The second possible means of developing an improved joint design would use the concept of a graded dielectric joint design. Much of the practical use of this approach will depend upon the dielectric characteristic measurement of Category 1, Step G, and upon determination of the characteristics of possible (develop-mental) joint insulations.

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(1) Design a graded dielectric joint based upon use of two or more joint insulations having different dielectric constants.

(2) Evaluate electrical stress levels through use of the electrical field computer program (Category 4, Step A) and through comparison of design values with proven design values.

(3) Construct a graded dielectric joint for thermal analysis.

(4) If the concept appears to be acceptable, proceed into the electrical test sequence.

(C) The third possible means of developing an improved joint design would be through the use of a poured (rather than taped) joint insulation. A number of elastomeric materials with good dielectric properties exist at present. Other improved materials may be possible. These materials are supplied in liquid form and are then mixed with a catalyst and poured. They cure at room temperature into a permanent elastomeric dielectric. The following steps will be used to evaluate this concept:

(1) Study and define all presently available poured dielectrics.

(2) Eliminate materials which would not be suitable. Select one or more of the most promising materials. Subject this material to measurement of the insulation characteristics as outlined in Step G of Category 1.

(3) Determine possible suitability of the insulation(s) in Step C2 for use in 230kV jointing.

(4) Design a poured joint and obtain necessary equipment.

(5) Construct one poured joint for thermal analysis.

(6) If the concept appears to be workable, proceed into the electrical test sequence.

(D) The fourth possible means of developing an improved joint design would use the concept of forced grading of longitudinal electrical stresses based upon location of conductive "shells" at various radial dimensions throughout the joint insulation. This concept might be combined with the taperless insulation concept (Step 3A) or might yield a variation of any of the other jointing techniques. Steps in the development are as follows:

(1) Design a "forced graded" taped joint. Conductive "shells" will be included in the design to grade tangential and longitudinal stresses. Possibly use analog field plotting to evaluate the design.

(2) Construct a joint of this design for thermal analysis.

(3) Construct one joint in Test Circuit A for preliminary electrical evaluation. If results are satisfactory, proceed with electrical evaluation sequence.

(4) Review results of Steps D1, D2 & D3, and evaluate. Proceed to design and test additional forced-graded designs.

(E) The fifth possible means of developing an improved joint design would be through the use of a pre-molded joint. At the present time, there is a possibility that the Elastimold 138kV concept may be upgraded to the 230kV level. Except for this there does not appear to be any possibility that any other U.S. pre-molded joint manufacturer could conceivably develop such a joint within the time and money constraints of the present contract. Therefore, the steps toward developing a suitable pre-molded 230kV joint would be:

(1) Study of possible use of the Elastimold concept at the 138kV and 230kV levels. This would include evaluation of Elastimold test results.

(2) Installation of a 138kV and/or 230kV Elastimold joint for thermal evaluation.

(3) Installation of a 138kV and/or 230kV Elastimold joint for electrical testing. If testing of the first joint at the 230kV level is successful, proceed with electrical evaluation sequence.

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APPENDIX 7.1   (Continued)

CATEGORY 4 -   COMPUTER PROGRAMS

A key to a full evaluation is the ability to assess joint designs in a
thorough manner.   Computer programs to allow more thorough data on certain joint
characteristics were considered to be the logical means of taking a closer look at
designs, due to the time-consuming nature of similar hand calculations.   The three
programs which will be developed are as follows:

(A)   Electrical Field Program -   This program has been developed
and yields the capability of looking closely at the electrical stress distribution in
joint designs.

(B)   Joint Design Program -   The initial program is presently being
being worked upon and is expected to be developed by mid-1976.   The purpose of the
program is to allow study of numerous possible designs and to design joints based upon
knowledge of insulation dielectric properties (from Category 1, Step G).   This program
will actually design joints based upon variable inputs of dielectric design values and
stress values.

(C)   Thermal Field Program -   This program is presently being worked
upon.   The purpose of the program is to allow quick assessment of the thermal profiles
of various joint designs.   Initially, the experimental data from Category 1, Step F,
will be used in developing and de-bugging the program.   The thermal characteristics
of joint designs have been shown to be very important from the view of joint reliability.
It is hoped that a program can be developed which will provide accuracy in predicting
thermal profiles of various joint designs, thus reducing the very time-consuming process
of experimentally checking each joint design under consideration.

In brief, use of these programs is expected to yield a more complete
capability for evaluating and designing joints.   The basic purpose of the programs is to
aid in the development of 230kV joint designs for fulfillment of requirements of the
ERDA contract.   The programs will supplement design work and aid in the analysis of
modes of joint failure.

APPENDIX 7.1 (Continued)

CATEGORY 5 - CONNECTOR EVALUATION

In order to develop a fully reliable 230kV joint, it is essential that the selected connector be reliable and that there be a knowledge of the characteristics of the connector. In order to take a thorough look at the problem of connector selection, the following steps will be taken to obtain data for evaluation.

(A)   Outline the experience to date with various types of connectors.

    (1)   Kaiser experience

    (2)   Utility and Industry experience. Contact individuals who are involved in connector testing and evaluation.

(B)   Define the methods for joining stranded aluminum conductors sized from 1000 KCM to 2500 KCM. These methods would all fall within one of the following classes:

    (1)   Inert gas welding (MIG, TIG)

    (2)   Exothermic   (Cadweld, Alutherm)

    (3)   Compression   (Burndy, T&B, etc.)

    (4)   Mechanical

    (5)   New concepts   (Cryocon, Ampact, etc.)

(C)   Define test criteria for connector evaluation. Using present standards (such as EEI TDJ-162, etc.), develop a realistic test specification.

(D)   Based on Step C, set up a test circuit for connector evaluation. Perform initial experiments for measurements of AC resistance, DC resistance and temperature.

(E)   Establish working relationships with connector suppliers. Arrange for a cooperative test program using the specification of Step C and the test circuit of Step D.

CATEGORY 5 - (Continued)

(F)   Perform specification tests on each connector type under consideration. Evaluate connectors for degree of acceptability.

(G)   Determine mechanical requirements for a fully reliable connector.

        (1)   Set up tests to measure mechanical forces within joints

        (2)   Establish mechanical test criteria for evaluating connectors passing Step F.

        (3)   Test and evaluate mechanical properties of connectors passing Step F.

(H)   Compile a bibliography of literature on aluminum connector design, use and research.

(I)   Determine connectors which are fully suitable for 230kV.

Finally, in order to outline the concurrent nature of each of these five divisions of the 230kV joint research program, a flow chart is shown. From time to time as changes are needed in the overall program the plan will be updated. Progress will be measured at one to three month intervals.

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FLOW CHART FOR 230-kV SPLICE RESEARCH PROGRAM

CATEGORY #1
TAPED SPLICE

CATEGORY #2
VULCANIZED SPLICE

CATEGORY #3
ALTERNATE SPLICING
CONCEPTS

CATEGORY #4
COMPUTER
PROGRAMS

CATEGORY #5
CONNECTOR
EVALUATION

Category #1 boxes: A, G, H, B, D, C, E, F

Category #2 boxes: A, C, D, B, E, M, F, G, H, I, J, K, L, N, O, P

Category #3 boxes: A, B, C, D, E

Category #4 boxes: A, B, C

AID FOR
SPLICE DESIGN
AND FAULT
ANALYSIS

Category #5 boxes: A, B, G, C, H, E, D, F, I

DESIGN EVALUATION AND MODIFICATION

(B)   SHORT-TERM ELECTRICAL TESTS (TEST CIRCUIT "A")

(C)   DC & IMPULSE TESTS   (TEST CIRCUIT "B")

(D)   LONG-TERM ELECTRICAL TESTS   (TEST CIRCUIT "A")

(E)   MECHANICAL TESTING

(F)   EVALUATION & SELECTION OF FINAL DESIGN(S)

(G)   INSTALLATION IN COMPLETE 230-kV CIRCUIT

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APPENDIX 7.2

From Neher-McGrath (Reference 7.2) a formula was derived which is commonly used in laboratory testing of solid dielectric cables. This formula is:

$$I_{tc} = \sqrt{\frac{(T_c - T_a) \times 10^6}{(R_{ac})(R_{ca}')}}$$

The elements of this formula are defined:

I_{tc} = 60 Hz current in amperes to maintain conductor temperature T_c.

T_c = Conductor temperature ($^\circ$C)

T_a = Ambient air temperature ($^\circ$C)

R_{ac} = The 60 Hz electrical resistance of the conductor at temperature TC (milliohms/1000 ft.)

R_{ca}' = Thermal factor derived from application of several formulae. It is equal to the sum of the factors RE, Ri and Rj.

RE is a factor dealing with the thermal emissivity of the cable (or joint)

Ri is a factor dealing with the geometric thermal resistivity of the cable (or joint) insulation

Rj is a factor dealing with the geometric thermal resistivity of the cable (or joint) jacket.

The derivation of these factors will not be discussed here, in the interest of brevity. It is sufficient to note that Rca' is a factor which describes the heat dissipating properties of a cable or joint. It is evident that if the unit value for Rca' is reduced the result will be higher cable ampacity to maintain a given conductor temperature. If I is held constant and Rca' is decreased the conductor will run cooler, having an effect similar to a reduction in Rac.

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APPENDIX 7.2 (Continued)

In the interest of joint design the ideal situation would be for the separately calculated I_{TC} values for joint and cable to be identical due to the denominator within the radical [(Rac) (Rca')] for the joint being equal to the demoninator for the cable. Then the ratio of joint/cable Rca' would be unity and the cable and joint would have equal conductor temperatures. Obviously, the reduction of Rac within the joint could also result in the same ratio. Calculations were performed to derive the ratio joint/cable for Rca' of three taped EPR splice designs. Assumptions in the calculations were:

1. All layers of both cable and splice remain the same value of thickness, only conductor size varies.

2. The joint was treated as an infinite cable length having dimensions equal to the joint center cross-section. Some axial heat flow actually occurs, but this is neglected in these calculations.

The values are seen graphed in FIGURE 7.9. Note that the 230kV design using electrical stresses based on the 138kV Waltz Mill design (FIGURE 7.10) has a substantially higher ratio than that of 230kV taped splice Design #1 (FIGURE 7.11).

This indicates that the former design would experience joint conductor overheating significantly greater than the approximately 170 C actually observed in both the latter design and the 138kV Waltz Mill design.

APPENDIX 7.3 - COMPUTER AIDS
              JOINT DESIGN PROGRAMS FOR ELECTRICAL
              AND THERMAL FIELDS
              (AS OF MARCH, 1976)

SUMMARY:

The purpose of this work is to develop a user-oriented computer program that will aid the joint design for the ERDA 230kV project. The program is to have three parts:

(1)   The first part will calculate the electric stresses at all points in the joint insulation

(2)   The second part will calculate the temperature at all points in the joint, both conductor, semi-conductor and insulation

(3)   The third part will use the preceding calculations and any additional design limitations (i.e., maximum joint diameter, maximum conductor temperature at connector, maximum radial stress, etc.) to predict optimum joint dimensions for a given conductor size, thermal conductivities of insulations, etc.

To date, the first part is about 75% complete, the second 25% complete and the third part is still in the discussion state (no programming has been done on the third part).

ELECTRIC STRESS CALCULATION:

The electric stress in the joint insulation may be calculated if one knows the voltage at all points. The voltage distribution in the joint insulation may be calculated by solving Laplace's Equation * in suitable form and applying the boundary conditions (voltage of shield and conductor). Equation (1) is Laplace's equation in cylindrical coordinates with symmetry assumed in the angular dimension -- it applies to a dielectric space with no free charge:

* Laplace's Equation is a differential form of Gauss' Law where there is no electric charge present.

(1)
$$\frac{1}{r}\frac{\partial u}{\partial r} + \frac{\partial^2 u}{\partial r^2} + \frac{\partial^2 u}{\partial z^2} = 0$$

This can be converted to an equivalent difference equation which lends itself to a numerical solution *.

(2)
$$\frac{1}{r}\left[\frac{[u(r+\text{DELTA } r,z) - u(r,z)]}{\text{DELTA } r}\right] + \frac{u(r+\text{DELTA } r,z) + u(r-\text{DELTA } r,z) - 2u(r,z)}{(\text{DELTA } r)^2}$$

$$+ \frac{u(r,z+\text{DELTA } z) + u(r,z-\text{DELTA } z) - 2u(r,z)}{(\text{DELTA } z)^2} = 0$$

Rearranging this equation one can express the voltage at the point (r,z) in terms of the four surrounding voltages.

$$u(r,z)\left[\frac{1}{r\,\text{DELTA } r} + \frac{2}{(\text{DELTA } r)^2} + \frac{2}{(\text{DELTA } z)^2}\right] = u(r+\text{DELTA } r,z)\left[\frac{1}{r\,\text{DELTA } r} + \frac{1}{(\text{DELTA } r)^2}\right] +$$

$$+ u(r-\text{DELTA } r,z)\left[\frac{1}{(\text{DELTA } r)^2}\right] + u(r,z+\text{DELTA } z)\left[\frac{1}{(\text{DELTA } z)^2}\right]$$

$$+ u(r,z-\text{DELTA } z)\left[\frac{1}{(\text{DELTA } z)^2}\right]$$

or multiplying by DELTA r^2 :

(3)
$$u(r,z) = \frac{u(r+\text{DELTA } r,z)\left[\frac{\text{DELTA } r}{r} + 1\right] + u(r-\text{DELTA } r,z) + \left[u(r,z+\text{DELTA } z) + u(r,z-\text{DELTA } z)\right]\left(\frac{\text{DELTA } r}{\text{DELTA } z}\right)^2}{\frac{\text{DELTA } r}{r} + 2 + 2\left(\frac{\text{DELTA } r}{\text{DELTA } z}\right)^2}$$

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If one draws an axial section of the joint insulation and superimposes a suitable grid as in FIGURE I, one can convert Equation (3) into a form suitable for numerical computation. To this end choose a grid fine enough (i.e., with enough grid points) to be able to describe the joint dimensions accurately as being so many grid points up or to the right of the origin.

* The difference equation may be derived from the differential equation by noting the definition of a derivative:

$$df/dx = \frac{f(x + DELTA\ x) - f(x)}{DELTA\ x} \qquad \text{where} \quad DELTA\ x \longrightarrow 0$$

Next, choose a radial and axial distance increment, H_r and H_z, respectively, so that:

$$DELTA\ r = H_r$$
$$DELTA\ x = H_z$$

Where H_r and H_z are the radial and axial distances between grid points in Figure I. A good fit of the joint dimensions is accomplished with a grid of 24 x 100 points. Thus H_r and H_z are:

$$H_r = .106 \text{ inches}$$
$$H_z = .200 \text{ inches}$$

and the overall dimensions of the splice shown in Figure I are 2.544" x 20.000". Referring to this figure at grid position (I, J) and noting that the grid line I= 1 corresponds to r = o and J = I corresponds to z = o, we have:

$$r = (I-1)\ H_r = .106\ (I-1)$$
$$z = (J-1)\ H_z = .200\ (J-1)$$

Thus in terms of the grid we can rewrite Equation (3) letting

U (r, z)	U (I, J)
r	(I-1) DELTA r = (I-1) H_r
z	(J-1) DELTA z = (J-1) H_z

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$$U(I,J) = \frac{U(I+1,J)\left[\frac{1}{(I-1)}+1\right] + U(I-1,J)}{\left(\frac{1}{I-1}\right) + 2\left[1 + \left(\frac{H_r}{H_z}\right)^2\right]} +$$

$$+ \frac{\left(\frac{H_r}{H_z}\right)^2 \left[U(I,J+1) + U(I,J-1)\right]}{\left(\frac{1}{I-1}\right) + 2\left[1 + \left(\frac{H_r}{H_z}\right)^2\right]}$$

The program simply applies this equation to all the non-boundary points of the grid in sequence and repeats this process until the change of voltage values from one complete iteration to the next becomes arbitrarily small.

The accuracy of this method is limited only by the cost of using the computer to do the repeated calculations and by the fineness of the grid relative to the idealized joint cross-section, and to the accuracy of the boundary values specified.

BOUNDARY CONDITIONS ON STRESS:

As noted above, the accuracy of the calculated voltages depends on the accuracy of the boundary values. Fortunately the voltage of the grid points corresponding to the outside of the strand shield and to the inside of the insulation shield are nearly identical to the voltages of the conductor and the shield, respectively. The voltage values - referring to Figure 1 - at the boundary points J=1, I=8 to 16 and at J=101, I=8 to 24 are not exact but are taken equal to those values that we know are true for a simple coaxial geometry:

$$U(r,z) = \frac{DELTA\ V}{\ln(r_o/R)}\ \ln(r/R)$$

where r_o –   is the inside radius of the coax
          R –   is the outside radius of the coax
DELTA V   –   is the phase-to-ground voltage

or in the terms of the grid of Figure 1 we have:

At   J = 1
_____

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$$(5\,a) \qquad U\,(I,\,1) \quad = \quad \frac{DELTA\ V}{\ln\,(6/16)} \quad \ln \quad (I\text{-}1/16)$$

At J = 101

$$(5\,b) \qquad U\,(I,\,101) \quad = \quad \frac{DELTA\ V}{\ln\,(6/24)} \quad \ln\, (I\text{-}1/24)$$

MULTIPLE DIELECTRIC LAYERS:

As was stated on Page (152), Laplace's Equation applies to any uni-form uncharged dielectric space. If the joint consisted of only one dielectric material, this equation would apply to the whole insulating region and the preceding boundary conditions would be sufficient for a solution. In the joint of Figure I, how-ever, the dielectric constant of the crosslinked polyethylene cable insulation is some-what different from that of the joint tape insulation. At this dielectric interface, Laplace's equation will not hold true because of the presence of polarization change. Instead, a grid point on the interface is related to adjacent grid points by the boundary equation:

$$(6) \qquad \epsilon_1 \left[\frac{V_o - V_1}{H_r} \right] = \epsilon_2 \left[\frac{V_2 - V_o}{H_r} \right]$$

where

$V_o \equiv$ voltage of point on interface

$V_1 \equiv$ voltage of adjacent point in dielectric 1

$V_2 \equiv$ voltage of adjacent point in dielectric 2

This equation is rigorously true only for a pencil slope of zero. How-ever, since normally the pencil slope is no more than 10 degrees, it is applicable to the joint shown in Figure I.

When the grid points do not fall precisely on the interface, a slightly more complex form of Equation (6) is used.

STRESS PROGRAM FLOW:

We have faced a limitation in the amount of available storage in the IBM 360-30 that has been used to date. This is a result of the relatively large number of grid values that must be stored simultaneously (24 x 100 = 2400 words x 4 = 9600 bytes) out of some 15,000 to 20,000 bytes for the Fortran Program, library function and any storage combined. Thus, to date, I have approached the stress program using two simpler programs. Program B calculates voltages in a joint of constant outside

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STRESS PROGRAM FLOW (Continued)

diameter, constant dielectric interface diameter but variable conductor/strand shield diameter (Cadweld connector) with the results presented graphically (see listing of Program B attached and Figure 2). Program A calculates voltages in a joint of variable outside diameter, variable interface diameter and constant conductor/strand shield diameter (see listing of Program A attached and Figure I). The results of this calculation are simply listed at the end of the Program Listing.

Presently we are replacing the IBM 360-30 with a remote link to an IBM 370 with no such memory limitation. Thus we will combine these two programs within the next twelve months. The new longer program will be more user oriented and will provide a number of output options.

TEMPERATURE DISTRIBUTION CALCULATION:

The temperature distribution in the joint insulation follows Laplace's equation if one ignores dielectric losses. This was done in the initial program to calculate the joint temperature distribution.

The dielectric interface is handled in the same manner as outlined previously.

One can specify the shield temperature as a single value. One can then calculate the end boundary values using Equations (5) with DELTA V replaced by DELTA T (the difference between conductor temperature and shield temperature). The conductor/strand shield temperature is not so simply determined.

In considering methods of determining the temperature of the insulation/strand shield boundary consider the following:

(1)   The temperature should be higher at the joint center because of the higher thermal resistance of the thick joint wall.

(2)   Total current through the conductor is the same for all z.

(3)   The heat generated in the conductor can either flow axially down the phase conductor or radially through the joint insulation.

(4)   Neglect temperature drop across ohmic heating in strand shield.   In order to calculate the temperature at the inside of the insulation wall one finds the following equation by expressing (3) above mathematically:

TEMPERATURE DISTRIBUTION CALCULATION (Cont'd.)

$$(7) \quad \frac{\sigma_{IT}}{\sigma_{ECT}} R_o \cdot \left[\frac{\partial T}{\partial r} \bigg|_{R_{o,z}} + \frac{\partial T}{\partial r} \bigg|_{R_o,\, z + DELTA\, z} \right] +$$

$$+ \left[\frac{\frac{\partial T}{\partial z} \bigg|_{R_o,\, z + DELTA\, z} - \frac{\partial T}{\partial z} R_{o,z}}{\Delta z} \right] + I_o^2 / A^2 \, \sigma_{ECC} \, \sigma_{ECT} = 0$$

where:

T	temperature in insulation at conductor boundary	$\left[{}^{o}C \right]$
A_o	cross-sectional area of conductor	$\left[in.^2 \right]$
I_o	total r.m.s. current in phase conductor	$\left[amps \right]$
ECC	electrical conductivity of EC aluminum	$\left[mhos/in. \right]$
IT	thermal conductivity of cable insulation	$\left[watts/{}^{o}C\ in. \right]$
ECT	thermal conductivity of EC aluminum	$\left[watts/{}^{o}C\ in. \right]$

As with Equation (I) this is converted to a form suitable for computation in Equation (8).

$$(8) \qquad U(I\,II, J) = \left[\frac{1}{\frac{\sigma_{II}}{\sigma_{ECT}} (III\text{-}I) + 2 \left(\frac{H_r}{H_z} \right)^2} \right] \cdot$$

$$\cdot \left\{ H_r^2 I_o^2 \Big/ \sigma_{ECC} \, \sigma_{ECT} \, A^2 + \left(\frac{H_r}{H_z} \right)^2 \cdot \left[U(I\,II, J+1) + U(I\,II, J-1) \right] \right.$$

$$+ \left(\frac{\sigma_{IT}}{\sigma_{ECT}(I\,II\text{-}I)} \right) \cdot \left. \left[U(III+I, J) + U(III+I,\ J+1) - U(III, J+1) \right] \right\}$$

where   U (I II, J) is the temperature at the inside boundary of the insulation.

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TEMPERATURE DISTRIBUTION CALCULATION (Cont'd.)

The temperature calculation process begins with an initial assumed set of array values including boundary values. By use of Equation (4) and these boundary values a new set of array values is calculated. Then a new set of U (I II, J) values are calculated by Equation (8). Using these new boundary values in combination with the constant boundary values for sheath temperature and end values calculated by Equations (5), the array values are recalculated using Equation (4) again.

JOINT DESIGN PROGRAM:

This program will eventually incorporate the preceding two programs and will present the joint designer with the capability of quickly coming up with approximate joint dimensions given performance requirements and material limitations. This is still in the discussion and flow chart state.

In addition to providing approximate joint dimensions, the program should be able to rapidly review various material refinements, indicating the most profitable areas of study (i.e., thermal conductivity of tape, shape of connector, etc.).
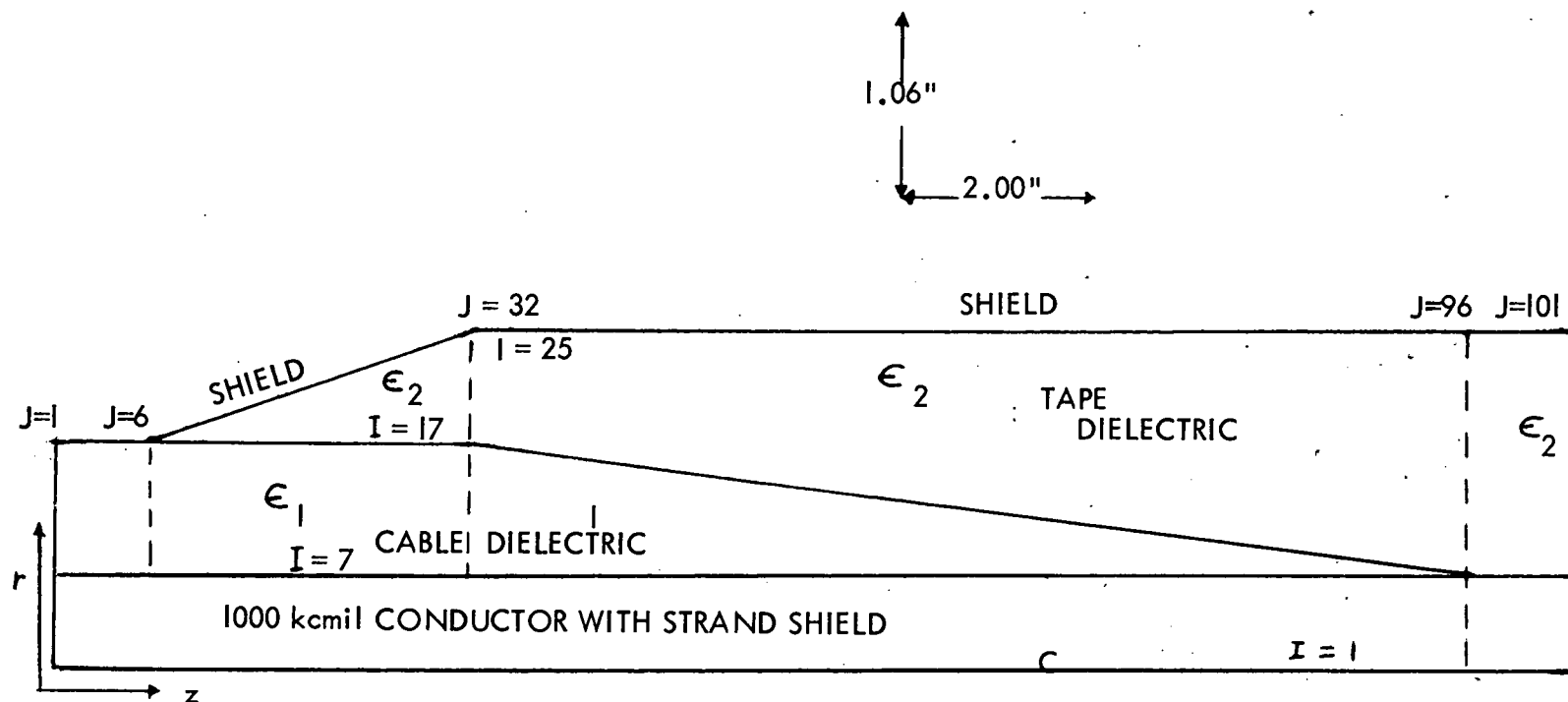
FIGURE I   AXIAL SECTION OF HALF OF IDEALIZED, 230kV JOINT WITH MIGWELD CONNECTOR AND 1000 kcmil CONDUCTOR
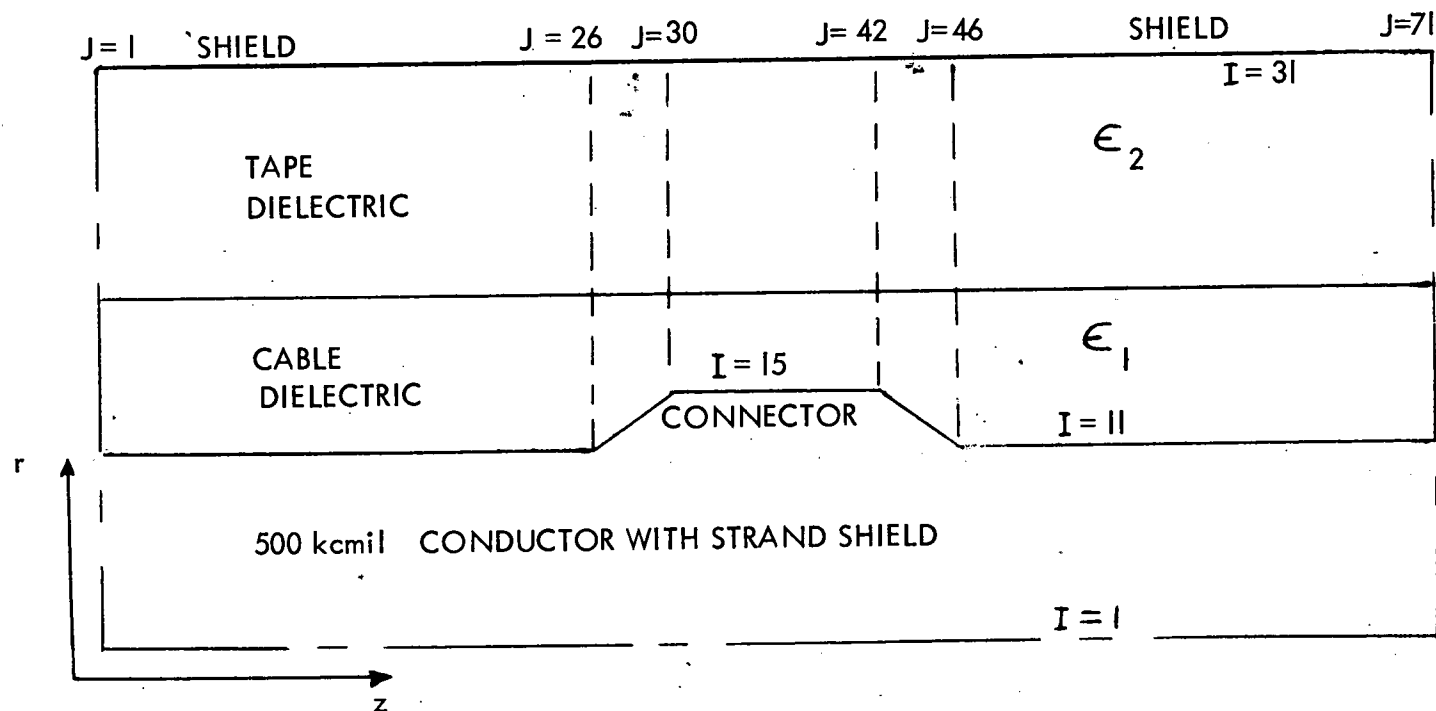
FIGURE 2   AXIAL SECTION OF 138kV JOINT WITH CADWELD CONNECTOR
ON 500 kcmil ALUMINUM CONDUCTOR, CONSTANT O.D. AND
ZERO PENCIL SLOPE

```fortran
// JOB PP950 230KV SPLICE POTENTIAL PLOT
// OPTION LINK
// EXEC FORTRAN
C SECOND PROJECT - SOLUTION OF LAPLACE'S EQUATION TO FIND POTENTIAL IN
C RZ PLANE OF SIMPLE SPLICE
      REAL U(3,71), LINE(118),H(5)
      INTEGER BOTT(71),SYMBOL(16),PLOT(118)
      SYMBOL(2) = 1077952576
      DO 2 I=4,16,2
    2 SYMBOL(I) = SYMBOL (I-2)
      SYMBOL(1)= -1052753856
      DO 1 I=3,15,2
    1 SYMBOL(I) = SYMBOL(I-2) + 16777216
      H(1) = 0.0
      H(2) = 0.6
      H(3) = 0.2
      H(4) = 0.8
      H(5) = 0.4
    3 READ(1,4) VIN,MAXIT,EPS,OMEGA,I11,I22,I33,I44,J11,J22,J33,J44,J55
     1           DI1, DI2
    4 FORMAT(F10.0,I5, F5.0, F5.3, 9I5,2F3.1)
      IF(OMEGA) 3000,3000,99
C LOCATE BOUNDARY OF CONDUCTOR RADIUS. SUBSCRIPTS STORED IDENTIFY
C 'INTERIOR PTS. NOT 'BOUNDARY PTS. ALL DEFINED PTS LIE IN THE INSULATION
   99 IP1 = I11+1
      IP2 = I22+1
      IM3 = I33-1
      JM1 = J11-1
      JP1 = J11+1
      JM2 = J22-1
      JP4 = J44+1
      JM5= J55-1
      DO 7 J=1, J11
    7 BOTT(J)=I11+1
      DO 8 J =JP4,J55
    8 BOTT(J)= I11+1
      G = I11 + 1 - .001
      SL =FLOAT(I22 - I11)/ (J22 - J11)
      DO 11 J = J11, J22
      BOTT(J) = G + 1
      G = G + SL
      J1= J55+1-J
   11 BOTT(J1)= BOTT(J)
      DO 13 J= J22,J33
   13 BOTT(J) = I22+1
      WRITE (3,98)  BOTT
   98 FORMAT(1H , 'I COORDINATES OF CONDUCTOR BOUNDARY'/ 20I5/
     1 20I5/ 20I5/ 20I5 )
C    CLEAR ARRAY TO APPROX.LOGARTHMIC DEPENDENCE
      DO 5 J = 1, J55
      L = BOTT(J)
      DO 5 I = L,I44
    5 U(I,J) = VIN*(ALOG(I/FLOAT(I44))+ (DI1/DI2) * ALOG(FLOAT(I44)/I33)
     1 ) /(ALOG((BOTT(J)-1)/FLOAT(I44))  + (DI1/DI2)* ALOG(FLOAT(I44)
     1 /I33))
      DO 51 I= I44,I33
   51 U(I,J) = VIN*((DI1/DI2)*ALOG(FLOAT(I)/I33))
```

```
1      /(ALOG((BOTT(J)-1)/FLOAT(I44))   +  (DI1/DI2)* ALOG(FLOAT(I44)
   1 /I33))
       DO 6 J=1,J55
       L = BOTT(J) -1
       DO 6 I = 1,L
   6   U(I,J) = VIN
       G = I11
       DO 14 J= JP1,JM2
       I = BOTT(J) -1
       X = FLOAT(I)
       G = G+SL
       U(I,J) = VIN * (ALOG(X/I33)/ ALOG(G/I33))
       J1 = J55+1-J
  14   U(I,J1) = U(I,J)
C      SET THE ITERATION COUNTER TO 1
       IIN = 1
C  PUT TITLES ON COLUMNS
       WRITE (3,91)
  91   FORMAT(1H0,' NO.   V(12,46)   V(16,51)   V(21,56)   V(26,61)   V(16,65)
   1   RSUM ')
C   SET SUM OF RESIDUES TO ZERO
   9   SUM = 0.0
C   THE LEFT SIDE
       DO 10 I= IP1,IM3
       DO 10 J= 2 , JM1
       IF (I-I44) 42,43,42
  43   DIFF = OMEGA* (( DI2/(DI1+DI2))*U(I44+1, J) + (DI1/ (DI1+ DI2))*
   1 U(I44-1, J)+ .000001- U(I44,J))
       GO TO 44
  42   DIFF=OMEGA*(((1+1./I)*U(I+1,J)+U(I-1,J)+U(I,J+1)+U(I,J-1))/(4.
   1+(1./I))+.000001-U(I,J))
  44   U(I,J) = U(I,J) + DIFF
       J1 = J55+1-J
       U(I,J1) = U(I,J)
  10   SUM = SUM + ABS(DIFF)
C   THE CENTER SECTION AROUND CONNECTOR
       DO 12   J= JI1,J44
       L = BOTT(J)
       DO 12   I= L,IM3
       IF (I-I44) 45,46,45
  46   DIFF = OMEGA* (( DI2/(DI1+DI2))*U(I44+1, J) + (DI1/ (DI1+ DI2))*
   1 U(I44-1, J)+ .000001- U(I44,J))
       GO TO 47
  45   DIFF=OMEGA*(((1+1./I)*U(I+1,J)+U(I-1,J)+U(I,J+1)+U(I,J-1))/(4.
   1+(1./I))+.000001-U(I,J))
  47   U(I,J) = U(I,J)+ DIFF
       J1 = J55+1-J
       U(I,J1) = U(I,J)
  12   SUM = SUM + ABS(DIFF)
C  THE RIGHT SIDE
       DO 40 I= IP1,IM3
       DO 40 J= JP4,JM5
       IF (I-I44) 48,49,48
  49   DIFF = OMEGA* (( DI2/(DI1+DI2))*U(I44+1, J) + (DI1/ (DI1+ DI2))*
   1 U(I44-1, J)+ .000001- U(I44,J))
       GO TO 50
  48   DIFF=OMEGA*(((1+1./I)*U(I+1,J)+U(I-1,J)+U(I,J+1)+U(I,J-1))/(4.
```

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```fortran
     1+(1./I))+.000001-U(I,J))
50   U(I,J) = U(I,J) + DIFF
     J1 = J55+1-J
     U(I,J1) = U(I,J)
40   SUM = SUM + ABS(DIFF)
     WRITE(3,95) ITN,U(12,46),U(16,51),U(21,56),U(26,61),
    1                  U(16,65), SUM
95   FORMAT ( 1H ,I5, 5F10.4, 1PE12.4)
     ITN = ITN + 1
C CHECK FOR FAILURE TO CONVERGE IN MAXIT ITERATIONS
     IT = 1 + ITN/MAXIT
     GO TO (21,20),IT
C CHECK FOR CONVERGENCE
21   IF(EPS-SUM) 22,20,20
C NOT CONVERGED YET--GO BACK FOR ANOTHER ITERATION
22   GO TO 9
C EITHER THE PROCESS HAS CONVERGED OR MAXIT HAS BEEN EXCEEDED.WANT TO
C PLOT RESULTS EITHER WAY. IF THERE IS ANY DOUBT ABOUT WHICH OCCURRED, A
C COUNT OF NO.OF RESIDUES PRINTED OUT WILL TELL.
C WRITE ARRAY OF POTENTIALS   FOR ARBITRARY POINT IN INSULATION
20   WRITE(3,901) VIN,MAXIT,EPS,OMEGA,I11,I22,I33,J11,J22,J33,J44,J55
    1 ,I44,DI1,DI2
901  FORMAT(1H1,//'VIN=', F8.1, '  MAXIT=', I5, '  EPS=', F8.3, '  OME
    1GA=', F8.3//' RADIAL COORDINATES'/' I11=', I3,' I22=', I3,
    1 ' I33=', I3,' I44=', I3// ' AXIAL COORDINATES'/ ' J11=', I3,
    1' J22=',I3,' J33=',I3,' J44=',I3,' J55=',I3,
    1 ' DI1=', F5.2, ' DI2=', F5.2)
C CONVERT POTENTIALS TO SYMBOLS
     L = (10.*FLOAT(J55))/6
     DO 9011 I= 1,I33
     DO 37 K=1,L
     J1 = 1 + (3*(K-1))/5
     IF (J1-J55) 71,72,72
71   J2 = J1 + 1
     GO TO 73
72   J2 = J1
73   M = 1 + MOD(K-1,5)
     LINE(K) = U(I,J1)+H(M)*(U(I,J2)+.0001-U(I,J1))
     K1 = BOTT(J1)
     IF (I-K1 ) 36,39,39
36   PLOT(K) = -415219648
     GO TO 37
39   N = LINE(K) /(VIN/15) + 1
     IF (N-16) 19,19,18
18   N=16
19   PLOT(K) = SYMBOL(N)
37   CONTINUE
9011 WRITE(3,9014) PLOT
9014 FORMAT (1H , 118A1)
     WRITE(3,9015)
9015 FORMAT(1H1)
     GO TO 3
3000 STOP 9999
     END
/*
// EXEC LNKEDT
// EXEC
```

```
++WRITE  PRINT.EP951
C         DATA SET EP951         AT LEVEL 001 AS OF 02/15/77
C  SIXTH PROJECT-SOLUTION OF LAPLACES EQ TO FIND POTENTIAL IN RZ PLANE OF00001
C  230KV TAPED SPLICE- SPLICE HAS VARIABLE OD   CADWELD CONNECTOR(VARIABLE00002
C  CONDUCTOR DIAMETER) FINITE PENCIL SLOPE(VARIABLE INTERFACE DIAMETER)   00003
C  GRID IS INTENDED TO GIVE A POINT EVERY 0.1 INCH IN AXIAL DIRECTION AND00004
C  0.01 INCH IN RADIAL DIRECTION.                                       00005
       REAL U(255,260), LINE(1000), H(4)                                00006
       INTEGER BOTT(260),TOPP(260),DINT(260),SYMBOL(20),PLOT(118)       00007
       SYMBOL(2)= 1077952576                                            00008
       DO 2 I=4,36,2                                                    00009
    2  SYMBOL(I) = SYMBOL(I-2)                                          00010
       SYMBOL(1) = -1052753856                                          00011
       DO 1 I=3,17,2                                                    00012
    1  SYMBOL(I) = SYMBOL(I-2)+ 16777216                                00013
       SYMBOL(19) = -784318400                                          00014
       DO 222 I= 21,35,2                                                00015
  222  SYMBOL(I)= SYMBOL(I-2)+ 16777216                                 00016
    3  READ(1,4) VIN,MAXIT,EPS,OMEGA,I11,I22,I33,I44,J11,J22,J33,J44,J55,00017
      1 J66,J77,DI1, DI2 ,MK                                            00018
    4  FORMAT( F5.0,I3,F5.0,F5.3,11I5,2F3.1,I1)                         00019
       IF(OMEGA) 3000, 3000, 99                                        00020
   99  WRITE(6,901) VIN,MAXIT,EPS,OMEGA,I11,I22,I33,I44,J11,J22,J33,J44, 00021
      1 J55,J66,J77, DI1, DI2, MK                                       00022
       HR = 0.01                                                       00023
       HZ = 0.10                                                       00024
       I11P1 = I11+1                                                   00025
       I22P1 = I22+1                                                   00026
       I33M1 = I33-1                                                   00027
       I44M1 = I44-1                                                   00028
       J11P1 = J11+1                                                   00029
       J22M1 = J22-1                                                   00030
       J22P1 = J22+1                                                   00031
       J33M1 = J33-1                                                   00032
       J33P1 = J33+1                                                   00033
       J44M1 = J44-1                                                   00034
       J44P1 = J44+1                                                   00035
       J55M1 = J55-1                                                   00036
       J55P1 = J55+1                                                   00037
       J66M1 = J66-1                                                   00038
       J66P1 = J66+1                                                   00039
       J77M1 = J77-1                                                   00040
C LOCATE BOUNDARY PTS OF NON-HORIZONTAL BOUNDARIES.ALL DEFINED POINTS   00041
C ARE IN THE INSULATION NOT ON SHIELD OR PHASE CONDUCTOR.              00042
C REGION 1                                                             00043
       DO 5 J=1,J11                                                    00044
       DINT(J)= I33                                                    00045
       BOTT(J)= I11+1                                                  00046
    5  TOPP(J)= I33-1                                                  00047
C  REGION 2                                                            00048
       SLS = FLOAT(I44-I33)/ (J22-J11)                                 00049
       GS = I33 +.000001                                               00050
       DO 6 J= J11,J22                                                 00051
       BOTT(J) = I11+1                                                 00052
       DINT(J) = I33                                                   00053
       TOPP(J) =  GS- 1                                                00054
    6  GS = GS + SLS                                                   00055
C  REGION 3                                                            00056
       SLP= FLOAT(I11- I33)/(J44-J22)                                  00057
       GP= I33                                                         00058
       DO 7 J= J22,J33                                                 00059
       BOTT(J)= I11+1                                                  00060
       DINT(J)=  GP+ 0.500001                                          00061
       TOPP(J)=  GS-1                                                  00062
       GS= GS+ SLS                                                     00063
    7  GP= GP+ SLP                                                     00064
C REGION 4                                                             00065
       DO 8 J= J33,J44                                                 00066
       BOTT(J)= I11+1                                                  00067
       DINT(J)=  GP+ 0.500001                                          00068
       TOPP(J)= I44-1                                                  00069
    8  GP = GP + SLP                                                   00070
C  REGION 5                                                            00071
       DO 9 J= J44,J55                                                 00072
       BOTT(J)= I11+1                                                  00073
       DINT(J)= I11                                                    00074
    9  TOPP(J)= I44-1                                                  00075
```

```
C  REGION 6                                                            00076
         GC = I11                                                      00077
         SLC = FLOAT(I22-I11)/ (J66-J55)                               00078
         DO 10 J= J55,J66                                              00079
         TOPP(J)= I44-1                                                00080
         BOTT(4) = GC+1                                                00081
         DINT(J)= BOTT(J)                                              00082
   10    GC = GC + SLC                                                 00083
C  REGION 7                                                            00084
         DO 11 J= J66,J77                                              00085
         BOTT(J)= I22+1                                                00086
         DINT(J)= BOTT(J)                                              00087
   11    TOPP(J)= I44-1                                                00088
C  INITIALIZE  ARRAY IN SPLICE INSULATION                              00089
         DO 12 J= 1,J77                                                00090
         IBOTT=BOTT(J)-1                                               00091
         IDINT=DINT(J)                                                 00092
         ITOPP=TOPP(J)+1                                               00093
         R0 = IBOTT - 1.                                              00094
         R1 = IDINT - 1.                                              00095
         R2 = ITOPP + 1.                                              00096
         DENOM = ALOG(R0/R1) +(DI1/DI2)* ALOG(R1/R2)                   00097
         DO 13 I= IBOTT, IDINT                                         00098
   13    U(I,J) =(VIN/DENOM) * (ALOG((I-1)/R1) +(DI1/DI2)*ALOG(R1/R2)) 00099
         DO 14 I= IDINT, ITOPP                                         00100
   14    U(I,J) =(VIN/DENOM) * ((DI1/DI2)* ALOG((I-1)/R2))             00101
   12    CONTINUE                                                      00102
C  SET SUM OF RESIDUES TO ZERO AND BEGIN ITERATION                     00103
   15    SUM = 0.0                                                     00104
C  ITERATION-REGION 1                                                  00105
         DO 16 J=1,J11                                                 00106
         IBOTT= BOTT(J)                                                00107
         ITOPP= TOPP(J)                                                00108
         DO 16 I= IBOTT,ITOPP                                          00109
         DIFF= OMEGA*(((1.+(1./(I-1))*U(I+1,J)+U(I-1,J)+(HR/HZ)**2*(U(I,J+00110
        1)+U(I,J-1)))/((1./(I-1))+2.*(1.+(HR/HZ)**2))*.000001-U(I,J))  00111
         U(I,J)= U(I,J)+ DIFF                                          00112
   16    SUM = SUM + ABS(DIFF)                                         00113
C  ITERATION- REGION 2,3+4                                             00114
         DO 17  J= J11P1, J44                                          00115
         IBOTT = BOTT(J)                                               00116
         ITOPP = TOPP(J)                                               00117
         IDINT = DINT(J)                                               00118
         DO 17  I= IBOTT, ITOPP                                        00119
         IF(I-IDINT) 18,19,18                                          00120
   18    DIFF= OMEGA*(((1.+(1./(I-1))*U(I+1,J) .+ U(I-1,J)+ (HR/HZ)**2* 00121
        1 (U(I,J+1)+ U(I,J-1)))/ ((1./(I-1))+ 2.+ (1.+(HR/HZ)**2))     00122
        1 +.000001 - U(I,J))                                           00123
         GO TO 20                                                      00124
   19    DIFF= OMEGA* ( (DI2/(DI1+DI2))* U(IDINT+1,J) + (DI1/(DI1+DI2))* 00125
        1 U(IDINT-1,J)+ .000001- U(I,J))                              00126
   20    U(I,J)= U(I,J) + DIFF                                         00127
   17    SUM = SUM + ABS(DIFF)                                         00128
C  ITERATION -  REGION 5,6 AND 7                                       00129
         DO 21 J= J44, J77M1                                           00130
         IBOTT = BOTT(J)                                               00131
         ITOPP = TOPP(J)                                               00132
         DO 21 I= IBOTT, ITOPP                                         00133
         DIFF =OMEGA*(((1.+(1./(I-1))) + U(I+1,J)+ U(I-1,J)+(HR/HZ)**2* 00134
        1 (U(I,J+1)+ U(I,J-1)))/ ((1./(I-1)) +2.+ (1.+(HR/HZ)**2))     00135
        1 +.000001- U(I,J))                                           00136
         U(I,J) = U(I,J) + DIFF                                        00137
   21    SUM = SUM + ABS(DIFF)                                         00138
         IAVG =(I11+I33)*0.5                                           00139
         WRITE(6,95)ITN,U(IAVG,1),U(IAVG,J22),U(IAVG,J33),U(IAVG,J44),SUM 00140
   95    FORMAT( 1H0,I5,4FI0.4,IPEI2.4)                                00141
         ITN = ITN + 1                                                 00142
C  CHECK FOR CONVERGENCE OF ITERATION                                  00143
         IT = 1 + ITN / MAXIT                                          00144
         GO TO (22,23),IT                                              00145
   22    IF( EPS-SUM ) 24,23,23                                        00146
C  NOT CONVERGED -REITERATE                                            00147
   24    GO TO 15                                                      00148
C  EITHER THE PROCESS HAS CONVERGED OR MAXIT HAS BEEN EXCEEDED. WANT TO 00149
C  PLOT RESULTS IN EITHER CASE.                                        00150
  901    FORMAT(1H1,//' VIN=',F8.1,' MAXIT=',I5,' EPS=', F8.3, ' OMEGA=',00151
        1 F8.3//' RADIAL COORDINATES '/ ' I11=', I3,' I22=',I3, ' I33=',I3,00152
```

```
        1'.I44=',I3//(' AXIAL COORDINATES'/ ',J11=',I3,',J22=',I3,' J33=',00153
        I3,' J44=',I3,' J55=',I3,' J66=',I3,' J77=',I3//' DIELECTRIC CONST00154
        IANTS OF CABLE AND SPLICE TAPE,RESPECTIVELY'/' DI1(CABLE)=',F5.2,00155
        I' DI2=',F5.2 //' OUTPUT OPTIONS ACCORDING TO CHOSEN VALUE OF MK 00156
        I'/ MK=',I3)                                                      00157
   23   WRITE(6,9013) DINT                                                00158
        WRITE(6,9013) TOPP                                                00159
 9013   FORMAT(1H ,           5X,(26I4))                                  00160
C   CONVERT POTENTIALS TO SYMBOLS                                         00161
        WRITE(6,9015)                                                     00162
        DO 9011 J=1,260                                                   00163
        DO 37 I=55,255,2                                                  00164
        LINE(I) = U(I,J)                                                  00165
        N = LINE(I)/4. + 1.001                                          /00166
   30   PLOT(J) =  SYMBOL(N)                                              00167
   37   CONTINUE                                                          00168
 9011   WRITE(6,9014) PLOT                                                00169
 9014   FORMAT(  //// 5X,'J=',I5,100A1)                                   00170
 9012   FORMAT(1H1)                                                       00171
        WRITE (3,9015)                                                    00172
 9015   FORMAT (1H1)                                                      00173
        GO TO 3                                                           00174
 3000   STOP                                                              00175
        END                                                              00176
***** ABOVE ACTION SATISFACTORILY COMPLETED *****
```

IN=   80.0   MAXIT=   2.   EPS= 1....   OMEGA=   1.7..

RADIAL COORDINATES
  I11= 11   I22= 14   I33= 31   I44= 2.

AXIAL COORDINATES
  J11= 36   J22 36   J33= 46   J44= 71   J55= 21   DI1= 5.0.   DI2= 2.3.

PHASE CONDUCTOR

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SHIELD   SHIELD

```
+.WRITE  PRINT,EP950
C       DATA SET EP950       AT LEVEL 001 AS OF 02/15/77
C  FIRST DECK OF THERMAL PROFILE PROGRAM- SOL'N OF LAPLACES EQUATION TO   00001
C TEMPERATURE IN RZ PLANE OF 230KV TAPED SPLICE                          00002
       REAL U(30,200),TCDR(200),TSH(200),ICDR,LINE(100)                  00003
       INTEGER TOPP(200),DINT(200),BOTT(200),SYMBOL(40),PLOT(30)         00004
     3 READ(1,4) MAXIT,EPS,OMEGA,I11,I22,I33,I44,J11,J22,J33,J44,J55,DIO,00005
      1DI1,DI2                                                           00006
     4 FORMAT(I5,F5.0,F5.3,9I4,      F5.3,2F8.5,)                        00007
       READ(1,104) TCOND1,TCOND2,ICDR,ECCOND,H1,H2,AREA,EPSCDR,MAXITC,OME00008
      1GAC                                                               00009
   104 FORMAT (2F10.5,F10.3,F10.1,3F5.3 ,F5.3,I5,F5.3)                   00010
       IF(OMEGA) 3000,3000,99                                           00011
   901 FORMAT(1H1,// ' MAXIT=',I5,' EPS=',F8.3,' OMEGA=',F8.3,' ICDR=',  00012
      1 F10.1, ' ECCOND=', F10.3//                                      00013
      1 ' RADIAL COORDINATES'/ ' I11=', I3, ' I22=', I3,                00014
      1 ' I33=', I3,' I44=', I3// ' AXIAL COORDINATES'/ ' J11=', I3,     00015
      1 ' J22=',I3,' J33=',I3,' J44=',I3,' J55=',I3//' THERMAL COND'/    00016
      1 ' DIO=', F8.3, ' DI1=',F11.5,' DI2=', F11.5 //' SCALE FACT'/     00017
      1 ' H1(AXIAL)=', F8.3, ' H2(RADIAL)=', F8.3, ' AREA(SQ IN)=',F8.3, 00018
      1 ' EPSCDR=',F8.3,' MAXITC=', I5//' INITIAL TEMPERATURES'/         00019
      1 ' TCOND1=TCDR= ', F8.0,' TCOND2=TSH= ',F8.0,'--OMEGAC=', F8.3)   00020
    99 WRITE(6,901) MAXIT,EPS,OMEGA,ICDR,ECCOND,I11,I22,I33,I44,J11,J22, 00021
      1 J33,J44,J55,DIO,DI1,DI2,H1,H2,AREA,EPSCDR,MAXITC,TCOND1,TCOND2   00022
      1 ,OMEGAC                                                         00023
C   SET UP SYMBOLS FOR ARRAY PLOT                                        00024
       SYMBOL(2) = 1077952576                                           00025
       DO 2 I=4,36,2                                                    00026
     2 SYMBOL(I) = SYMBOL(I-2)                                          00027
       SYMBOL(1) = -1052753856                                         00028
       DO 1 I=3,17,2                                                    00029
     1 SYMBOL(I) = SYMBOL(I-2) + 16777216                              00030
       SYMBOL(19) = -784318400                                         00031
       DO 222 I = 21,35,2                                              00032
   222 SYMBOL(I) = SYMBOL(I-2)+ 16777216                               00033
C LOCATE BOUNDARY OF CABLE INSUL AND TAPE DIELECTRICS.  ALL ARRAY POINTS00034
C DINT(J), LIE IN CABLE OR TAPE INSULATION OR ON BOUNDARY, ALWAYS GIRD  00035
C POINT NEAREST TO THE ACTUAL INTERFACE.  ARRAY POINTS TOPP(J), LIE     00036
C IN CABLE OF TAPE INSULATION NOT ON SHIELD BOUNDARY.                   00037
C INITIALIZE CDR TEMP ARRAY                                             00038
       DO 5 K=1, J44                                                   00039
       K1 = J55 - K                                                    00040
       TCDR(K) = TCOND1                                                00041
       TSH(K) = TCOND2                                                 00042
       TCDR(K1) = TCDR(K)                                              00043
     5 TSH(K1) = TSH(K)                                                00044
       J11P1 = J11+ 1                                                  00045
       J22M1 = J22-1                                                   00046
       J33M1 = J33-1                                                   00047
       J33M3 = J33-3                                                   00048
       I11P1 = I11+1                                                   00049
       I22M1 = I22-1                                                   00050
       I33M1 = I33-1                                                   00051
       J44M1 = J44-1                                                   00052
       J22P1 = J22+1                                                   00053
       J33M2 = J33-2                                                   00054
C SET PHASE CDR ARRAY PTS TO TCDR - REGION (6)                          00055
       DO 6 J=1,J44                                                    00056
       J1 = J55 - J                                                    00057
       DO 6 I = 1,I11                                                  00058
       U(I,J) = TCDR(J)                                                00059
     6 U(I,J1) = U(I,J)                                                00060
C PENCIL REGION(3)-CALCULATE DINT(J) AND TOPP(J)                        00061
       G = I22                                                         00062
       SL = FLOAT(I11-I22)/(J33-J22)                                   00063
       DO 11 J= J22,J33                                                00064
       J1=J55-J                                                        00065
       TOPP(J) = I33-1                                                 00066
       DINT(J) = G + .5001                                             00067
       TOPP(J1)=TOPP(J)                                                00068
       DINT(J1)=DINT(J)                                                00069
       K = G / DINT(J)                                                 00070
```

```
      U(1,J) = FLOAT(K)                                              0007
      U(2,J) = G                                                     0007
      U(3,J) = I33                                                   00073
      U(1,J1) = U(1,J)                                               00074
      U(2,J1) = U(2,J)                                               00075
      U(3,J1) = U(3,J)                                               00076
   11 G = G + SL                                                     00077
C SET SHOULDER REGION (5) ARRAY OUTSIDE INSUL TO SHEATH TEMP        00078
      DO 14 J=1, J22                                                 00079
      J1=J55-J                                                       00080
      DO 14 I=I22,I33                                                00081
   14 U(I,J) = TSH(J)                                                00082
      U(I,J1)=U(I,J)                                                 00083
C INITIALIZE U(I,J) ARRAY IN REGION (1)                             00084
      XI2 = FLOAT(I22-1)                                             00085
      DO 101 J=1,J11P1                                               00086
      TOPP(J) = I22-1                                                00087
      J1 = J55-J                                                     00088
      TOPP(J1)=TOPP(J)                                               00089
      DO 101 I= I11,I22                                              00090
      U(I,J)=(TCDR(J)-TSH(J))*ALOG((I-1)/XI2)/ALOG((I11-1)/XI2)+TSH(J) 00091
  101 U(I,J1)=U(I,J)                                                 00092
C SHOULDER-REGION(2)- CALC DINT(J) AND TOPP(J)                      00093
      G = I22+.0001                                                  00094
      SL = FLOAT(I33-I22)/(J22-J11)                                  00095
      DO 7 J=J11,J22M1                                               00096
      J1 = J55-J                                                     00097
      DINT(J) = I22                                                  00098
      DINT(J1)=DINT(J)                                               00099
      XI2 = FLOAT(DINT(J)-1)                                         00100
      TOPP(J) = G-1                                                  00101
      TOPP(J1)=TOPP(J)                                               00102
      IG = TOPP(J) +1                                                00103
      U(IG,J)=(TCDR(J)-TSH(J))*((DI1/DI2)*ALOG((IG-1)/(G-1)))/(ALOG((I11 00104
     1-1)/XI2) +(DI1/DI2)*ALOG(XI2/(G-1))) + TSH(J)                  00105
      U(1,J) = 1.00                                                  00106
      U(2,J) = I22                                                   00107
      U(3,J) = G                                                     00108
      U(IG,J1) = U(IG,J)                                             00109
      U(1,J1) = U(1,J)                                               00110
      U(2,J1) = U(2,J)                                               00111
      U(3,J1) = U(3,J)                                               00112
    7 G = G+SL                                                       00113
C REGION(4)- INITIALIZE U(I,J) ARRAY                                00114
      XI3 = FLOAT(I33-1)                                             00115
      DO 102 J= J33M1, J44                                           00116
      J1 = J55-J                                                     00117
      TOPP(J) = I33-1                                                00118
      TOPP(J1)=TOPP(J)                                               00119
      DO 102 I= I11P1, I33                                           00120
      U(I,J)=(TCDR(J)-TSH(J))*ALOG((I-1)/XI3)/ALOG((I11-1)/XI3)+TSH(J) 00121
  102 U(I,J1)=U(I,J)                                                 00122
C INITIALIZE U(I,J) ARRAY IN REGIONS (2) AND (3)                    00123
      DO 209 J= J22P1,J33M2                                          00124
      J1 = J55-J                                                     00125
      IT = TOPP(J) +1                                                00126
      U(IT,J) = TSH(J)                                               00127
  209 U(IT,J1) = U(IT,J)                                             00128
      DO 51 J= J11, J33M3                                            00129
      J1 = J55-J                                                     00130
      XM = FLOAT(TOPP(J) + 1) - 1.                                   00131
      M1 = TOPP(J)                                                   00132
      DO 51 I=I11, M1                                                00133
      U(I,J)= (TCDR(J)-TSH(J))*ALOG((I-1)/XM)/ALOG((I11-1)/XM)+TSH(J) 00134
      U(I,J1) = U(I,J)                                               00135
   51 CONTINUE                                                       00136
C     SET THE ITERATION COUNTER TO 1                                00137
      ITN = 1                                                        00138
C     SET SUM OF RESIDUES TO ZERO                                   00139
    9 SUM = 0.0                                                      00140
C     REGION 1                                                      00141
      DO 10 I= I11P1, I22M1                                          00142
      DO 10 J = 2, J11                                               00143
      J1 = J55-J                                                     00144
      DIFF= OMEGA*(((1.+(1./(I-1)))*U(I+1,J)+U(I-1,J)+(H2/H1)**2*      00145
     1 (U(I,J+1)+ U(I,J-1)))/((1./(I-1))+2.+(1.+(H2/H1)**2))+.000001   00146
     L -U(I,J))                                                      0001
```

```
         U(I,J) = U(I,J) + DIFF                                         00148
         U(I,J1) = U(I,J)                                               00149
   10    SUM = SUM + ABS(DIFF)                                          00150
C  REGION 4                                                             00151
         DO 103 I= I11P1,I33M1                                          00152
         DO 103 J= J33,J44                                              00153
         J1 = J55-J                                                     00154
         DIFF= OMEGA*(((1.+(1./(I-1)))*U(I+1,J)+U(I-1,J)+(H2/H1)**2*     00155
        1 (U(I,J+1)+ U(I,J-1)))/((1./(I-1)+2.*(1.+(H2/H1)**2))+.000001   00156
        1 -U(I,J))                                                      00157
         U(I,J) = U(I,J) + DIFF                                         00158
         U(I,J1) = U(I,J)                                               00159
  103    SUM = SUM + ABS(DIFF)                                          00160
C  REGIONS 2 AND 3                                                      00161
         DO 12 J= J11P1, J33M1                                          00162
         J1 = J55-J                                                     00163
         L = TOPP(J)                                                    00164
         M = OINT(J)                                                    00165
         DO 12 I= I11P1, L                                              00166
         IF ( I-M) 45,46,45                                             00167
   46    G= U(2,J)                                                      00168
         K = U(1,J)                                                     00169
         DI1 = 1./(115. + 0.233* (U(I,J) - 20.))                        00170
         DI2 = DI1                                                      00171
         RAPA= (ALOG((G-2)/(G-1)+(DI1/DI2)*ALOG((G-1)/(U(3,J)-1)))/      00172
        1(ALOG((M-2)/(G-1)+ (DI1/DI2)* ALOG((G-1)/(U(3,J)-1)))          00173
         RCPC= ALOG(G/(U(3,J)-1)/ ALOG((M*0.000001)/(U(3,J)-1))         00174
         IF(K-1) 30,30,31                                               00175
   30    RBPB= ALOG((G-1)/(U(3,J)-1))/ ALOG((M-1)/(U(3,J)-1))           00176
         GO TO 39                                                       00177
   31    RBPB=(DI1/DI2)*ALOG((G-1)/(U(3,J)-1))/(ALOG((M-1)/(G-1))+       00178
        1(DI1/DI2)*ALOG((G-1)/(U(3,J)-1)))                             00179
   39    DIFF =OMEGA*(((DI1/(DI1+DI2))*(RAPA/RBPB)* U(I-1,J)            00180
        1 +(DI2/(DI1+DI2))* (RCPC/RBPB)* U(I+1,J)+.000001-U(I,J))       00181
         GO TO 47                                                       00182
   45    DIFF= OMEGA*(((1.+(1./(I-1)))*U(I+1,J)+U(I-1,J)+(H2/H1)**2*     00183
        1 (U(I,J+1)+ U(I,J-1)))/((1./(I-1)+2.*(1.+(H2/H1)**2))+.000001   00184
        1 -U(I,J))                                                      00185
   47    U(I,J) = U(I,J) + DIFF                                         00186
         U(I,J1) = U(I,J)                                               00187
   12    SUM = SUM + ABS(DIFF)                                          00188
         WRITE(6,95) ITN,U(10,2),U(10,20),U(10,51),U(10,81),U(20,51),SUM, 00189
        1 DI1,ECCOND                                                    00190
   95    FORMAT (1H ,I5,5F10.4,1PE12.4,F10.6,F10.1)                     00191
         ITN = ITN + 1                                                  00192
C CHECK FOR FAILURE TO CONVERGE IN MAXIT ITERATIONS                     00193
         IT = 1 + ITN/MAXIT                                             00194
         GO TO (21,20),IT                                               00195
C CHECK FOR CONVERGENCE                                                 00196
   21    IF(EPS-SUM) 22,20,20                                           00197
C NOT CONVERGED YET--GO BACK FOR ANOTHER ITERATION                      00198
C  AFTER RECALCULATING THE CONDUCTOR TEMP ARRAY,TCDR(J)                 00199
   22    DO 88  KM=1, MAXITC                                            00200
         SUMCDR = 0.0                                                   00201
         DO 49 J= 2,J44                                                 00202
         ECCOND = 1./(1.113E-6* (1.+4.03E-3* (U(I11+1,J)- 20.)))        00203
         DI1 = 1./ (115. + 0.233* (U(I11+1,J) -20.))                    00204
         DEN = DI1 / (DIO + (I11-1)* H2**2)+ 2./H1**2                   00205
         DI2 = DI1                                                      00206
         J1 = J55-J                                                     00207
         DIFF=((1/DEN)*(((CDR**2/(AREA**2*ECCOND                        00208
        1 *DIO)+ DI1*(U(I11+1,J)+U(I11+1,J+1))/(H2**2*DIO*(I11-1))      00209
        1 -TCDR(J+1)*(DI1/(H2**2*DIO*(I11-1))-1/H1**2)+TCDR(J-1)/H1**2) 00210
        1 +.000001- TCDR(J)) * OMEGAC                                   00211
         TCDR(J) = TCDR(J) + DIFF                                       00212
         TCDR(J1) = TCDR(J)                                             00213
         SUMCDR = SUMCDR + ABS(DIFF)                                    00214
         U(I11,J) = TCDR(J)                                             00215
         U(I11,J1)= TCDR(J1)                                            00216
   49    CONTINUE                                                       00217
         IF(EPSCDR- SUMCDR) 88,90,90                                    00218
   88    CONTINUE                                                       00219
   90    WRITE(6,213) (TCDR(K),K=1,81,10), SUMCDR                       00220
  213    FORMAT(1H ,' COND TEMP'/ (5X,7F10.4))                          00221
         GO TO 9                                                        00222
C EITHER THE PROCESS HAS CONVERGED OR MAXIT HAS BEEN EXCEEDED,WANT TO    00223
C PLOT RESULTS EITHER WAY. IF THERE IS ANY DOUBT ABOUT WHICH OCCURRED, A00224
```

```
C  COUNT OF NO.OF RESIDUES PRINTED OUT WILL TELL.                    00225
C  WRITE ARRAY OF POTENTIALS   FOR ARBITRARY POINT IN INSULATION     00226
C     LIST ALL POTENTIAL VALUES                                      00227
   20 WRITE(6,9013) OINT                                             00228
      WRITE (6,9013) TOPP                                            00229
      WRITE(6,9015)                                                  00230
      DO 9011  J= 1,J55                                              00231
      BOTT(J) = III + 1                                              00232
      DO 37 I= 1,144                                                 00233
      LINE(I) = U(I,J)                                               00234
      KB = BOTT(J)                                                   00235
      KT = TOPP(J)                                                   00236
      IF(I-KB) 36,38,38                                              00237
   38 IF(I-KT) 40,40,36                                              00238
   36 PLOT(I) = -415219648                                           00239
      GO TO 37                                                       00240
   40 TDIFF = TCOND1 - TCOND2                                        00241
      N = (LINE(I)- COND2) / 5.+ 1.0001                              00242
      IF (N-36) 19,19,18                                             00243
   18 N = 36                                                         00244
   19 PLOT(I) = SYMBOL(N)                                            00245
   37 CONTINUE                                                       00246
 9011 WRITE(6,9016) PLOT                                             00247
 9016 FORMAT(1H ,(15X,30A1))                                         00248
      WRITE(6,9015)                                                  00249
 9015 FORMAT (1H1)                                                   00250
 9013 FORMAT(1H , (5X,26I4))                                         00251
      WRITE  (6,9014) U                                              00252
 9014 FORMAT(1H , (5X,10F10,4))                                      00253
      GO TO 3                                                        00254
 3000 STOP 9999                                                      00255
      END                                                            00256
```

***** ABOVE ACTION SATISFACTORILY COMPLETED *****

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KAISER STANDARDS
FOR

UNDERGROUND TRANSMISSION AND DISTRIBUTION

CONNECTORS FOR ALUMINUM CONDUCTORS

I. SCOPE

These standards identify devices used for making electrical connections between like-sized aluminum conductors and specify their performance in meeting electrical and mechanical requirements.

II. GENERAL

These standards are intended to give reasonable assurance to the user that the connectors deemed acceptable under these requirements will perform in a satisfactory manner, provided that they are installed correctly and properly used.

III. TEST CONDITIONS – GENERAL

A. Test Connectors

1. Description: A complete description of each connector for proper identification must be included in the test results

2. Number of Sizes: If a line of connectors of different sizes are to be qualified, a representative selection of sizes, including the largest and smallest, must be acceptable.

3. Multirange: If a multirange connector is to be qualified, a representative selection of conductor sizes, including the largest and the smallest, must be acceptable.

B. Test Conductors: All test conductors used in connector evaluation shall be new bare conductor conforming to the applicable ASTM standards.

C. Test Assembly Methods: All details of the installation not covered in this section must be included in detail in the test results.

1.   Connector Preparation: All connectors shall be installed in the original condition from the manufacturer without additional preparation of their contact surfaces.

2.   Conductor Preparation: The contact area of the Aluminum Conductor shall be mechanically cleaned with a clean steel wire brush until the entire contact area is completely scoured.

3.   Installation Method: Connectors shall be installed by the method and tooling recommended by the manufacturer.

IV.   HEAT CYCLE TESTS

Heat Cycle Tests shall be carried out in accordance with Section III and the following sub-sections:

A.   Test Connectors:

1.   Connector Combinations: All connectors shall be installed in series in a heat cycle loop.

2.   Number of Samples: In each of the tests, a minimum of five connectors of each size and type are required for test.

B.   Equalizers: In order to provide equipotential planes for resistance measurements compression equalizers shall be installed on each side of each connector in the stranded conductor. One sheet metal screw shall be imbedded into each equalizer to provide taps for resistance leads.

C.   Conductor Length: The exposed length of conductor between connector and equalizer shall be one inch. The exposed length of conductor between equalizers shall be four feet. These lengths do not include the amount within the connector or equalizer. The loop shall be joined to an appropriate power source with additional lengths of conductor of not less than four feet.

D.   Ambient Conditions: All heat cycle tests shall be carried out in a draft-free environment at an ambient temperature which is controlled between temperatures 20C to 30C. A draft-free environment is an area where the control conductor temperature does not vary more than 5C at the end of each heating period during the evaluation section of the test.

E.   Control Conductor: In order to monitor conductor temperature, a control conductor of equal type and size, shall be installed in the heat cycle loop between two equalizers. The length of this conductor shall be eight feet.

F.   Test Conditions: Heat Cycle Tests shall be of the following duration:

Class G	125 Cycles @ 130°C
Class F	250 Cycles @ 130°C
Class E	500 Cycles @ 130°C
Class D	500 Cycles @ 130 °C 100 Cycles @ 160 °C
Class C	500 Cycles @ 130°C 100 Cycles Each @ 160°C & 190°C
Class B	500 Cycles @ 130°C 100 Cycles Each @ 160°C, 190°C & 220°C
Class A	500 Cycles @ 130°C 100 Cycles @ 160 °C, 190 °C, 220°C & 250°C

Each user must make the decision regarding which class is best for a given application.

G.   Heat Cycle Current: The Heat Cycle Current shall be adjusted to result in a steady-state temperature on the control conductor. This adjustment may be made during the heating periods of the first 26 cycles. From this point on, no adjustment can be made for the remainder of test, regardless of control conductor temperature variation.

H.   Heat Cycle Period: Each cycle of the Heat Cycle Test shall consist of a "Current On" period and a "Current Off" period. The length of these periods shall be chosen to allow equilibrium temperature to be reached within 2°C. The length of these periods can be extended for the time necessary to take measurements.

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I.   Loop Configuration: The loop assembly shall be mounted in a "U" or "Zig-Zag" shape in which each connector shall be lying in a horizontal plane with at least eight inches of separation between adjacent conductors. The assembly must be at least one foot from any walls and at least two feet above the floor.

J.   Measurements: Temperature and resistance measurements shall be taken at the beginning and end of the test and approximately after each 25 cycles. The actual number of cycles between measurements may be adjusted to conform to normal working hours.

D.C. resistance measurements shall be made at the end of the current-off period. These measurements shall be made across each connector, between potential points on the equalizers. For D.C. measurements the current must be of sufficiently low magnitude to avoid heating.

The ambient temperature must be recorded concurrently with each set of resistance measurements. The resistance measurements are then corrected to 20°C.

Temperature measurements shall be made at the end of the current-on and current-off cycle. These temperatures shall be measured by the use of thermocouples permanently attached to the center of each connector and the control conductor.

K.   Thermocouples:

1.   Test Connectors: Thermocouples shall be installed so as to obtain a good thermal and mechanical bond with the surface of the connector and without causing an appreciable change in the temperature of the connector (e.g. by peening or use of a thermally conductive adhesive).

2.   Test Conductors: The thermocouple shall be secured to the control conductor by soldering, use of a thermally conductive adhesive or other equivalent means which will not require the penetration of the conductor surface (e.g. Drilling and peening is not permitted).

L.   Number of Heat Cycles: The number of heat cycles at the completion of the test may be extended so that final measurements may be made during normal working hours.

M.   Evaluation Interval: The evaluation of each connector will be based on those measurements taken during an interval which includes the measurements taken on or about the 25th cycle, the end of the test, and approximately every 25th cycle between them.

N.   Performance Criteria: When installed in an assembly and tested with the methods above, the connectors shall conform to the following performance criteria.

   1.   The resistances measured shall show a condition of stability by a variation of not more than 5% from the average measured values.

   2.   The temperatures measured shall not exceed the temperature of the control conductor. The temperature difference between the control conductor and the connector shall decrease not more than 10°C from the average measured values.

V.   MECHANICAL TESTS

Mechanical Tests on non-heat cycled connectors shall be conducted in accordance with Section III and the following paragraphs. Mechanical tests on heat cycled connectors shall be conducted in accordance with Section III, Section IV, and the following paragraphs.

A.   Test Conductors:

   1.   Non-Heat Cycled: Three samples of each connector/conductor combination shall be subjected to Mechanical Test.

   2.   Heat Cycled: Three samples of each connector/conductor combination heat cycled to its rated temperature (Section III, Paragraph F) shall be subjected to Mechanical Test.

B.   Test Conductors:

   1.   Pullout Strength Tests shall be performed on each connector/conductor combination.

V. MECHANICAL TESTS: (Cont'd.)

    2. If qualifying a line of connectors at least the largest and smallest connector/conductor combination must be tested.

    3. If qualifying a multirange connector, at least the largest and the smallest conductor size must be tested.

C. Test Conditions: Connectors shall be classified regarding tensile strength as follows:

	Non-Heat Cycled	Heat Cycled
Class 1	Full Tension	Full Tension
Class 2	Full Tension	Non-Tension
Class 3	Non-Tension	Non-Tension

D. Tensile Strength:

    1. Care shall be taken to insure that all conductor strands are loaded simultaneously in the tensile testing machine.

    2. Crosshead speed shall not exceed 1/4 inch per minute per foot of length between jaws.

    3. The length of free conductor between connector and gripping device shall not be less than two feet.

    4. Tensile strength shall be measured as the maximum load applied at failure. An accuracy of 1% for Class 1 and 5% for the other classes shall be measured with ASTM Specification E-4 calibrated instruments. The mode of failure shall be recorded.

E. Performance Criteria: The tensile strength of sample tested in accordance with Section D above shall be at least equal to the following values.

    1. Class 1- Full Tension-Full Tension: 100% of the rated breaking strength of the conductors joined, for both Non-Heat Cycled and Heat Cycled Connectors.

V.   MECHANICAL TESTS (Cont'd.)

2. ·Class 2- Full Tension-Non Testion: 100% of the rated
    breaking strength of the conductors joined, for Non-Heat
    Cycled Connectors. 40% of the rated breaking strength
    of the conductor joined for Heat Cycled connectors.

3. Class 3- Non Tension-Non Tension: 40% of the rated
    breaking strength of the conductors joined, for both Non-
    Heat Cycled and Heat Cycled connectors.

VI.   ACCEPTANCE CRITERIA:

A.   Heat Cycled: All sample sets shall be rated one step below the
     point of the first failure within the set.

B.   Mechanical: All sample sets shall be rated at the lowest level
     within the set.

C.   Non-Acceptance: Any sample within a set which does not meet the
     minimum requirements (e.g.   125 cycles @ 130° and 40%
     breaking strength) shall result in a non-acceptance of the set.

8.0 TERMINATIONS FOR USE ON 230KV EXTRUDED SOLID DIELECTRIC CABLE

Several manufacturers of cable terminations were approached relative to their ability and interest in developing terminations suitable for use on 230kV extruded solid dielectric cable. The G & W Electric Specialty Company (REF. 8.1) and Joslyn Manufacturing & Supply Company ('REF. 8.2), expressed an interest in undertaking such a project. Subsequently, we collaborated with each on the design parameters and arrangements were formally entered into to procure one terminal from each manufacturer.

8.1 THE G & W TERMINATOR

The G & W 230kV terminator consisted of a conventional 230kV porcelain housing designed and used traditionally for oil-filled cable terminations. The customary reinforcing paper roll build-up and several other inner components were replaced or modified as follows:

8.1.1 Oil-impregnated paper roll build-up and stress relief cone: replaced with hand-applied varnish-dacron-glass (VDG) tape, constructed on the prepared cable insulation.

8.1.2 Semi-conducting elastomeric sleeve to provide stress cone shielding.

8.1.3 Pre-cast epoxy stress control assembly in lieu of porcelain stress control assembly.

8.1.4 Accumulator oil reservoir unit attached to base of terminal.

The accumulator provided an expansion chamber which makes allowances for volume changes in the approximately 22 gallons of de-gassified oil contained in the pothead. Volume changes would occur as a function of temperature. Additionally, the accumulator diaphragm is pressurized with an inert gas, typically nitrogen, such that a positive pressure is maintained within the terminal. The recommended pressure of 16 PSIG was used. The cable conductor was terminated with a Cadweld connector (REF. 8.3) provided by the terminal manufacturer. Ordinarily, this terminator would be provided pre-assembled. However, since the porcelain housing was already in the laboratory, the inner components were procured and assembly was done in the laboratory.

The basic design parameters of the G & W termination was an extension of their standard 138kV slip-on terminal, extrapolated to conform to the

230kV stress conditions anticipated. The 138kV terminal was thoroughly tested and found to conform to the requirements of IEEE Standard No. 48 for terminators (REFERENCE 8.4).

As a result of tests performed on the 69kV and 138kV terminators, considerable data were collected which defined the radial stresses at various points in the assembly. These tests were conducted using several voltage references -- relative to magnitudes, duration and waveforms. The one minute 60 hertz dry test is the reference most commonly used by terminator manufacturers when defining radial stresses. The following summary of radial stresses at selected points in the termination, were arrived at through the aforementioned tests on the 138kV terminal. Through extrapolation, corresponding data for the 230kV terminal were established. These calculated results are referenced to a one minute 60 hertz dry test of 460kV; the required 230kV terminator reference voltage:

8.1.5   Stress Control assembly base plate/semi-conducting elastomer top edge

a)   121 Volts/mil @ 138kV level
b)   120 Volts/mil @ 230kV level

8.1.6   Oil gap at base of stress control assembly taper

a)   231 Volts/mil @ 138kV level
b)   202 Volts/mil @ 230kV level

8.1.7   VDG Tape in flat adjacent to lip of stress control assembly

a)   74 Volts/mil @ 138kV level
b)   76 Volts/mil @ 230kV level

8.1.8   Oil bulk in region adjacent to lip of stress control assembly

a)   140 Volts/mil @ 138kV level
b)   127 Volts/mil @ 230kV level

8.1.9   Innermost region of stress control assembly, in-line with lip of assembly

a)   50 Volts/mil @ 138kV level
b)   50 Volts/mil @ 230kV level

The stress data developed for the 230kV terminator were based on a cross-linked polyethylene insulation wall thickness of 1.050 inches, and a VDG tape

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build-up of 0.375 inches at the stress cone apex. In most instances, it can be seen that the 230kV termination was projected to operate at stresses lower than those observed in the operational 138kV terminal, at comparable points.

8.2   THE JOSLYN TERMINATOR

The Joslyn terminal was designed specifically as a slip-on for the 230kV cable. Here too, the basic concept was an extension of their operational 138kV terminal for extruded solid dielectric cables. Additionally, considerable laboratory test data had been gathered with a much earlier 230kV cable design, terminated with a prototype of the current termination. As in the first case, this manufacturer's 138kV terminator had been tested and found to conform to the requirements of IEEE Standard No. 48 for terminators (REFERENCE 8.4).

The Joslyn terminal consisted of a conventional porcelain housing, pre-assembled with a semi-conducting elastomeric stress cone, solid insulating phenolic-like tubes and compression mounted terminal cover. Silicone fluid is utilized to supplement the solid terminating components after the assembly is properly and securely installed on cable end. Termination of the cable conductor is accomplished with a compression connector provided by the terminal manufacturer. The design concepts were based on the maximum stresses that the stress cone would experience during the required one minute 60 hertz dry test of 460kV. These calculated values using a stress cone contour of 7 degrees, are as follows:

(a)   SIC of Urethane compound (stress cone material):   3.89
(b)   Maximum longitudinal stress: 18.99 volts/mil
(c)   Maximum radial stress: 160.06 volts/mil

The preceding values were calculated on the basis of 20C ambient temperature. At 60C ambient, the following parameters applied:

(a)   SIC of Urethane compound: 3.50
(b)   Maximum longitudinal stress: 21.05 volts/mil
(c)   Maximum radial stress: 177.79 volts/mil

Cable preparation and terminating instructions were provided by both terminal manufacturers and did not conflict with the standards of workmanship that are customarily observed. Finally, both terminals were designed to meet the required 230kV rating of 1050kV BIL, based on a standard 1-1/2 x 40 microsecond impulse wave, in accordance with IEEE Standard No. 82 (REFERENCE 8.5).

Detailed drawings which describe the features of each termination, are included herewith as Figures 8.1 and 8.2.

1.   G & W ELECTRIC SPECIALTY COMPANY
      3500 West 127th Street
      Blue Island, Illinois 60406

2.   JOSLYN MANUFACTURING & SUPPLY COMPANY
      155 North Wacker Drive
      Chicago, Illinois 60638

3.   CADWELD ®- ERICO PRODUCTS, INC.
      Cleveland, Ohio 44139

4.   IEEE STD. 48-1975. IEEE Standard Test Procedures
      And Requirements for High Voltage Alternating
      Current Cable Terminations. The Institute of
      Electrical And Electronics Engineers, Inc.,
      New York, N.Y.

5.   IEEE STD. 82. Test Procedures For Impulse Voltage
      Tests On Insulated Conductors. The Institute Of
      Electrical and Electronics, Engineers, Inc.,
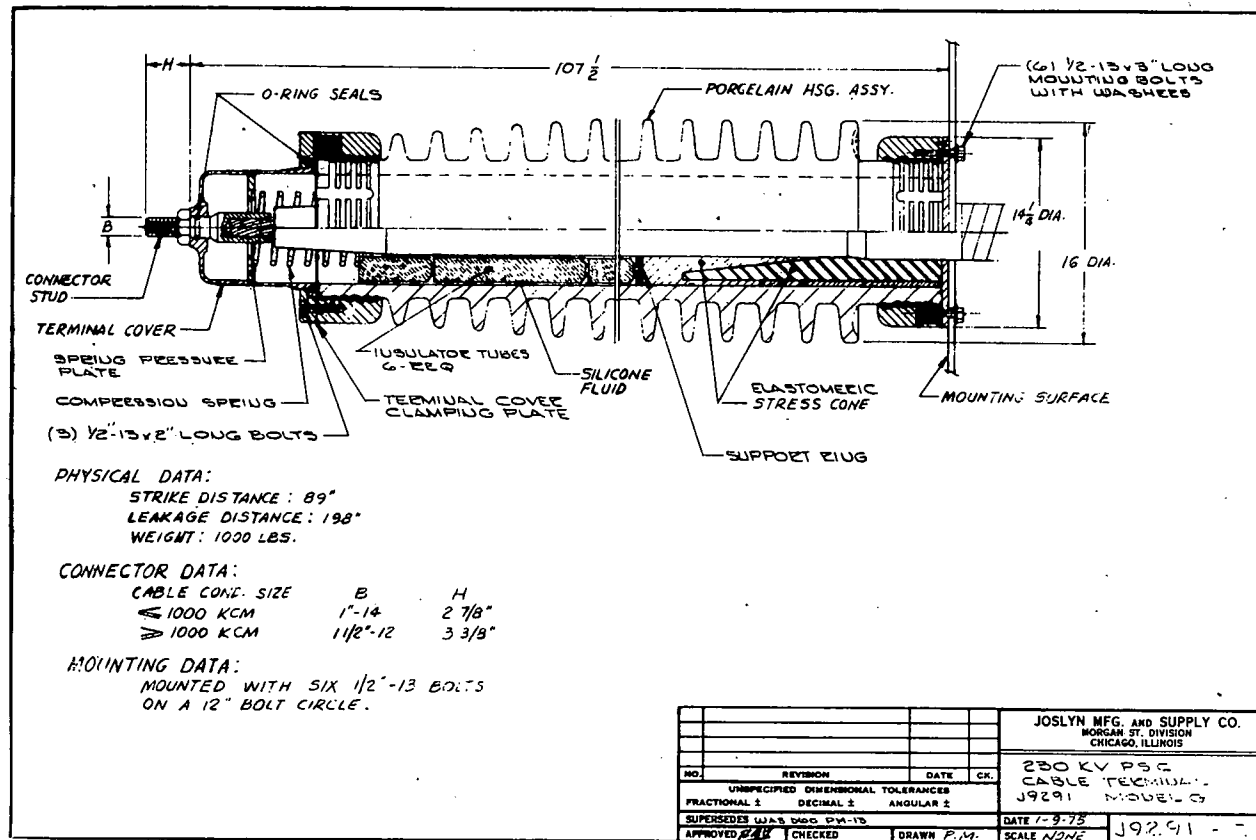   New York, N.Y.

FIGURE 8.1

DETAILED ASSEMBLY DRAWING OF G & W

230kV TERMINATOR

Physical data and drawing labels:

(6) ½-13×3" LONG MOUNTING BOLTS WITH WASHERS

O-RING SEALS

PORCELAIN HSG. ASSY.

107 ½

H

B

CONNECTOR STUD

TERMINAL COVER

SPRING PRESSURE PLATE

COMPRESSION SPRING

(3) ½"-13×2" LONG BOLTS

INSULATOR TUBES 6-REQ

TERMINAL COVER CLAMPING PLATE

SILICONE FLUID

ELASTOMERIC STRESS CONE

SUPPORT RING

MOUNTING SURFACE

14 ¼ DIA.

16 DIA.

PHYSICAL DATA:
   STRIKE DISTANCE : 89"
   LEAKAGE DISTANCE : 198"
   WEIGHT : 1000 LBS.

CONNECTOR DATA:
   CABLE COND. SIZE   B   H
   ≤ 1000 KCM   1"-14   2 7/8"
   ≥ 1000 KCM   1 1/2"-12   3 3/8"

MOUNTING DATA:
   MOUNTED WITH SIX 1/2"-13 BOLTS
   ON A 12" BOLT CIRCLE.

JOSLYN MFG. AND SUPPLY CO.
MORGAN ST. DIVISION
CHICAGO, ILLINOIS

230 KV PSG
CABLE TERMINAL
J9291   MODEL G

NO.	REVISION	DATE	CK.

UNSPECIFIED DIMENSIONAL TOLERANCES
FRACTIONAL ±   DECIMAL ±   ANGULAR ±

SUPERSEDES WAS D100 PM-15

APPROVED   CHECKED   DRAWN P.M.   DATE 1-9-75   SCALE NONE   J9291

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FIGURE 8.2

DETAILED ASSEMBLY DRAWING OF JOSLYN 230kV TERMINATOR

9.0   SUMMARY AND CONCLUSIONS

9.1   SUMMARY

The project was able to show that, based upon a minimal amount of cable produced and short term testing performed, that the extruded solid dielectric cable could be used for cable systems through the 230kV voltage class. The 400 feet of cable, produced after several attempts, did provide reasonably satisfactory interfaces at the semi conducting/insulation interfaces. The construction behaved reasonably well under 60 Hertz testing at both elevated and room temperatures. The construction appeared to experience difficulties in being capable of withstanding voltage impulses at the System Basic Insulation Level (BIL) while the conductor temperature was elevated to 90C. Two impulse voltage failures were experienced while the conductor temperature was at 90C. One failure was located in the cable itself, the other in the joint. Both failures were at a voltage level of 1050kV. There were no impulse failures in the system while the conductor was at room temperature.

Two cable joints, of the hand-applied variety were constructed. One joint was the one mentioned above, which suffered a failure under impulse voltage. The second joint was constructed in the sample for voltage endurance and current cycling tests. That test simulated actual installation characteristics. The constructed joint successfully withstood all of the 60 Hertz voltages applied and exhibited no signs of failure despite voltages in excess of normal operating levels and conductor temperatures as high as 130C.

Additional work was performed on the development of alternative methods for joining cables. Considerable effort was expended on the field vulcanization of cross-linked polyethylene joints. No field vulcanized joints were constructed at the 230kV voltage level. Ten field vulcanized joints were constructed and tested at the 69kV voltage level. This testing pointed out the need for controlled pressure and environmental conditions for this type of jointing method at levels above 69kV and conductor sizes larger than 500 kcmil. Work on alternate methods of applying semi-conducting strand shields in field vulcanized joints showed that semi-conducting heat shrinkable sleeves are an improvement over hand applied semi-conducting tapes. Further testing indicated that the curing cycle, at least at the 69kV level, can be reduced in time by rapid cooling without degradation of joint characteristics.

Testing on compression type connectors and exothermic type welded connectors showed that some are capable of operating capably at temperatures at or near levels anticipated in cable joints.

Terminations manufactured by two U.S. manufacturers performed satisfactorily under short term 60 Hertz testing under overvoltage conditions and at conductor temperatures elevated to as high as 130C. Time did not permit testing of the terminators under impulse voltage conditions.

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9.2   CONCLUSIONS

Based upon the limited data collected and the abbreviated scope of work performed, we are led to conclude the following:

9.2.1   METHOD OF MANUFACTURING EXTRUDED SOLID DIELECTRIC CABLES

Normal methods for making extruded solid dielectric cables employing conventional extruder processes and steam curing is a possible means of producing 230kV Cables. This is based on only a short sample – 400 feet – and minimal amount of testing performed. Provisions must be made for the melting or softening temperatures of the individual extruded layers. Obviously, long term and accelerated testing must be completed to assure that this type of cable will provide the long term reliable performance required for utility system operation.

9.2.2   CAPABILITY OF EXTRUDED SOLID DIELECTRIC CABLES

Based on short term testing and a single sample, extruded solid dielectric cables, manufactured as stated above, employing crosslinked polyethylene insulation and extruded semi-conducting conductor and insulation shields appear to be capable of operating at voltage stresses higher than previously used. However, further testing is required to ensure that the long term performance of cables operating at higher voltage stresses is not adversely affected.

9.2.3   230kV TAPED JOINTS

Hand applied taped joints made with Ethylene-propylene rubber (EPR) tapes appear to have the capability of operating at significantly higher stresses than those previously considered as maximum stresses allowable. When properly constructed, they appear to have the capability of operating at levels as high as 230kV and to be compatible with crosslinked polyethylene insulations.

9.2.4   230kV TERMINATIONS

Terminations capable of operating at 230kV voltages and suitable for use on extruded solid dielectric cable are commercially available, relatively easy to install, provided that normal precautions for circuits of this type are taken, and are compatible with the crosslinked polyethylene insulation and semi-conducting insulation shield.

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