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**Cryogenic Power Transmission Technology—
Cryogetic Dielectrics
Fourteenth Quarterly Report
April 1, 1976–June 30, 1976**

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OAK RIDGE NATIONAL LABORATORY

OPERATED BY UNION CARBIDE CORPORATION FOR THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

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CRYOGENIC POWER TRANSMISSION TECHNOLOGY -
CRYOGENIC DIELECTRICS

Fourteenth Quarterly Report

April 1, 1976 - June 30, 1976

Cryoelectrics Section
Engineering Sciences Group
Fusion Energy Division

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ABSTRACT

The fourteenth Quarterly Report of the Oak Ridge National Laboratory Cryogenic Dielectrics Program covers the period from April 1, 1976 to June 30, 1976.

Partial discharge characteristics of three-layer polymer samples, impregnated with helium in a wide range of pressure and temperature (0.3-1.5 MPa and 4.2-12 K), are reported. Electrode-adjacent and mid-dielectric butt gaps are investigated. Results of PD measurements conducted on embossed films and on a sample with a shielded butt gap are discussed.

DC dielectric strength measurements on two layers of cellulose paper, impregnated by helium at 1 MPa and 12 K, are reported. Flashover problems, encountered with dc measurements on polymer films, are also summarized.

Results of low temperature resistivity measurements made on a conducting paper are given. Experimental plans for the forthcoming and final quarter of the program are presented.

A. INTRODUCTION

The major objective of the Cryoelectric Project is to obtain test data on the dielectric behavior of solid, liquid, and gaseous materials at cryogenic temperatures. These data will be used in the design of cryogenic superconducting power transmission lines (SPTL). An SPTL design can be broken down into four major systems: conductor, electrical insulation, coolant, and thermal insulation. Each of these must meet certain design specifications to ensure proper cable operation, and must also withstand the rigors of field installation, thermal cycling, and electrical transients produced by network faults, switch operation, and lightning surges. In order to assess the performance of cryogenic dielectrics under such conditions, breakdown strength tests are being conducted with dc, ac, and impulse voltages on cryogenic liquids and on multilayer samples of thin plastic tapes. Partial discharge (electrical arcing in small flaws in the insulation, causing long-term deterioration, but not leading immediately to complete electrical breakdown) is being monitored as a function of the thermodynamic conditions and previous electrical and thermal history. All of these experiments are carried out under the full ranges of temperature and pressure of interest for practical SPTL designs, that is, for about 4.2-13 K and 0.1-1.2 MPa.

B. ACTIVITY DURING QUARTER

1. EXPERIMENTAL EQUIPMENT

a) Cryostats

Cryostat IV-1 continued to operate successfully throughout this quarter and was used continuously for ac experiments.

During modifications to the terminating closure of the IV-3 bushing, the IV-2 bushing was adapted for use in the IV-3 dewar. Experiments with this arrangement are described in the next section.

Most of the leakage problems with the IV-3 bushing appeared to result from insufficient pressure on the lead O-ring seals on the lower insulating disc. The bushing could usually be re-sealed by warming it to room temperature and tightening the bolts. A new G-10 bushing closure, with stainless steel lead O-ring flanges having twice the previous number of bolt holes, was machined and welded to the IV-3 bushing. It was tested for leaks and found to perform satisfactorily at room temperature. Tests at helium temperature were delayed by problems with the vacuum jacket of the IV-3 dewar. Cracks were observed near the edges of the inner cryogenic window and the dewar would no longer hold a vacuum. The dewar was dismantled and the quartz window was found to be badly cracked around the edges. The supplier of the dewar had used a window with a stainless steel mounting ring instead of the kovar or invar ring required to minimize expansion and contraction. The proper window was ordered and will be installed early next quarter.

A new 28-cm-diameter sample holder (Fig. 1) for pressurized He tests in IV-3 was designed, built, and tested, for use after the dewar is repaired. This sample holder is similar in concept to the smaller holders already in use, but has a top plate made of G-10 fiberglass rather than Stycast epoxy.

b) Instrumentation

A Rosemount pressure transducer capable of measuring pressures up to 250 psia was installed and calibrated against a Wallace and Tiernan pressure measuring instrument.

The impulse memory voltmeter ordered over a year ago from Ross Engineering Co. was not delivered by the final deadline of April 16, 1976, and the order was cancelled.

The computer program for obtaining densities of He gas at low temperatures and elevated pressures had been found inaccurate above 10 atm. The program was debugged in May and is now giving accurate results.

c) Other Experimental Activity

BNL had requested data on butt gaps in plastic films in which all surfaces of the gaps were metallized. Suitable vacuum deposition equipment for aluminizing plastic films was available at ORNL in the Thermonuclear Division. Several Valeron films with simulated butt gaps were successfully aluminized in the appropriate sites by J. E. Simpkins of the Thermonuclear Division.

Existing equipment was modified to perform a resistivity experiment at low temperature on analog plotting paper. This experiment is described in Sect. C.3 of this report.

Preliminary designs were made for an experiment to measure the breakdown strength of He in small gaps at low temperatures and elevated pressures.

2. COLLABORATION WITH OTHER LABORATORIES, MEETINGS, AND VISITS

The second bimonthly meeting between representatives of DEES-funded SPTL projects was held at ERDA-DEES, Washington, D. C., on April 1, 1976. H. M. Long, M. M. Menon, O. B. Morgan, and S. W. Schwenterly of ORNL attended. BNL, LASL, and NBS were also represented. A report of this meeting was prepared on April 15, 1976 and was distributed to all parties concerned.

In June 1976 the third bimonthly meeting of personnel from the DEES-funded SPTL projects was held at Oak Ridge, Tennessee. A full report on this meeting was distributed to those concerned on July 19, 1976. Participants from ORNL, BNL, NBS, UCC-Linde, and LASL discussed the progress made since the previous meeting. Since the ORNL cryoelectric program will be terminated on October 1, 1976, the disposition of the ORNL equipment was discussed. The preliminary proposal for the division of the equipment

by A. Clorfeine, was discussed and accepted with a few modifications. A summary of the final equipment disposition is given in Appendix A.

H. M. Long, M. M. Menon, and S. W. Schwenterly attended the 1976 IEEE International Symposium on Electrical Insulation on June 14-16, in Montreal, Canada. The abstract of the paper presented there by S. W. Schwenterly was published in the last quarterly report.¹

The next round of visits in the U. S.-Soviet collaboration on dielectrics for SPTL development was postponed until after June 1976.

C. EXPERIMENTAL WORK

1. DC MEASUREMENTS

DC dielectric strength measurements for the LASL cable were initiated during this quarter. Cellulose paper (Crocker - 75 μ m thickness) was the first candidate material to be selected for breakdown measurements. Two layers of this material were assembled in the specimen chamber described in our last quarterly report.¹ Eight stainless steel rods with 6.35-mm-diameter hemispherical ends, equally spaced on a 6.35-cm-diameter circle and encapsulated in epoxy, served as the high voltage electrodes. An aluminized Mylar sheet acted as the ground electrode. The specimen chamber was installed in IV-2.

Since our earlier measurements on polymers immersed in slowly boiling liquid helium yielded breakdown strengths greater than 400 kV/mm, we were concerned whether the clearances in the specimen chamber and the cryostat itself were adequate for successful breakdown measurements. It was therefore decided to conduct some preliminary measurements at and around 4.2 K where the dielectric strength of the helium surrounding the specimen chamber is better. The voltage was measured by a resistive potential divider with a chart recorder, calibrated against an electrostatic voltmeter. Manual and motorized (2 kV/sec) ramps were used to increase the voltage. Temperature was measured using a carbon resistance thermometer mounted inside the specimen chamber and calibrated against a commercial germanium thermometer. During the first half of the experiment the voltage polarity was positive; during the second half it was changed to negative. Measurements at 4.2 K were made when the liquid helium was in contact with the specimen chamber. The higher temperature readings were obtained when the level of the liquid was below the specimen chamber. Prior to measurements the bushing was conditioned to 41 kV in the case of positive polarity and 23.7 kV in the case of negative polarity. The results of the experiments are shown in Table 1.

The results shown in Table 1 were quite puzzling. Since we could reapply approximately the same voltage (sometimes even higher) even after the breakdown was supposed to have occurred, we were inclined to believe

Table 1. Experimental observations with two layers of
75- μ m cellulose paper stressed with dc, in
helium pressurized to 1 MPa

Position	Temperature (K)	Breakdown Voltage (kV)	Comments
0°	4.2	+20.0	Manual ramp. No light visible inside dewar.
	4.2	+22.0	Higher voltage when reapplied. Manual ramp and no visible light.
	4.2	+12.7	Voltage reapplied with manual ramp. No light.
90°	4.2	+15.0	Manual ramp. No light.
		+18.5	Voltage reapplied. Manual ramp. No light.
		+14.7	Voltage reapplied. Manual ramp. No light.
		+14.5	Voltage reapplied. Manual ramp. No light.
45°	5.40	-14.8	Manual ramp. No light.
	5.45	-17.2	2 kV/sec ramp. No light. Voltage reapplied.
		-18.3	2 kV/sec ramp. No light. Voltage reapplied again.
135°	7.33	-15.4	2 kV/sec ramp. Could see glow inside the dewar.
	7.54	-14.5	2 kV/sec ramp. No light.
180°	9.1	-17.3	2 kV/sec ramp. Could see light.
		-15.5	2 kV/sec ramp. No light.

that what we were observing was a flashover, either in the specimen chamber or in the vacuum bushing. However, each time the voltage tripped it was accompanied by a transient pressure and temperature rise which suggested that the event was occurring within the specimen chamber and not in the bushing. The occasional incidence of glow inside the dewar further confused the picture.

Examination of the specimens on the following day showed some interesting results. At all positions where the voltage was applied, breakdown punctures were visible. Moreover, the number of punctures was the same as the number of voltage applications. The metallized Mylar surface that acted as the cathode also showed breakdown damage. In fact, the arcing caused the metallizing to be eaten away at each breakdown site. This, together with the lack of carbonization of the paper at the breakdown sites, could explain the high levels of voltages that could be re-applied to each electrode position.

This experiment revealed that the clearances in the IV-2 dewar are marginal for conducting dc dielectric strength measurements at 12 K. Since the IV-3 bushing was not ready, due to leak problems, it was decided to repeat the experiment systematically in the IV-3 dewar, using the IV-2 bushing. This allowed use of the IV-3 cooling coil. The experimental setup is shown in Fig. 2.

Two fresh layers of 75- μ m-thick cellulose paper were assembled in the specimen chamber, which was mounted on the IV-2 bushing. The metallized Mylar in the new assembly was replaced by a 25- μ m-thick aluminum foil. The bushing was then introduced into the IV-3 dewar with the help of appropriate adapting flanges. The specimen was precooled by circulating liquid nitrogen through the cooling coil. The sample chamber was filled to a pressure of 1 MPa of helium, and liquid helium was transferred into the dewar. The high voltage arm was raised away from the electrodes and the bushing was conditioned to about 40 kV. The helium was then boiled off to a level below the sample chamber to allow the chamber and the specimen to warm up slowly to 12 K. The temperature was monitored with a carbon resistance thermometer. When the temperature registered approximately 11 K the cooling coil was connected to the liquid helium tank. Care was taken not to freeze air in the cooling coil. Liquid helium was then circulated through the cooling coil. By adjusting the liquid helium flow, the temperature of the specimen could be kept very nearly constant. Breakdown measurements were then made and the results are shown in Table 2.

Table 2. DC breakdown values for cellulose paper impregnated by supercritical helium at 1 MPa, at a ramp rate of 2 kV/sec (top electrode negative)

Position	Temperature (K)	Breakdown Voltage (kV)	Average Breakdown Voltage (kV) ^a	Average Dielectric Strength ^a (kV/mm)
0°	11.54	9.4		
	11.59	6.6		
45°	11.52	8.5		
	11.42	6.5		
90°	11.74	11.7		
	11.68	4.3	10.38 ± 1.69	69.2 ± 11.3
135°	11.49	12.1		
180°	11.63	10.4		
225°	11.68	12.9		
	11.74	9.4		
270°	11.68	9.6		
315°	11.84	8.4		
	11.94	4.8		

^a Only the first readings are counted toward the average.

Examination of the paper sample after breakdown showed clean breakdown sites less than 1 mm in diameter. No carbonization was visible at the breakdown site, as in the earlier experiment. Breakdown was apparently through the helium-filled pores of the paper, which explains the relatively low values for the dielectric strengths.

Encouraged by the success with paper, we decided to test two layers of 75- μ m-thick Mylar film using the same arrangement. However, when voltage was applied to one electrode position (the specimen being kept at 12 K in 1 MPa helium) the supply tripped at 39.6 kV. During successive voltage applications at the same position the specimen withstood 36.6 kV, 39.5 kV and 42.5 kV prior to the tripping of the supply. Once, arcing inside the helium dewar was also observed, suggesting that the clearances are not sufficient for operating the bushing when it is surrounded by warm (>12 K) helium gas.

In order to overcome this problem, we began modifying the experimental setup so that the specimen chamber could be surrounded by vacuum instead of helium. A heat exchanger was incorporated to cool the specimen chamber directly by circulating liquid helium through the cooling coil. Thermal shields were installed in the annular space between the IV-2 bushing and the IV-3 dewar to minimize convection and radiation heat leaks. In spite of all these efforts it was difficult to cool the specimen chamber below 15 K by circulating liquid helium through the cooling coil. Breakdown was attempted at about 15 K but the voltage tripped again between 35 and 40 kV during successive operations.

When the film was examined after the sample chamber was opened, it was obvious that the tripping of the supply was the result of surface flashover along the helium interface between the epoxy and the film (see Fig. 3). The flashover occurred between the top electrode and the indium edge seal of the chamber over a distance of about 2 cm.

These results were communicated to Dr. Chowdhuri of LASL and it was agreed that we test single layers of polymers instead of double layers. One layer of 75- μ m Mylar was therefore installed in the specimen chamber. The experimental procedure was the same as before and the results are shown in Table 3. However, when the specimen chamber was opened it was discovered that the film was not broken down at any of the eight positions. Instead, clear signs of surface flashover were again visible. As in the two-layer case, the flashover occurred in the epoxy film interface over a distance of about 2 cm.

The result of dc measurements were discussed during the cryogenic dielectric collaboration meeting held in June. There was some concern as to whether the surface flashover was precipitated by the onset of partial discharges in the helium at the epoxy film interface. It was decided to conduct some partial discharge and breakdown measurements with dc in three-layer samples with and without butt gaps. At the same time we also decided to design a larger sample chamber that would increase the flashover path (Fig. 1).

Three layers of 75- μ m-thick cellulose paper with 1-mm-diameter butt gaps at certain electrode positions were installed in the small sample chamber. Partial discharge measurements yielded inconclusive results.

Table 3. DC measurements with one layer of Mylar in
1 MPa helium at 10/kV/sec ramp rate
Top electrode - vc

Position	Temperature (K)	Maximum Voltage (kV)	Comments
0°	11.92	27.7	Light inside the dewar.
	12.00	28.4	No light. Voltage applied again.
	12.00	17.4	No light. Voltage applied again.
	12.02	17.7	No light. Voltage applied again.
180°	11.97	30.0	No light. Voltage applied again.
90°	11.95	25.0	No light. Voltage applied again.
	11.95	19.8	No light. Voltage reapplied.
270°	12.02	26.7	
45°	12.05	26.3	Light observed.
	12.05	23.5	Light observed. Voltage reapplied.
	12.05	24.5	Light observed. Voltage reapplied.
225°	12.02	26.6	No light.
135°	12.00	25.0	No light.
315°	12.00	26.2	Light observed.
	12.08	30.3	Light observed.
	12.08	20.0	No light.

Occasional discharge pulses appear every 20 or 30 sec. The random nature of the pulses and their low repetition rate made it difficult to distinguish them from noise pulses. Moreover, the experiments were performed in a large hall with other experimental activities and hence considerable background noise. PD measurements for the above sample were therefore abandoned and breakdown readings were taken. The results are shown in Table 4. No significant deterioration in breakdown strength was noticed at the butt gap positions. The average dielectric strength was 52 kV/mm for the three-layer paper sample as opposed to 69 kV/mm for the two-layer sample, bearing in mind that the polarity and ramp rate were different for the two cases.

Table 4. DC breakdown values for three layers of
75- μ m-thick Crocker cellulose paper
at 1 MPa (top electrode positive)

Position (degrees)	Temperature (K)	Breakdown Voltage (kV)	Comments
135	11.92	10.2	Cathode-adjacent butt gap.
	11.92	8.5	When voltage was reapplied.
0	12.00	12.1	No butt gap.
180	12.08	12.5	No butt gap.
90	12.08	10.9	Mid-layer butt gap.
	12.06	9.1	When voltage was reapplied.
270	11.98	10.5	Mid-layer butt gap.
225	11.94	17.8	Anode-adjacent butt gap.
	12.00	5.6	When voltage was reapplied.
315	12.06	9.35	Cathode-adjacent butt gap.
	12.06	7.10	When voltage was reapplied.
45	12.02	10.6	Anode-adjacent gap. Broke down while doing PD measurements.

Careful partial discharge measurements were conducted using three layers of 37- μ m-thick nylon (samples were used earlier for ac discharge measurements). These measurements were done in a small laboratory where the noise problems were less severe. The bushing, with the high voltage electrode raised, withstood 29.8 kV with only occasional discharge pulses (6-10/min). When the voltage was raised beyond this value huge discharges appeared, presumably due to "conditioning". The voltage was immediately lowered and the bushing vacuum was found to have deteriorated. With time, the vacuum improved and the bushing could withstand up to 24 kV discharge-free. The voltage was brought back to zero and the high voltage arm was connected to the 90° position (mid-layer butt gap 1-mm-in-diameter). At 7.41 kV discharges with a very low repetition rate (one in 40-45 sec) appeared. The voltage could, however, be raised to 21.5 kV without producing discharge pulses at a higher repetition rate. Similar results were

obtained at 135° (cathode-adjacent gap), 45° (anode-adjacent gap) and 0° (no butt gap). In all the cases from about 9 kV onwards bursts of discharges of about 100 pC appeared while raising or lowering the voltage. No such discharge bursts occurred when the sample was not connected, nor did they appear if the voltage was held constant. When the voltage was left at 25 kV (limited by bushing conditioning) for the mid-layer butt gap position, pulses of about 30 pC appeared at a repetition rate of about 4 sec.

It appears from the above measurements that partial discharges do not constitute a serious problem in the case of dc operation. Not only are their repetition rates low, but they appear only at very high stress levels (~100 kV/mm). Moreover, their magnitudes are low even at these high stress levels.

2. AC MEASUREMENTS

Partial discharge measurements continued with the demountable pressurized sample chamber shown in Figs. 1 and 2 of the previous quarterly report.¹ All work was carried out with a chamber top having eight 6.3-mm-diameter, flat-faced high voltage electrodes. The electrode edges were curved to a radius of 0.8 mm. No further alterations were made to the apparatus or procedure, other than use of the Rosemount capacitive pressure transducer with digital readout to measure pressures up to 1.7 MPa. Partial discharge inception was investigated as a function of temperature and pressure for samples of polyethylene, embossed polycarbonate, and polyamide films. As before, butt gaps were simulated by punching holes one or two millimeters in diameter in various layers. The effects of aluminized electrostatic shielding around the butt gap holes were also explored, in response to a suggestion by BNL.²

a) Polyethylene

The tests begun in the previous quarter with a three-layer sample of 102- μ m Valeron were completed. PD inception voltages vs temperature at various pressures are shown in Figs. 4-8. The extinction voltages were generally about 90-95% of the inception values at the highest pressure.

At the lowest pressure, the ratio was between 60-90% and decreased markedly as the temperature rose. Hence, pressurization enhances the extinguishing of the discharges. Butt gap holes 1 mm in diameter were punched in the top, middle, or bottom layer as indicated in the figures. The tick mark on each point indicates the angular location of the electrode at which the measurement was taken. Over the entire pressure range from 0.3 to 1.5 MPa, the locations with gaps adjacent to the top and bottom electrodes show slightly higher inception voltages than those with the middle-layer gaps. This behavior may result from the fact that the electrode surface establishes an equipotential on one side of the gap. Equipotentials can only curve into the gap from the opposite side, which might result in a smaller field enhancement in the electrode-adjacent gap than in the mid-dielectric gap. The locations with no holes show the lowest inception voltages of all. The spread between the highest and lowest values increases as the pressure increases, and is about 30% of the average value at all pressures. Averaged curves (neglecting the non-gap positions) of the inception voltages vs temperature are shown in Fig. 9. Little effect on the inception voltages was seen when the pressure was increased from 1.2 to 1.5 MPa. Otherwise, a clear temperature and pressure effect is evident. The curves are quite consistent with the previous data taken with round electrodes¹ for the higher pressures. However, the previous 0.35-MPa curve with round electrodes lies closer to the 0.6 MPa flat electrode curve than to the 0.3-MPa curve.

The PD magnitudes jumped discontinuously from the background level (usually about 0.5 pC) at inception. Generally, the inception magnitudes for the mid-layer gaps were a few pC, but the magnitudes with the electrode-adjacent gaps tended to grow spontaneously to several thousand pC. The locations with no gaps showed very erratic behavior. It was often difficult to determine a clear inception voltage, because the discharges were barely distinguishable from the noise, and their size and frequency tended to increase continuously above the background as the voltage was raised. At some voltage, the magnitude would often suddenly increase to above 10,000 pC and saturate the detector, just as for the electrode-adjacent gaps.

After the cryogenic experiments were completed, a few PD measurements were carried out with room temperature gases. Helium at room temperature behaved very erratically. The inception voltages tended to decrease with successive voltage applications and showed virtually no pressure effect. However, inception voltages with SF_6 had little scatter and increased strongly with pressure. In fact, under 1.4 MPa SF_6 pressure the 45° position (mid-dielectric gap) broke down completely at 15.5 kV. When the sample chamber was opened, no evidence of flashover across the films was found. The 45° position had a large puncture through all three films, and the center layer was darkened noticeably inside the electrode-adjacent gaps. Probably all of this damage occurred during the room temperature measurements.

b) Polyethylene with aluminized gaps

Another three-layer sample of 102- μm Valeron was assembled with six mid-dielectric butt gaps. Three were bare and three were aluminized on the top, bottom, and sides in order to suppress PD by enclosing the helium in a field-free conducting "pillbox", as shown in Fig. 10. Aluminum was also applied as shown to the outer films adjacent to the electrodes, to minimize effects of residual gaps at the electrodes. Inception voltages for this arrangement are shown in Figs. 11 and 12 for pressures of 0.6 MPa and 1.5 MPa. It is evident that the inception voltages for the three locations with the "pillbox" were much lower than the rest. In this case, the highest inception voltages were recorded for the 135° position, which had aluminizing between all dielectric-dielectric and dielectric-electrode interfaces, but no butt gap hole. The PD magnitudes for the bare butt gap holes were always on the order of 1000 pC, whereas for the other locations they were less than 3 pC. When the sample was opened, the only evidence of damage was a 1-cm-diameter brown discoloration on the top layer adjacent to the 45° and 90° high voltage electrodes which were bare gap positions. Nothing was seen at the 135° position, which was also a bare gap position showing high PD magnitudes.

c) Embossed Polycarbonate

A sample of embossed Makrofol polycarbonate was received from BNL early in the quarter. This material is of interest because the total

area of contact between adjacent layers should be smaller, resulting in decreased friction and greater cable flexibility. The basic material was measured to be 61 μm thick (the same as the flat material tested in the previous quarter). With embossing, the total thickness was about 100 μm . Butt gap holes 1 and 2 mm in diameter were cut in the top, center, or bottom layer as indicated by the key in Fig. 13, which shows PD inception voltages vs temperatures at three pressures. The inception voltages are slightly higher than those for the polyethylene sample shown in Fig. 9. The position or size of the hole seemed to have little effect on the inception voltages. However, the discharge behavior was much more unstable than with the previous flat samples. Intermittent discharges appeared as the voltage was raised. At the plotted inception voltage, continuous discharges appeared and usually grew quickly to several thousand picocoulombs. This is not surprising, in view of the multitude of gaps between layers. When the chamber was opened, extensive tracking across the surfaces of the films was observed.

d) Nylon

In order to see the effect of thinner materials on PD performance, same measurements were conducted on triple layers of 38- μm nylon. The experimental assembly and procedure were identical to those employed for polyethylene samples. Of the eight electrode positions, two were provided with high-voltage-electrode-adjacent butt gaps, two with ground-electrode-adjacent gaps and two with mid-dielectric gaps. There were no butt gaps at the remaining two positions. All butt gaps were 1-mm-diameter holes. Measurements were conducted at 0.3, 0.9 and 1.5 MPa.

The results of the measurements are shown in Fig. 14. The discharge behavior was, in general, similar to that of polyethylene samples. As in our earlier measurements, the discharge at the non-butt gap positions was consistently low in magnitude and the inception voltages at these positions were no better than those for the butt gap positions. The PD inception stress for the thin nylon samples was slightly higher than for the thicker polyethylene samples under identical conditions.

e) Discussion of PD inception measurement results

Extending the helium pressure from 1.2 MPa to 1.5 MPa produced only a marginal improvement in the PD inception levels (Fig. 9). For higher pressures, the fall of inception voltage levels off only at high temperatures, exhibiting the general shape of density vs temperature curves for helium.

Results with polyethylene with conducting butt gap (aluminized "pill-boxes") were not surprising. The lower PD inception voltages obtained with this arrangement can be explained in terms of the shorting of one layer of insulation by the conducting "pillbox". It was, however, interesting to note that with the conducting wall gaps, the magnitudes of the discharges were considerably lower (<1 pC).

PD inception levels with embossed polycarbonate were nearly the same as those for a non-embossed film of the same thickness. The major difference observed with embossing was the tendency of the discharge pulses to grow to large values (~ 1000 pC). This could be a direct consequence of the multitude of interconnected cavities that constitute an embossed film.

The results obtained with three layers of 38- μ m-thick nylon were similar in nature to those described for polyethylene in the last report.¹ However, for a given helium condition, the total stress across the insulation (marked E_I in Fig. 14) is slightly higher for the nylon sample.

3. AUXILIARY MEASUREMENTS

a) Resistivity of field plotting paper

A possibility for the resistive grading material for a high voltage cable termination would be a thin semiconducting layer. One candidate for this application might be the conducting paper used in analog field plotting. One test at low temperature (4.2 to 0.05 K) on Teledeltos paper manufactured in England has been reported.³

Low temperature resistivity tests were performed on P-24L field plotting paper furnished by Sunshine Scientific Instruments Company for use with their analog field plotter. Two 0.3-cm $\times$ 1.0-cm samples of the 0.008-cm-thick paper were cut from a sheet of P-24L field plotting paper.

Table 5. Resistance of Sunshine plotting paper vs temperature

Temp K	Sample #1 K Ω /sq	Sample #2 K Ω /sq
300	1.84	2.28
77	3.84	4.68
20	13.4	16.9
12	34.0	44.0
8	100	126
4.2	1350	1670

The first sample (#1) was cut with the grain of the paper and the second (#2) was cut across the grain of the paper. The two samples were mounted with N grease on thin cigarette paper that was glued to a copper block. The cigarette paper furnished electrical insulation, while the N grease facilitated thermal conduction. The copper block also contained a calibrated germanium thermometer. The block and a small heater were mounted in a vacuum chamber that could be immersed in a cryogenic bath. In addition to room temperature and liquid nitrogen temperature measurements, 22 resistance readings were taken between 4.2 K and 20 K. In all cases, the paper resistance readings came to equilibrium with the Ge thermometer readings in about 2 min, indicating excellent thermal equilibrium. The results are summarized in Table 5.

The room temperature value (300 K) agrees well with that of Teledeltos paper previously reported;³ however, the lower temperature values are much higher. It is also well known that the nominal resistance of these papers (i.e. 2 k Ω /sq) is 10-20% higher when measured across the grain of the paper, as our result shows.

The very large increase in resistance between 8 and 4 K might make this paper a poor candidate for a grading material at these temperatures, but on the other hand the paper could be useful as a low temperature thermometer in the range of 4.0 to 20 K.

b) Small gap helium breakdown

The onset of PD in multi-layer insulation with helium-filled butt gaps is the result of either partial or complete breakdown of helium inside the cavity. It is therefore important to relate the stress across the gap (E_g) during PD inception to the breakdown strength of helium under identical conditions. Since no information is available on the breakdown properties of supercritical helium at very small gaps ($\approx 100 \mu\text{m}$) we undertook to measure these properties in gaps ranging from 10-200 μm in a wide range of pressure and temperature. However, the initial experiments were unsuccessful due to dimensional instability of the gap and an improved apparatus is being designed.

D. VISITORS

The following visitors were received during the quarter:

April 8	J. Blevins, ERDA-ORO
	L. Radcliffe, ERDA-ORO
April 20	George Bakale, Case Western Reserve University
May 6	M. Pace, Health Physics Division-ORNL
	B. Boulton, Health Physics Division-ORNL
	J. Pih, Health Physics Division-ORNL
	R. James, Health Physics Division-ORNL
May 7	Tom Bement, LASL
June 7	M. Kosaki, Nagaya University, Japan
June 9-11	P. Chowdhuri, LASL
June 9-10	W. Anderson, NBS-Gaithersburg, Maryland
	D. Bosack, UCC-Linde, Tarryton, New York
	A. Clorfeine, ERDA-DEES
	S. Rigby, BNL
June 16	L. Radcliffe, ERDA-ORO
June 18	G. M. Sommerman, Consultant

E. FUTURE PLANS

During the final quarter of the program some experiments are planned to obtain missing information on PD phenomena in multilayer plastic insulation filled with supercritical helium.

One planned experiment is the measurement of the dielectric strength of supercritical helium over a range of densities around the expected operating point of a superconducting transmission line and range of gaps from 10-200 μm . The philosophy behind this experiment has already been outlined in Section 3B.

Some additional experiments are planned with polyethylene samples under very clean conditions, in order to assess the effect of cleanliness on earlier measurements. One discrepancy encountered during the PD measurements is that the PD inception voltages at electrode positions without butt gaps were no higher than those where butt gaps were present. These discharges could be the result of residual gaps between the electrode and the samples. In order to clarify this point, measurements will be made on samples held under compressive pressures similar to those encountered during cable winding (500-700 kPa).

A new arrangement incorporating a large-area top electrode ($\approx 20 \text{ cm}^2$) and a ground electrode with two isolated halves will be used to conduct PD measurements. A guard ring will be provided around the split electrode to isolate the possible edge discharges when the two halves of this electrode act as the balancing arms of the bridge. A butt gap will be provided in one half of the split-electrode arrangement. This is a tested technique at room temperature,⁴ and will provide additional qualification of previous PD measurements. Measurements of the dc dielectric strength of plastics will continue, using a larger specimen chamber and the IV-3 cryostat.

The experimental activities will be terminated by the end of August. The remaining time will be utilized to write a final report of the program and to prepare the experimental results for publication in appropriate journals. The shipment of various equipment to different laboratories will also be undertaken during the next quarter.

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2. Brookhaven National Laboratory Power Transmission Project, Report PTP #47, p. 45 (November 1975).
3. M. J. Lea and E. R. Dobbs, Cryogenics 13, 114 (1973).
4. J. C. Vos and J. Vermeer, International Conf. on Large Electric Systems, Paris (CIGRE) 1958, paper #207.

APPENDIX A
DISPOSITION OF EQUIPMENT

At the third bimonthly ERDA-DEES cryogenic dielectrics meeting the following disposition of ORNL equipment was agreed upon by the participants.

Los Alamos Scientific Laboratory

Hipotronics Pinhole Counter

Tektronics 7904 Scope with 7A18 and 7A10 preamps, 7B92 Dual Time Base, and C51R Scope Camera

American Magnetics Helium Level Meter KE101 and Automatic Helium Level Controller

Lakeshore Cryotronics Automatic LN Level Controller

Lakeshore Cryotronic Thermometer Model DT-500 calibrated for 4.2 K to 40 K with constant current source

CRYOFAB Liquid Helium Dewar, 13 in. ID, 304 stainless steel with 2 in. diameter quartz window for IV-3

Data Technology Model 20 Digital Voltmeter

McMaster Bench Lapping Table

Technology, Inc. Helium Flow Meter calibrated 0-10 SCFM

Universal Voltronics 250-KV, 600-J Impulse Generator

Veeco MS 17 AB Leak Detector

Welch 1397B Mechanical Vacuum Pump

American Optics Fiberoptic Peeper Scope

Cryostat IV-3 with stand

Brookhaven National Laboratory

American Magnetics Helium Level #100 with 2 Sensors

Wallace and Tiernan Pressure Gauges

0-100 psig; 0.1-psi graduations

0-200 psig; 0.2-psi graduations

Ceramaseal HV Bushing - 100 kV

Data Technology Model 1301-04 ac Digital Volt Meter

Hewlett Packard HP-65 Calculator

Varian 10" LN Cooled Diffusion Pump Baffle

Veeco MS 17 AB Leak Detector

National Bureau of Standards, Gaithersburg

J. G. Biddle Balanced Partial Discharge Detector Rack Mounted
American Magnetics Cryogenic Thermometer #210

Lakeshore Cryotronics Thermometer Model DT-500 calibrated for
4.2 K to 40 K with constant current source

High Energy, Inc. 120-pF, 60-kV Corona Free Capacitor

Rosemount Pressure Transducer 0-250 psia, linear output 0-5V

PAR 122 Lock-in Amplifier

Raytheon Infrared Snooper scope

Cryostat IV-1 with stand

Cryostat IV-2 with stand

Union Carbide Corporation, Tarrytown

Lakeshore Cryotronics Automatic LN Level Controller

Cole Palmer Precision Magnifier, 60X

Rogowski Electrodes and HV cryostat parts

Store or Scrap

Hipotronics 700-kV Series Resonant Transformer

LIST OF FIGURES

1. Pressurized test cell for IV-3 vacuum bushing. 1) High voltage stainless steel electrode, 2) retaining ring, 3) brass insert, 4) G-10 disk, 5) 2850 FT blue epoxy, 6) two layer specimen, 7) aluminum ground plane, 8) spring, 9) indium O-ring seal, 10) aluminum support plate, 11) carbon thermometer well, 12) electrical lead-through connection, 13) slotted center support screw, 14) O-ring seal, 15) pressurized He inlet fitting, and 16) helium gas inlet.
2. DC breakdown-experimental setup.
3. Flashover on dc sample.
4. PDIV vs T - $3 \times 102 \mu\text{m}$ Valeron polyethylene, 0.304 MPa.
5. PDIV vs T - $3 \times 102 \mu\text{m}$ Valeron polyethylene, 0.608 MPa.
6. PDIV vs T - $3 \times 102 \mu\text{m}$ Valeron polyethylene, 0.912 MPa.
7. PDIV vs T - $3 \times 102 \mu\text{m}$ Valeron polyethylene, 1.216 MPa.
8. PDIV vs T - $3 \times 102 \mu\text{m}$ Valeron polyethylene, 1.520 MPa.
9. Average PDIV vs T for Figs 4-8.
10. Aluminized butt gap hole.
11. PDIV vs T - $3 \times 102 \mu\text{m}$ Valeron polyethylene with aluminized mid-dielectric gaps, 0.608 MPa.
12. Same as Fig. 11, with pressure of 1.520 MPa.
13. PDIV vs T - $3 \times 100 \mu\text{m}$ embossed polycarbonate. Key: 1 M, 1 B, 1 T - 1 mm diameter mid, bottom, and top gaps. 2M, 2 B, 2 T - 2 mm diameter mid, bottom, and top gaps. N - no gaps.
14. PDIV vs T - $3 \times 38 \mu\text{m}$ Rilsan Nylon 11.

Fig. 1.

Fig. 2.

PHOTO 5079-76

Fig. 3.

ORNL-DWG 76-10248

Fig. 4.

Fig. 5.

Fig. 6.

Fig. 7.

Fig. 9.

ORNL-DWG 76-15230

ALUMINIZING

Fig. 10.

SAMPLE: THREE LAYERS OF 100- μ m-THICK VAN LEER

VALERON POLYETHYLENE

FLAT ELECTRODES

0° NO BUTT GAP

45°, 90°, 135° MID-DIELECTRIC BUTT GAP

180°, 225°, 270° ALUMINIZED HOLES COVERED ON TOP
AND BOTTOM BY ALUMINIZED FILM

315° FILMS ALUMINIZED ON BOTH SIDES WITH NO BUTT GAPS

PRESSURE = 0.608 MPa

Fig. 12.

Fig. 13.

Fig. 14.

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