**Cryogenic Power Transmission Technology
Cryogenic Dielectrics**

MASTER

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

Twelfth Quarterly Report
October 1, 1975 - December 31, 1975

Cryoelectrics Section
Engineering Sciences Group
Thermonuclear Division

APRIL 1976

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ABSTRACT

The twelfth quarterly progress report of the ORNL Cryogenic Power Transmission Technology Program covers the period from October 1, 1975 to December 31, 1975. During this period, breakdown measurements with ac, dc, and impulse voltages were taken on several polymer film samples immersed in boiling liquid helium. The observed impulse strengths were found to be a factor of two to a factor of three higher than previously-measured ac strengths.

Progress was made on experimental equipment, including reassembly and successful testing of Transformer B of the 700 kVac test system, repair of the Intermediate Voltage Cryostat IV2, and final testing of the 250 kV impulse generator. Voltage and pressure instrumentation underwent improvements, and a new pressurized test fixture for polymer film samples was constructed.

The collaborative programs with cryogenic power transmission projects at Los Alamos Scientific Laboratory and Brookhaven National Laboratory were solidified. Group members also attended various technical meetings.

Residual resistivity ratio (RRR) and microhardness measurements were completed on various dispersion-hardened aluminum-gold alloys. Microstructure studies on a 0.12 wt % gold alloy indicated the formation of precipitates, presumably Al_2Au , during thermal aging of the solution-heat-treated and quenched sample.

I. CRYOGENIC DIELECTRICS

A. Introduction: Aims and Goals

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, as well as 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. Flashover voltages will also be measured on solid insulators and wrapped tape stress cones immersed in cryogenic liquids. Attempts will be made to learn the effect of mechanical stresses, resulting from field installation and cooldown, on the electrical performance of the insulation. Partial discharge (electrical arcing in small flaws in the insulation, causing long-term deterioration, but not leading immediately to complete electrical breakdown) will be monitored as a function of the thermodynamic conditions and previous electrical and thermal history. All of these experiments will be carried out under the full ranges of temperature and pressure of interest for practical SPTL designs, that is, from about 4.2-10K and 0.1-1.2 MPa.

B. Activity During Quarter

1. Experimental Equipment

a) High-Voltage Cryostat

The copper radiation shield on the high-voltage cryostat was wrapped with six double layers of super-insulation. The large outer vacuum tank was fitted over the copper shield and both the bushing space and vacuum space were evaluated to about 100 μPa (1×10^{-6} torr) at room temperature. The rate of pressure rise was checked over a four-day period and was found to be 34 Pa/hr.

A cool-down of the copper radiation shield with liquid nitrogen was attempted. No leaks were discovered, but the cool-down rate was much too slow, apparently because of poor thermal contact between the nitrogen reservoir and the copper shield. The vacuum tank and thermal insulation were removed so that the copper shield could be modified mechanically for better thermal contact with the nitrogen reservoir. The modification was completed, and the vacuum section of the cryostat is ready for reassembly.

The 0.9-m-diameter flat fiberglass head intended for closure of the vacuum bushing could not be sealed satisfactorily. The head seal is being reworked to allow easier assembly.

Design studies are complete on the 1.0-m-diameter conical fiberglass head for high pressure operation. Fig. 1 shows the calculated displacement of the head (accentuated by a factor of 34) at 1.1 MPa (160 psi), when it is constructed of a material with a modulus of elasticity of 13.8 GPa (2.0×10^6 psi). Fig. 2 shows the calculated hoop

stress distribution. The dotted lines show surfaces of zero hoop stress. The increment between surfaces of constant stress is 1.7 MPa. Compressive and shear stresses were also calculated; their values were well within quoted specifications for G-10 fiberglass, allowing a substantial safety margin.

b) Intermediate Voltage Cryostats:

The second 15 cm-diameter cryostat IV2 was fitted with a new G-10 epoxy-fiberglass disc at the cold end of the vacuum bushing, after attempts to use a Mycalex insulator failed. The bushing was evacuated and determined to be leak-tight.

The external refrigeration coil for the 30-cm-diameter cryostat IV3 (see Fig. 3 of the report for the previous quarter, ORNL/TM-5250) was completed and tested for helium leaks. No further progress was achieved on the vacuum bushing of IV3, due to a lack of personnel. A second technician, Mr. E. C. Moore, was hired at the end of the quarter. He is now working on putting IV3 into full operation.

A new pressurized test fixture for polymer film samples was fabricated for use with the intermediate voltage cryostats. Fig. 3 shows a cross section of the device. The film samples F are held between a low voltage plate electrode G made of stainless steel and a thick Stycast epoxy disc D. Disc D contains eight stainless steel high voltage electrodes E, each of which may be individually selected. It also has a grounded insert M which accepts the cap screw C. This cap screw supports disc D at the center and prevents bulging under pressure. The pressure vessel is completed by the lower housing A. The retaining ring B pulls epoxy disc D down onto a lead or Indium O-ring O, and seals D to housing A.

Helium from pressure line L is injected through fitting P and is led by a slot in cap screw A into the region between the polymer film layers. P also contains a bronze wool filter to keep particles out of the pressure chamber. A spring S pushes the ground electrode G and the polymer film layers F tightly against epoxy disc D. Figs. 4 and 5 are photographs of the major parts.

The test fixture has been pressurized in liquid nitrogen to 1.2 MPa (170 psi). A few leaks were encountered at seal O, but these were repaired. Experiments on polymer film samples at high pressures will begin early in the next quarter.

c) Power Supplies:

The moisture in the windings of the recently-repaired 350 kV transformer B has been further reduced by heating the transformer winding and by continuously purifying the oil with a molecular sieve filter. After using this equipment for six weeks, the power factor fell from 4.1% to 2.3%, and the primary winding resistance-to-ground increased from 250 M Ω to 1800 M Ω . The moisture content of the transformer oil after six weeks of molecular sieve filtering was 9 ppm.

Although the above results were not quite as good as those on the nearly similar transformer A, they were deemed satisfactory, and preparations were made to test run transformer B at gradually increasing voltage steps.

With no load, the Q of transformer B was about 10.5. No partial discharge (PD) was observed up to 265 kV; at that level the transformer tripped off. It was possible to raise the voltage again, and faint PD was noted at about 220 kV. The source of the PD is not certain at

this time. Further drying of the insulation may be necessary. The PD may also be external to the windings.

Transformer A and transformer B were also connected in series and were operated satisfactorily, with slight partial discharge showing up at about 375 kV.

The 250 kV impulse generator (Fig. 6) which was received from the Universal Voltronics Corporation in the previous quarter was put into good working order. Mr. Stuart Thorn, a factory engineer, visited the laboratory to investigate the trigatron firing circuit. He installed an improved power supply for this circuit, and no further problems have been encountered. The generator was put to considerable use in breakdown experiments on polymer films, as reported in Section C.

d) Instrumentation:

Measuring and recording of ac voltages has been improved, by applying the signal from the capacitive voltage divider to a Burr-Brown rms-to-dc convertor module. The dc output from this module is fed to a dc strip chart recorder, allowing a resolution of 0.02 kV for voltages up to 10 kV.

A pressure system has been constructed for use in experiments at elevated helium pressure. The system incorporates a high-precision Bellofram pressure regulator, and a 0-0.7 MPa Wallace and Tiernan pressure gauge with an accuracy of 0.7×10^{-3} MPa. Another Wallace and Tiernan gauge for pressures to 1.4 MPa and a Rosemount capacitive pressure transducer for measurements to 1.7 MPa have also been purchased. A 0-10 SCFM helium flowmeter for precise boiloff rate measurements was received from Technology Incorporated.

Several months ago an impulse memory voltmeter was ordered from Ross Engineering Corporation. Although promised for delivery early in November, this instrument has still not been received, due to problems with the memory feature on production models. It is now promised for shipping in January, 1976.

2. Collaboration with Other Laboratories, Meetings and Visits

The current major project objective is to obtain ac and dc dielectric strength measurements and PD data on polymeric insulating films in cold pressurized helium. These data are for use in the ac SPTL project at Brookhaven National Laboratory (BNL), and in the dc SPTL project at Los Alamos Scientific Laboratory (LASL). On November 12, 1975, H. M. Long, M. M. Menon, and S. W. Schwenterly visited ERDA-DEES, for a review of the ORNL Cryogenic Dielectrics Program. At this meeting, further discussions took place on collaborative work with BNL representatives A. McNerney and S. Rigby. Telephone and mail contacts have also been maintained with P. Chowdhuri at LASL.

All of these proceedings were combined into a memorandum (Appendix A) which describes the current status of the test programs for BNL and LASL.

At the November 12 meeting, A. Clorfeine expressed a desire for more frequent personal contact between staff members at the various laboratories engaged in ERDA-supported SPTL work. He proposed that a bimonthly schedule of meetings be set up for review and discussion of cryogenic dielectric research at the various laboratories. The first of these meetings has been set for January 23, 1976, in Oak Ridge. Representatives

from BNL, LASL, UCC-Linde, NBS and Stanford University have been invited. The ORNL polymer film test program as outlined in Appendix A will be the working document for discussion at this meeting.

In other meetings and visits, Menon attended a program review of the LASL dc SPTL project on October 7, 1975. Schwenterly and Menon visited the Massachusetts Institute of Technology on October 23, 1975 for an information meeting on the liquid-nitrogen-cooled vacuum cryocable under development at the Bitter Magnet Laboratory. On November 3-6, 1975, Schwenterly and Menon attended the 1975 Conference on Electrical Insulation and Dielectric Phenomena, where Menon presented a paper on ORNL measurements of ac breakdown and partial discharge in polymer films. An abstract of this paper is given in Appendix B. On December 3, 1975, Schwenterly visited the UCC-Linde Tarrytown Technical Center for discussions on recent problems with anomalously low spacer flashover voltages in the liquid-helium-insulated ac SPTL under development by Linde.

C. Experimental Work

1. ac Measurements

It was reported earlier that in the ac dielectric strength measurements on thick polymeric films ($> 75 \mu\text{m}$) the problem of surface flashover preceding bulk breakdown was encountered. To minimize this effect, it was decided to try a new electrode arrangement, wherein the size of the epoxy encapsulation was increased substantially. A spherical stainless steel electrode, 9.5 mm in diameter, was fixed to one end of a brass wire and the other end of the arm was connected to the central high voltage lead. The electrode and the wire were encapsulated with epoxy, the epoxy encapsulation forming a disc of 11.5 cm in diameter (Fig. 7). The disc so produced was carefully lapped, exposing a tiny area of the spherical electrode. Since, as in the previous arrangement, the high voltage lead could be lifted and rotated from outside, the electrode could be positioned at any point along the circumference of a 46-mm-diameter circle. A flexible bellows placed as shown in Fig. 7 allowed the epoxy disc to align itself with the ground electrode. A 125- μm -thick Hercules polypropylene film was used as the sample. The Biddle partial discharge detector was employed to monitor the discharge activity.

The result using the above arrangement was far from what was expected. While the first partial discharge inception voltage was measured to be 9.2 kV, all subsequent measurements gave much lower, erratic values. It was soon obvious that bubbles resulting from the first voltage application had become trapped between the large epoxy disc and the specimen, and that these bubbles were responsible for the erratic nature of the

results. When the epoxy disc was lifted, numerous trapped bubbles could be observed on its bottom surface. Attempts to obtain breakdown using the above arrangement were also not successful, as partial discharges precipitated surface flashover at relatively low voltages (7 - 10 kV).

During this quarter, we obtained two more samples from BNL: Hercules EK500 and EK503 polypropylene. Both were thin films (25 μm); hence we decided to test them using our old arrangement. The Biddle detector was employed for the partial discharge measurements. The results are shown in Table I. Both films showed a wide variation in dielectric strength at different positions. We suspect that this is mainly due to the fact that the films were badly wrinkled when we received them. However, NBS has reported large shallow craters on the surface of these films¹. Such craters might also be contributing to the large variation in breakdown strength that was observed.

2. Impulse Measurements

Impulse dielectric strength measurements were carried out on a variety of films during this quarter. The experimental arrangement used was the same as for ac measurements. Single films, immersed in slowly boiling liquid helium, were impulsed with standard lightning waves (1.2/50 μsec) at progressively higher levels, until the breakdown occurred. Ten shots were applied at each voltage before the level of lightning wave impulse was raised; the increments between steps were of approximately 2 kV. Since the impulse generator was rated 250 kV (10 stages, 25 kV each), it was necessary to disconnect some stages

Table I. ac measurements on polymer films

SAMPLE	POSITION (DEGREES)	PDIV (kV)	PDEV (kV)	DISCHARGE MAGNITUDE (pC)	V _B (kV)	E _B (kV/mm)
Hercules Polypropylene EK-500 (38 μ m thick)	0	1.09	0.9	22 Approx.	4.1	187
	60	1.18	0.9	22 "	4.2	
	120	1.35	1.08	55 "	5.0	
	180	1.15	1.00	25 "	5.2	
	240	1.26	1.05	30 "	3.9	
	300	1.35	1.05	30 "	6.1	
Hercules Polypropylene EK-503 (38 μ m thick)	0	1.43	1.03	70 "	~4.4*	198
	60	1.27	1.03	35 "	5.2	
	120	1.23	1.00	50 "	~5.1*	
	180	1.15	1.02	40 "	4.8	
	240	1.25	1.03	25 "	5.1	

* Very high partial discharge activity caused the recorder needle measuring the voltage to flutter.

for better control of the output level. The breakdown could be observed on the oscilloscope display, as well as from the bright flash and sound inside the dewar. However, the only way to distinguish a bulk breakdown from a surface flashover, without taking the sample out, was by reapplying the impulse at the suspected site. In the case of breakdown, reapplication of the voltage, even at reduced levels, resulted in a considerably distorted and relatively flat output on the oscilloscope. On the other hand, a site where a flashover had occurred could withstand relatively large impulse voltages without distorting the waveform. Of course, once the film is taken out of the cryostat, tracking characteristic of surface flashover can be observed in the latter case (see Fig. 8).

Results of dielectric strength measurements using the standard lightning waveform are shown in Table II. With one film (Van Leer Valeron polyethylene), impulse dielectric strengths were measured under positive and negative polarity. No significant polarity effect was observed. In general, it can be said that the impulse dielectric strength is significantly higher than the ac dielectric strength. For a 25 μm Cryovac 929D polyethylene film, the ratio of the peak impulse to rms ac dielectric strength was as high as three. For thicker films, the ratio was lower, but this could very well be due to measurement problems (see comments in Table II). With certain films, particularly the 100- μm -thick Rowland polysulfone application of the impulse voltage resulted in ripping of the film. This may be due to some physical peculiarity of the film at low temperature.

3. dc Measurements

During this quarter, the dc dielectric strength of a 38- μm -thick

TABLE II.

SAMPLE	POSITION (DEGREES)	$\hat{V}_B$ (kV)	MEAN $\hat{E}_B$	COMMENTS
Van Leer Valeron Polyethylene (4 mil or 101.6 μm thick)	0 180 60 120 240 300	- 30 - 28 - 30 + 30 + 28 + 26	7.16 kV/mil or 282 kV/mm	Although breakdown punctures occurred at some positions, flashover paths could be seen over the surface of the film. The film was ripped at the 240° position.
Makrofol KG Poly- carbonate (3 mil or 76 μm)	0 180 60 120 240 300	+ 23.7 + 22.0 + 18.0 + 22.0 + 20.0 + 20.0	6.67 kV/mil or 262 kV/mm	All electrode positions were interconnected by trackings. Puncture could be observed only at 60° and 120° positions, although small burned holes could be observed along the trackings
Rowland Polysulfone (4 mil or 101.6 μm)	---	+ 17.5 to - 27	----	The film was badly ripped open on two separate attempts.
Cryovac 929D Polyethylene (1 mil or 25.4 μm)	0 180 270 90	+ 18 + 19 + 17 + 16	17.5 kV/mil or 539 kV/mm	All clean breakdowns.
Cryovac D-330DW (1.5 mil or 38 μm)	C 90 180 270	+ 21.2 + 20.0 + 20.0 + 17.5	13.12 kV/mil or 516 kV/mm	Flashover paths could be seen, although the film was punctured at all four electrode positions. At 0° and at 90° flashover occurred at 21.6 and 20.6 kV respectively.
Cryovac D-330 SW (1.5 mil or 38 μm)	0 90 180 270	+ 16.8 + 16.5 + 18.8 + 18.8	11.82 kV/mil or 465 kV/mm	Some evidence of partial discharge spread, but no major trackings. The film was punctured at all four positions.

Cryovac D-330 SW polyethylene film was measured. This was done primarily to assess the behavior of the film under dc fields, in view of the needs of the LASL cable program. The results of this investigation were very encouraging. Breakdown occurred without any visible partial discharges. The dc dielectric strength (see Table III) was much higher than the ac and of about the same magnitude as the peak impulse. The average dc dielectric strength was 529 kV/mm, while the ac (rms) and impulse strengths were 220 kV/mm and 465 kV/mm, respectively. Whether the same behavior will be exhibited by a thicker film or by a stack of films has yet to be seen. A systematic set of dc measurements is scheduled to start in the immediate future.

Table III. dc Breakdown Strength Measurements

SAMPLE	POSITION (DEGREES)	BREAKDOWN VOLTAGE (kV)	AVERAGE BREAKDOWN FIELD (kV/mm)
Cryovac D-330 SW polyethylene, 38 μ m thick	0	17.3	529
	90	18.2	
	180	22.6	
	240	20.0	
	300	22.7	

D. Visitors

The following visitors were received during the quarter:

October 2: S. Thorn, Universal Voltronics Corp.
 November 5: K. D. Srivastava, University of Waterloo, Canada
 November 7: G. L. Sommerman, Consultant.
 December 3: L. G. Christophorou, ORNL Health Physics Division
 J. G. Carter, ORNL Health Physics Division

E. Personnel

Personnel associated with the Cryogenic Dielectrics project during the quarter were:

Dr. H. M. Long, Program Manager
 Dr. S. W. Schwenterly, Assistant Program Manager
 Dr. M. M. Menon, Electrical Engineer
 Mr. R. H. Kernohan, Physicist
 Mr. W. J. Schill, Senior Research Technologist
 Mr. E. C. Moore, Senior Research Technologist
 Mr. G. F. Leichsenring, Mechanical Engineer
 Mr. T. Shannon, Mechanical Engineer
 Dr. W. F. Gauster, Consultant
 Dr. G. L. Sommerman, Consultant

Moore joined the group at the end of the quarter. Shannon will take over Leichsenring's duties as Lead Mechanical Engineer.

F. Future Plans

During the next quarter the test programs for BNL and LASL on polymer films in cold pressurized helium will be initiated. Partial discharge and breakdown studies with ac voltage under varying conditions of pressure, temperature, and butt gap characteristics will be carried out on multi-layer samples of the BNL films, using the pressurized test fixture described in Section B.1. Breakdown tests with dc voltage will be carried out in parallel. To speed up the work, the pressurized test fixture will be duplicated as soon as operating experience shows the design to be satisfactory or shows needed modifications. Further impulse breakdown tests will also be carried out on the films in pressurized helium.

Initial planning and preliminary experimentation on stress cone and joint flashover studies will begin. The larger intermediate voltage cryostat IV3 will be particularly useful for these studies, and this cryostat will be put into operation as quickly as possible. Final assembly of the high voltage cryostat will proceed as permitted by time and project budget limitations.

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APPENDIX A
COLLABORATIONS WITH BNL AND LASL SPTL PROGRAMS

INTRODUCTION

Discussions with personnel in the BNL and LASL SPTL programs have continued with regard to the future direction of collaborations on problems in cryogenic dielectrics. This memo summarizes the current status of these plans.

A. Collaborations with BNL SPTL Project.

During the review meeting at ERDA-DEES on November 12, we discussed further collaborations with A. McNerney and S. Rigby of BNL. The original plan included three phases. In the first phase, 60 Hz and impulse breakdown tests were to be made on materials in single layers as received from the manufacturers. Crude partial discharge (PD) tests were to be carried out in this phase. Measurements at pressures up to 0.3 MPa (3 atm) were to be carried out if possible. The next phase involved similar tests on materials which had been modified to improve deficient properties. In the final phase, the most promising materials were to be tested in multiple-layer samples having artificial butt gaps (holes or slots) either next to the electrodes or in the inside layers. Sensitive PD measurements would be made and the pressure and temperature capability would be extended to approximately 1 MPa and 10 K. A list of the materials currently under investigation is given in Table A-I.

Our latest discussions concerned a more detailed layout of Phase III. Topics suggested for investigation are listed below.

1. Breakdown and flashover of tapes in fields with both radial and axial components (for terminations).

TABLE A-I.

Materials for BNL Dielectric Test Program

<u>Phase I</u>				
	Vendor	Polymer	Trade Name	Thickness (μ)
1.	Bayer	Polycarbonate	Makrofol KG	61
2.	Van Leer	Polyethylene	Valeron	99
3.	Cryovac	Polyethylene	929D	25
4.	Hercules	Polypropylene	N-400-42	127
5.	Rowland	Polysulfone	--	94
6.	Dupont	Polyimide	Kapton 200H	51
7.	Dupont	Polyester	Mylar 300 WC	76
8.	Rylsan	Polyamide	Nylon 12B	104
9.	Rylsan	Polyamide	Nylon 11	37
10.	Rylsan	Polyamide	Nylon 11	48
11.	Rylsan	Polyamide	Nylon 11	71
12.	Rylsan	Polyamide	Nylon 11	142

<u>Phase II</u>				
	Vendor	Polymer	Trade Name	Thickness (μ)
1.	Cryovac	Polyolefin	D-330-OW	38
2.	Cryovac	Polyolefin	D-330-SW	38
3.	Cryovac	Polyolefin	BB-Dykes-Silica	51
4.	Cryovac	Polyolefin	BB-Dykes-Silica-DW	111
5.	Schweitzer	Polyether Sulfone		30
6.	Schweitzer	Polyether Sulfone (oriented)		10

2. Effects of tape imperfections (damaged edges or surfaces, solid conducting or dielectric particles, etc.) on partial discharge in the insulation.
3. Change of discharge spectrum with time to determine whether conditioning effects occur.
4. Insulation lifetime investigations.
5. Effects of semiconducting screens on PD inception.
6. All measurements in supercritical helium at high pressure.

A new pressurized sample holder (see Fig. 3) has been designed for pressures up to 1.4 MPa, and is undergoing final pressure tests. This holder will allow all of the above investigations to be made, hopefully without the PD problems encountered earlier in boiling liquid helium. Measurements at elevated temperatures will be made by suspending the sample holder in the vapor above a pool of liquid helium and energizing an attached heater. The maximum temperature will be determined by flashover across the epoxy casting holding the high voltage electrodes, which is immersed in helium at only 0.1 MPa. Temperatures of 10 K should be reached without difficulty. The impulse breakdown measurements now being carried out in boiling helium will also be transferred to this apparatus or to a duplicate which will be constructed as soon as the design is optimized. The PD spectrum measurements will require a multi-channel analyzer. Efforts are being made to borrow suitable equipment.

B. Collaborations with the LASL SPTL Project

A program of dc tests on polymer films has been developed in consultation with Dr. P. Chowdhuri of the LASL SPTL Project. The effects

of polarity, rate of voltage rise, and thermodynamic conditions are to be tested on a selection of 9 materials (see Table A-2.). All samples will be 75 μm to 125 μm in thickness.

The test program contains three phases (section C). In Phase I, three materials (cellulose paper, Makrofol, and Mylar) will be tested at 12 K and 1 MPa to ascertain the effects of voltage ramp rate and polarity. In Phase II, all 9 materials will be tested at 12 K and 1 MPa. One or both polarities and ramp rates will be used as determined by the results of Phase I. A randomizing procedure for the tests has been suggested by LASL statisticians. Finally, in Phase III, the three best materials will be selected and subjected to tests at both supercritical helium temperature and room temperature. A step-stress test to ascertain insulation lifetime is also being considered. Further details are given in the attached summary of the LASL Test Plan. These tests will also be carried out in the pressurized sample holder described previously.

TABLE A-II.

Materials for LASL Dielectric Test Program

1. Cellulose Paper (Crocker)
2. Polyethylene (Cryovac)
3. Polyethylene (Valeron)
4. Kapton (Dupont)
5. Mylar (Dupont)
6. Polycarbonate (Bayer Makrofol)
7. Nomex
8. Teflon
9. Polysulfone (Udel)

C. LASL Dielectrics Test Plan

Introduction

Data on breakdown strength of dielectric materials under dc stress are meager. Although data on breakdown strength under ac stress are available, such data cannot be applied to the dc case; this is primarily because of the difference in the stress distribution and breakdown mechanism under the two types of voltage applications. It was felt that ORNL will be the most suitable place to collect such basic data on dielectric materials under dc stress. The eight-sample cryostat at ORNL will be particularly useful in taking data expediently.

The ORNL data taken with sphere-plane electrodes at relatively low voltage (i.e. highest attainable voltage with ORNL set up) will be used to assess the relative standing of the various dielectric materials with respect to dielectric strength and life of the dielectric materials. The ORNL data will be analyzed to select three preferred dielectric materials. These three candidate materials will be extensively tested at LASL with cylindrical electrodes (to represent the cable) at realistic applied voltage levels.

It is well known that dielectric breakdown is a statistical phenomenon. Therefore, under certain circumstances, large scatter in breakdown level may be expected. Because of this, it may be difficult to distinguish between the breakdown levels caused by controlled variation of parameters and uncontrolled outside incipient effects unless the experiments are properly designed and executed. To avoid such errors,

the ORNL test plan was designed with the help of the Statistical Group at LASL.

Objective

The objective of the ORNL test plan is to determine:

- a) the relative standing in breakdown voltage levels of the various dielectric materials under the stated parameters,
- b) the effects of the various parameters on the breakdown voltage level,
- c) the interaction amongst the various parameters on the breakdown voltage level,
- d) the existence of any extraneous effect.

Test Conditions at ORNL

The following are the test conditions under which the various dielectric materials will be tested.

I. Types of Voltage Stress

- 1) DC breakdown at two rates at both polarities
 - a) 1 kV/sec.; b) 5 kV/sec.

2) Step-Stress Test

II. Temperatures

- 1) Room temperature (300 K) in air at 1 atm
- 2) Supercritical helium temperature (12 K at 10 atm)

III. Dielectric Materials

- 1) Cellulose paper
- 2) Cryovac
- 3) Kapton

- 4) Makrofol
- 5) Mylar
- 6) Nomex
- 7) Teflon
- 8) Udel
- 9) Valeron

Design of Experiments

The dc breakdown tests will be performed first.

Originally, a complete factorial design of experiments on 12 dielectric materials was proposed. ORNL estimated that at least 200 working days will be required to perform the tests. As a result, the program was revised to shorten the duration without sacrificing the essentials of the objectives. This included the reduction of dielectric materials from 12 to 9.

The program will be run in three phases. Phase I will determine the significance of rate of voltage rise and of polarity on the dc breakdown levels of three selected dielectric materials. Phase II will compare the dc breakdown levels of all nine dielectric materials. Phase III will determine the significance of temperature on the dc breakdown levels of the best three dielectric materials.

Phase I

Three dielectric materials (cellulose paper, Makrofol and Mylar) were selected, and are to be tested at supercritical helium temperature (12 K at 10 atm), two rates of voltage rise (1 kV/sec and 5 kV/sec) and two polarities. With two replications, this will require 24 set-ups.

The order of test conditions was determined at random.

The test results will be analyzed to determine if rate of voltage rise and/or polarity has any significant effect on dc breakdown voltage level.

Phase II

All nine dielectric materials will be tested at supercritical helium temperature in Phase II. If analysis of Phase I data shows that neither polarity nor rate of voltage rise has any significant effect on breakdown level, then Phase II tests will be carried out at one rate of voltage rise and one polarity. With a second replication, 18 set-ups will be required under these conditions.

If analysis of Phase I data shows that either polarity or rate of voltage rise or both have significant effects on the breakdown level, then the nine dielectric materials shall be tested with two polarities or two rates of voltage rise or both. Instead of a complete second replication, nine randomly-selected set-ups will be repeated. Therefore, for the worst condition, 45 set-ups will be required for Phase II.

Actual design of experiments will be provided after the Phase I data are analyzed.

The Phase II data will be analyzed to select three dielectric materials having the three highest breakdown voltages.

Phase III

The three selected dielectric materials will be tested at two temperatures - room temperature in air at 1 atm and supercritical helium temperature (12 K at 10 atm). If Phase I tests show that rate of voltage

rise and/or polarity has significant effects on breakdown voltage, then tests shall be performed under two rates of voltage rise and/or two polarities. Including a complete second replication, Phase III will require 48 set-ups under the worst conditions.

Actual design of experiments will be provided after the Phase II data are analyzed.

A comprehensive procedure for the step-stress test will be developed after the dc breakdown tests are completed and the data analyzed.

Analysis

The data obtained at ORNL will be analyzed at LASL with the help of the Statistical Group at LASL. The following questions will be endeavored to be answered if the experiments are conducted in the above manner.

- a) Is the breakdown level significantly different for different dielectrics?
- b) Is breakdown level affected by temperature?
- c) Is breakdown level affected by rate of rise?
- d) Is breakdown level affected by polarity?

It is important to note that all questions apply to specific temperatures, rates and dielectrics involved in the study.

APPENDIX B

DIELECTRIC STRENGTH OF LIQUID HELIUM

IMPREGNATED PLASTIC FILMS*

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ABSTRACT

Dielectric strength measurements were carried out on polyethylene, polycarbonate, polysulfone and nylon films, impregnated by liquid helium at atmospheric pressure, in order to arrive at an appropriate insulation material for flexible superconducting power transmission cables. Sphere-plane geometry was employed for the electrodes. The measurements were complicated by the fact that partial discharge developed at the liquid helium interface between the spherical electrode and the plastic. Epoxy encapsulation around the spherical electrode minimized this problem. The rms value of the breakdown strength for various materials varied in the range of 120 to 230 MV m⁻¹. In all cases partial discharge in the liquid impregnant occurred below 50% of the breakdown level. In order to assess the influence of liquid helium impregnant, measurements were also carried out wherein the dielectric strength of a polyethylene film was obtained at 4.2 K, following McKeown's technique, without permitting liquid helium to enter the highly stressed interelectrode region. In this case breakdown of the plastic film occurred without precursory partial discharges but the breakdown field was not significantly altered. The variation of dielectric strength with temperature will be presented.

* Research sponsored by the U.S. Energy Research and Development Administration under contract with Union Carbide Corporation.

Progress with experiments involving multi-layered samples with and without butt gaps in pressurized liquid helium will also be discussed.

REFERENCES

1. Progress Report on Polymer Film Investigations, Polymers Division, National Bureau of Standards, Gaithersburg, Maryland, January 15, 1976.

LIST OF FIGURES

1. 1-m-diameter conical head - deflections with pressure of 1.1 MPa applied to concave side. Displacements are accentuated by a factor of 34.
2. 1-m-diameter conical head - hoop stress distributions under same conditions as in Fig. 1.
3. Pressurized film test fixture. See text for explanation of labels.
4. Pressurized film test fixture. A: Stycast disc with high voltage electrodes and retaining ring; B: spring-loaded ground electrode assembly; C: polymer film sample.
5. Top side of pressurized film test fixture, showing high voltage electrodes.
6. 250 kV impulse generator (Universal Voltronics Corp.)
7. Modified encapsulated electrode.
8. 76- μ m Makrofol KG polycarbonate sample, showing tracking under application of 20 - 24 kV positive lightning impulses.

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Figure 1.

Figure 2.

Figure 3.

Figure 4.

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Figure 5.

PHOTO 4179-76

Figure 6.

ORNL DWG 76-4219

Figure 7.

PHOTO 0945-76

Figure 8.

II. DISPERSION HARDENING OF ALUMINUM

A. Activity During Quarter

Measurements of RRR and microhardness on solution-heat-treated, quenched and aged alloys of ultrahigh purity aluminum doped with 0.07, 0.12, and 0.26 wt % gold are now complete. The aging behavior of these alloys with regard to these properties has now been documented at aging temperatures of 98, 187, 240, 300 and 350°C. for times of up to 1000 hr. Similar data are now being taken for the 0.16 wt % alloy. Analysis of the data is underway and correlations between RRR and microhardness are being sought.

Examination of thin foils of these alloys in various conditions continues. Figure 1 shows the microstructure of the 0.12 wt % gold alloy after solution heat treatment, brine quenched and then aging for 1000 hr at 300°C. The precipitates, presumed to be Al_2Au , are thin discs with truncated surfaces which are parallel to specific crystal planes which are thought to be {001} planes. The matrix material is essentially pure aluminum. A view of the microstructure of the same alloy after quenching but with no aging is depicted in Fig. 2. No precipitates are evident here. Instead only dislocations which are heavily jogged along with small dislocation loops are present. Evidently during the aging process, the quenched-in dislocations climb and anneal out and precipitates of Al_2Au form and grow. Additional quantitative microstructural information is being sought.

During the next quarter, a short paper will be prepared for presentation at the Second International Conference on Mechanical Behavior of Materials to be held in Boston, Mass. on August 16-20, 1976. By directive of ERDA-DEES, the dispersion hardening studies will be closed out during the current fiscal year, and a final report will be submitted.

B. Personnel

Personnel involved in the dispersion hardening studies during the quarter were:

Dr. R. A. Vandermeer, Group Leader

Mr. J. C. Ogle, Technician

LIST OF FIGURES

1. Aluminum + 0.12 wt % gold solution heat-treated 16 hr. at 600°C, quenched and aged 1000 hr. at 300° C. Magnification 75000x.
2. Aluminum + 0.12 wt % gold solution heat-treated 16 hr. at 600°C and quenched. Magnification 60000x.

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Figure 1.

Figure 2.

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