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Development of Power System Measurements -- Quarterly Report July 1, 1983 to September 30, 1983

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
Center for Electronics and Electrical Engineering
Electrosystems Division
Washington, DC 20234

February 1984

Prepared for:
Department of Energy
Division of Electric Energy Systems
1000 Independence Avenue, SW
Washington, DC 20585

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DEVELOPMENT OF POWER SYSTEM MEASUREMENTS -- QUARTERLY REPORT JULY 1, 1983 TO SEPTEMBER 30, 1983

R. E. Hebner, Editor

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

Foreword

This report summarizes the progress on three technical investigations during the fourth quarter of FY 83. Although reasonable efforts have been made to ensure the reliability of the data presented, it must be emphasized that this is an interim report so that further experimentation and analysis may be performed before the conclusions from any of these investigations are formally published. It is therefore possible that some of the observations presented in this report will be modified, expanded, or clarified by our subsequent research.

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DEVELOPMENT OF POWER SYSTEM MEASUREMENTS -- QUARTERLY REPORT
July 1, 1983 to September 30, 1983

R. E. Hebner, Editor

This report documents the progress on three technical investigations sponsored by the Department of Energy and performed by the Electrosystems Division, the National Bureau of Standards. The work described covers the period from July 1, 1983 to September 30, 1983. The report emphasizes the measurement of the 60-Hz electric and magnetic field in biological exposure facilities, the measurement of water vapor, the production rates of oxyfluorides in SF_6 corona discharges, and in the measurement of space charge in transformer oil.

Key words: cables; composite insulation; electric fields; high voltage; incipient fault; insulation; liquid breakdown; SF_6; space charge; transformer oil.

1. INTRODUCTION

Under an interagency agreement between the U.S. Department of Energy and the National Bureau of Standards, the Electrosystems Division, NBS, has been providing technical support for DOE's research on electric energy systems. This support has been concentrated in the following areas -- the measurement of electric fields, the measurement of partial discharge phenomena, and the measurement of interfacial electrostatic field distributions and of space charge density. The technical progress made during the quarter July 1, 1983 to September 30, 1983 is summarized in this report.

2. ELECTRIC FIELD MEASUREMENTS
Subtasks Nos. 01 and 02

The objectives of this investigation are to develop methods to evaluate and calibrate instruments which are used, or are being developed, to measure the electric field, conductivity, the space charge density, and current density in the vicinity of high-voltage dc transmission lines and in apparatus designed to simulate the transmission line environment; to provide electrical measurement support for DOE-funded efforts to determine the effects of ac fields on biological systems, and to provide similar support for biological studies which are funded by the State of New York.

During the current reporting period, an NBS staff member made a site visit to the University of Utah in Salt Lake City to perform measurements of 60-Hz magnetic fields and observe procedures employed by researchers for the measurement of several related electrical parameters. The investigators are performing in vitro biological studies of cells exposed to 60-Hz electric and magnetic fields. The studies are funded by the State of New York Department of Health. Report of the measurements and observations has been forwarded to the State of New York and Department of Energy.

The third revision of an IEC draft standard for the measurement of power frequency electric fields was completed at NBS and distributed to members of Working Group 6 of TC42 for discussion at the time of the working group meeting

which is being planned for the month of November. Consensus is near on the draft document and preparation of a final draft may be possible after one more revision.

During the next quarter it is anticipated that preparation of the text for a technical note identifying electrical parameters which must be measured and controlled during biological experiments with 60-Hz electric and magnetic fields will be completed and ready for internal review. NBS staff will attend meetings of (1) an EPRI-sponsored instrumentation measurements field day in October at the Bonneville Power Administration to compare the performance of the BPA personnel electric field monitor and a vest-type monitor developed under contract to EPRI; (2) the DOE contractors review meeting during November in Kansas City during which a presentation on dc field and air ion measurements will be given; (3) an IEC working group meeting which will prepare a draft standard for power frequency electric field measurements. The meeting will take place in November near London.

For further information contact Dr. M. Misakian, (301) 921-3121.

3. TECHNICAL ASSISTANCE FOR FUTURE INSULATION SYSTEMS RESEARCH
Subtask No. 03

The objective of this project is to develop diagnostic techniques to monitor, identify, and predict degradation in future compressed gas electrical insulating systems under normal operating conditions. The focus is on the fundamental information and data needed to improve test design and performance evaluation criteria. The investigation of partial discharges (corona) in gaseous dielectrics is emphasized. This phenomenon gives rise to degradation of the gas under high electrical stress which leads to breakdown. Measurement of partial discharge inception in highly nonuniform fields may prove to be a preferred method to determine dielectric strength of electronegative gases.

The planned activities for FY83 include:

1) Preparation of conference and archival papers on the effect of radiation in enhancing electric discharge initiation near a positively stressed electrode in compressed SF_6 and O_2;

2) Extension of our previous measurements [1] of the production rates of oxyfluorides in SF_6 corona discharges to include negative discharges as well as other gas pressures and discharge power levels, and preparation of the results for publication in an archival paper;

3) Identification of the predominant gaseous decomposition products from corona in one or more of the following gas mixtures: $SF_6 + N_2$, $SF_6 + CO_2$, and $SF_6 + c\text{-}C_4F_8 + CHF_3$;

4) Evaluation of a thin-film, aluminum oxide hygrometer probe for calibration of a gas chromatograph-mass spectrometer (GC/MS) used to measure trace quantities of water vapor in SF_6 and other gaseous dielectrics, and extension of our previous measurements on the effects of trace levels of H_2O on electron avalanche growth and corona discharge characteristics in SF_6; and

5) Design and construction of a drift tube-mass spectrometer system to evaluate measurements proposed to identify and characterize corona-generated ion species in air, SF_6, and other gas dielectrics.

Activity 1 has been completed and an archival paper describing the results of this work has been published [2]. During the past quarter focus was on the tasks necessary to bring activities 2 and 4 to completion. Some of the results obtained as part of these efforts are highlighted in this report. Because of the priorities assigned to these tasks and the unanticipated problems encountered in completing them, it has been necessary to postpone beginning work on tasks 3 and 5 until FY84.

Priority was given to task 2 because of its relevance to the design of meaningful chemical diagnostics tests which could be used to evaluate performance of practical SF_6 insulated systems. The need here, of course, is for quantitative data on decomposition-species production rates that could be used to interpret information from gas analysis in a way which might reveal the nature of any internal electrical activity (incipient faults). The production rates that we have measured for the oxyfluorides, SOF_2 and SO_2F_2, in SF_6 can, in principle, be used to determine how long corona, or partial discharges, would have to persist in a system at particular levels in order to yield observable, known concentrations for these species. The data on production rates (see our previous two quarterly reports) are expressed in terms of either moles per unit of energy dissipated in the discharge, or moles per unit of charge transported in the gas during the discharge. If one knows the internal discharge power dissipation or current, then one can predict from our data the production rates expressed in terms of absolute quantities produced per unit of time. Conversely if one knows the production per unit-of-time, one can infer something about the level of discharge activity within the system, assuming of course that the volume, pressure, and gas content of the system are also known.

In order that our results might be more useful in the design of tests to evaluate practical system performance, it was decided during the past year that more data should be taken on production rates for a wider range of gas, gap, and discharge conditions than had originally been anticipated. Before our results can be applied to the interpretation of tests on high-voltage, gas-insulated apparatus, one needs to know how the rates of production of discharge-generated contaminants depend on the range of operating conditions likely to be encountered. In the present report, we show data recently obtained on the simultaneous variations in the absolute concentrations of SOF_2, SO_2F_2, SO_2, and H_2O during a continuous, negative, dc corona discharge in gaseous SF_6 at different pressures. Abstracts of papers describing some of these results have also been submitted for presentation at the Thirty-Sixth Gaseous Electronics Conference, October 11-14, 1983, and the Fourth International Symposium on Gaseous Dielectrics, April 29 - May 3, 1984.

More emphasis has also been given to activity 4 because of the persistent uncertainties and controversies associated with the establishment of meaningful criteria for standards of insulating gas purity, particularly as apply to water vapor contamination in compressed SF_6 now widely used in practical systems. Our measurements as part of both activities 2 and 4 have been directed at questions concerning: 1) the role of water vapor in the production of decomposition species such as the oxyfluorides and hydrogen fluoride which represent permanent damage to the gas insulation; 2) the effects of water vapor upon the electrical

performance of gaseous dielectrics, e.g., the dielectric strength and intensity of corona; and 3) the problems associated with the measurements of trace levels of water vapor, particularly when electric discharges are present. It is hoped that the results of our investigations can be used to help establish the acceptable levels of water contamination for different high-voltage applications, and suggest improved methods for monitoring water vapor in practical systems. Our results on corona characteristics and statistics of electron avalanche growth in SF_6/H_2O mixtures [3] already suggest that the presence of water vapor is much less tolerable in applications where SF_6 is used as a fast, pulsed-power switching medium than in applications where it serves primarily as an insulant.

In addition to the activities listed above, during the past quarter a draft of a computerized bibliography on electrical breakdown data for gases was prepared and distributed to members of the IEEE Insulation Society Technical Committee S-32-11 on Gaseous Dielectrics for comments and suggested additions. The relevant references have been entered into a computer database with a code giving the types of gases considered and data presented. It is intended that this bibliography will serve as a guide to current information available in the open literature on electrical breakdown in gases. The gases included are those considered most relevant to electrical insulation applications.

The bibliography will be discussed at the next meeting of the committee which will occur October 19, 1983 during the 1983 Conference on Electrical Insulation and Dielectric Phenomena. It is expected that during the next quarter all the information necessary to complete the bibliography will have been received, and a complete version with extensive cross referencing will be prepared for publication in a special NBS report. The intention is also to publish an abbreviated version in the IEEE Transactions on Electrical Insulation.

As part of our technical work, our previous measurements of the production rates for SOF_2 and SO_2F_2 in SF_6 negative corona have been extended to lower gas pressures. The data were found to be consistent with the trends discussed in our earlier reports and will not be shown here. Examples of simultaneous production curves for SOF_2, SO_2F_2, SO_2, and H_2O are displayed in figures 1 and 2 for negative corona discharges in SF_6 at pressures of 114 and 200 kPa, respectively. Shown are plots of measured absolute concentrations in μ-moles versus net charge, Q, transported across the discharge gap in coulombs. This latter quantity is given by

$$Q = \int_0^t I(t')dt' \ , \qquad (1)$$

where I(t') is the instantaneous discharge current measured at time t'. These figures show our first quantitative data on H_2O and SO_2.

The production rate for SO_2 is found to be more than an order-of-magnitude smaller than the production rates for either SOF_2 or SO_2F_2. This observation is consistent with the expected predominant mechanism for SO_2 formation, namely, a slow hydrolysis of SOF_2 via the reaction

$$SOF_2 + H_2O \rightarrow SO_2 + 2HF, \qquad (2)$$

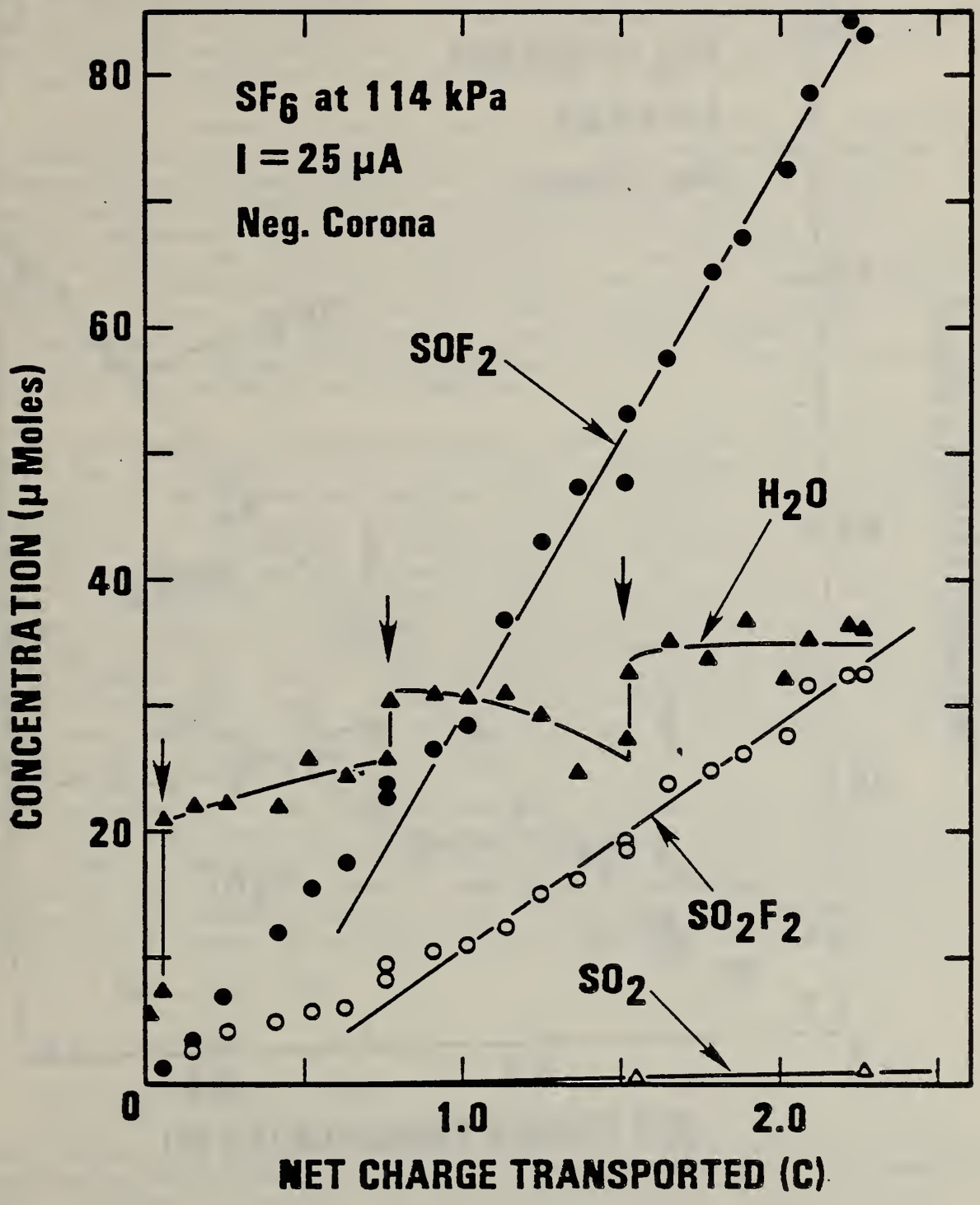

Figure 1. Measured production of SOF_2, SO_2F_2, H_2O, and SO_2 in a continuous negative, point-plane corona discharge with a current of 25 μA in SF_6 at 114 kPa.

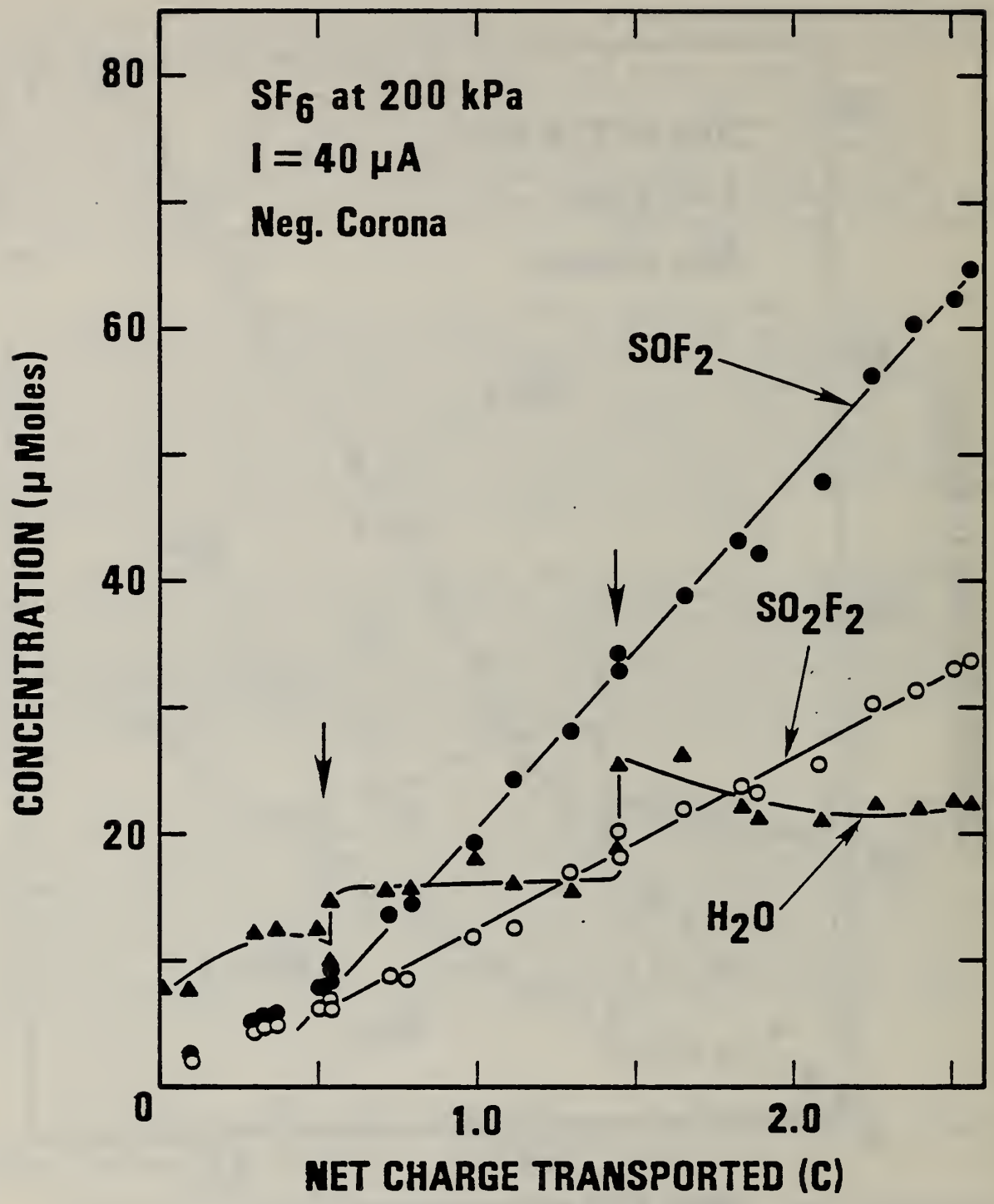

Figure 2. Measured production of SOF_2, SO_2F_2, and H_2O in a continuous negative, point-plane corona discharge with a current of 40 μA in SF_6 at 200 kPa.

(also see Table 1). The quantitative analysis for SO_2 was performed by the same method as used for SOF_2 and SO_2F_2. For the H_2O measurements, the gas-chromatograph mass-spectrometer (GC/MS) was calibrated by comparing its response to that of a previously calibrated thin-film aluminum oxide hygrometer probe under equilibrium conditions as will be discussed in more detail below.

The vertical arrows in figures 1 and 2 indicate times when the discharge was turned off for periods of 16 to 20 h. It is seen that during these periods the concentration of water vapor in the discharge cell generally tended to increase, whereas the concentrations of the oxyfluoride species remained essentially unchanged. It should be noted that this observation also applies to the species SOF_4, even though its absolute level of concentration could not be measured. This same behavior was found to occur under a wide range of discharge conditions. Figures 3 and 4 show similar data for positive corona at different discharge currents and gas pressures. In these figures, however, the concentrations for H_2O can only be considered approximate since no calibration of the GC/MS was performed for this species.

The results for H_2O indicate that water vapor is consumed during discharge activity and its equilibrium value in the cell is diminished. This is expected on the basis of the predominant reactions that are likely to occur in the gas both inside and outside of the discharge as given in Table 1. The hydrolysis of SF_4 in particular is known [4] to be quite rapid, and probably accounts for most of the H_2O consumption and the observed build-up of SOF_2. The fact that the H_2O content increases during periods when the cell is left undisturbed suggests that the hydrolysis of SF_4 is fairly complete within relatively short times after its production. The lack of significant change in the amounts of SOF_2, SO_2F_2, and SOF_4 during these same periods also indicates that the predominant reactions leading to these occur during, or shortly after, discharge activity. Moreover, this observation coupled with the measured slow rate of SO_2 production implies that the reactions of SOF_2 and SOF_4 with H_2O are very slow (see Table 1).

A consideration of the possible important reactions which could occur in the discharge and subsequently in the gas around the discharge, as given in Table 1, would suggest that formation of thermalized SO_2F_2 from the primary SF_6 dissociation species, i.e., lower valence sulfur fluorides and free radicals, would necessarily require the presence of O_2. Of course, it could also be formed in the discharge by reactions involving the other oxyfluorides, e.g.,

$$SOF_2 + OH^+ \rightarrow SO_2F_2 + H^+ \qquad (3)$$

$$SOF_2 + O \rightarrow SO_2F_2 \qquad (4)$$

$$SOF_4 + H_2O^+ \rightarrow SO_2F_2^+ + 2HF \ . \qquad (5)$$

These, however, are secondary reactions, and their predominance as formation mechanisms would require significant deviations from linearity in the production curves. As shown in figures 1 - 4, the production curves for both SOF_2 and SO_2F_2 eventually become quite linear, which is equivalent to saying that the production rates approach constant values. Initially, there are nonlinearities which could be accounted for by the times required for the decomposition species to attain equilibrium with the walls of the cell. The fact that the production curves eventually approach linearity is consistent with an assumption that

Table 1. Reaction Scheme

IN DISCHARGE:

$e + SF_6 \rightarrow SF_6^* + e$

$e + SF_6 \rightarrow SF_5 + F + e$

$e + SF_6 \rightarrow SF_4 + 2F + e$

$e + SF_6 \rightarrow SF_3 + 3F + e$

$e + SF_6 \rightarrow SF_2 + 4F + e$

$e + SF_6 \rightarrow SF_5 + F + 2e$

$e + SF_6 \rightarrow SF_5^- + F$

IN GAS:

$SF_4 + H_2O \rightarrow SOF_2 + 2HF$ (fast)

$SF_4 + O_2 \rightarrow SO_2F_2 + F_2$?

$SF_6^* + H_2O \rightarrow SOF_4 + 2HF$?

$SOF_2 + H_2O \rightarrow SO_2 + 2HF$ (slow)

$SOF_4 + H_2O \rightarrow SO_2F_2 + 2HF$ (slow)

$SF_2 + O_2 \rightarrow SO_2F_2$?

$SF_6^* + O \rightarrow SOF_4 + F_2$?

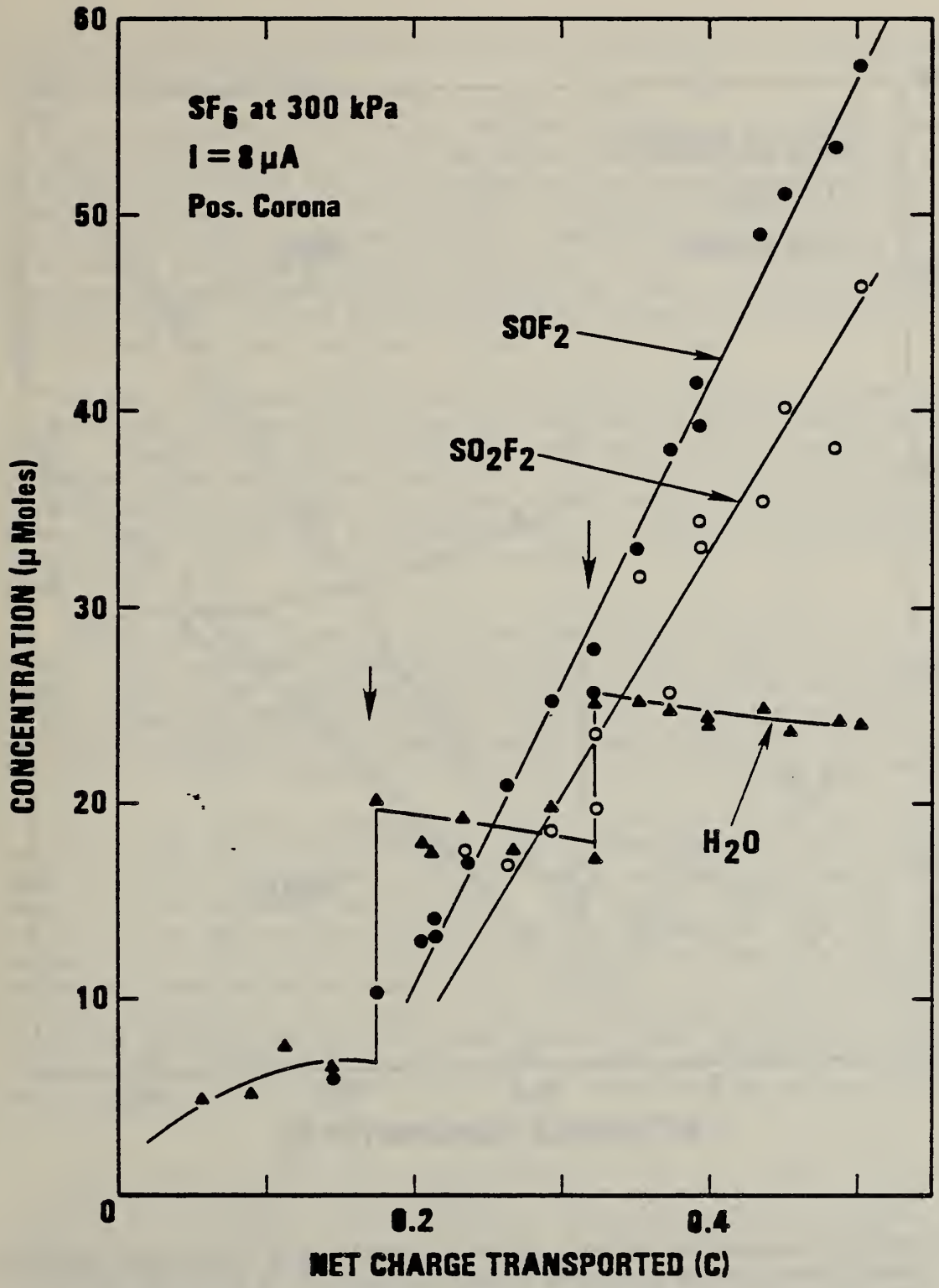

Figure 3. Measured production of SOF_2, SO_2F_2, and H_2O in a continuous positive, point-plane corona discharge with a current of 8 μA in SF_6 at 300 kPa. (The concentrations for H_2O are only approximate).

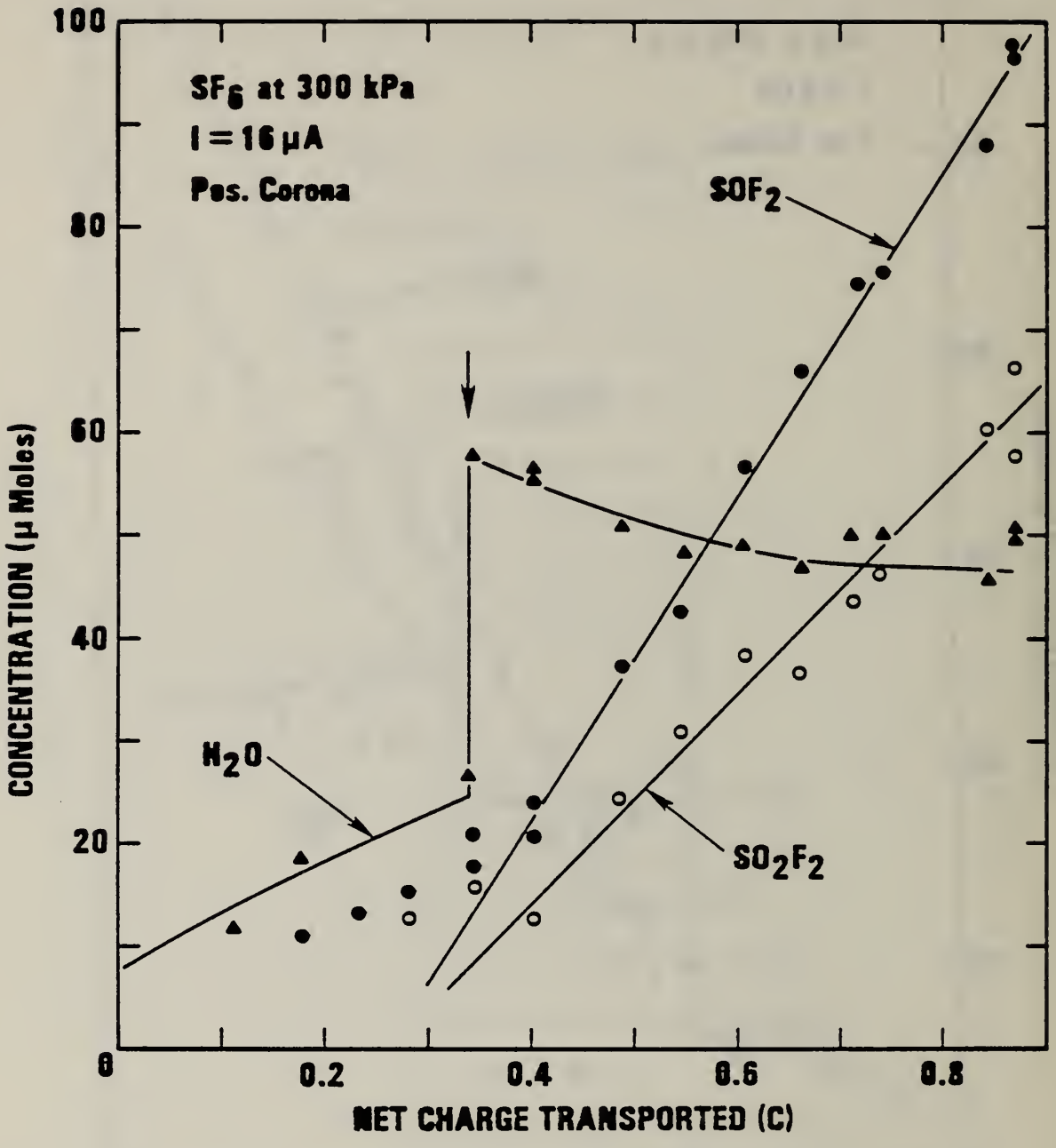

Figure 4. Measured production of SOF_2, SO_2F_2, and H_2O in a continuous positive, point-plane corona discharge with a current of 16 μA in SF_6 at 300 kPa. (The concentrations for H_2O are only approximate).

reactions involving the primary dissociation products of SF_6 predominate in the formation of oxyfluorides.

The presence of O_2 in the gas has been detected, and our measurements indicate a slow build-up of this contaminant during discharge activity. Because of problems associated with air contamination we have not attempted a quantitative analysis for this species. Presumably oxygen can be released from the stainless steel electrodes as well as being formed in the discharge. It is worth noting that the increase in production rates for SOF_2 and SO_2F_2 in going from negative to positive corona is consistent with the observation (see our previous report) that the point electrode is heated and deteriorated more under positive polarity thus implying a higher oxygen release.

As was noted above, thin-film aluminum oxide hygrometer probes were used to calibrate the GC/MS system for quantitative measurements of water vapor content in SF_6. Commercially available probes were used which had previously been calibrated under equilibrium conditions. In order to use these probes for calibration, it is essential to insure that an equilibrium is established between the probe and the surrounding gas. In a static gas not subjected to turbulence or circulation, the time necessary to achieve equilibrium might be quite long.

During the past quarter, tests were performed to evaluate the response times of the hygrometer probes to variations in water vapor content, i.e., the times necessary for the system plus probe to reach equilibrium after SF_6 gas with a known water vapor content was introduced. These measurements were performed by making a direct comparison of probe response to GC/MS response. For this purpose the response of the GC/MS may be considered instantaneous.

Data from one such comparison is shown in figure 5. In this test relatively dry SF_6 with less than 50 ppm H_2O was introduced into a vessel at an absolute pressure of 200 kPa, and after about an hour simultaneous readings were made from the hygrometer and the GC/MS. The GC/MS in this case was operated in the single-ion monitoring mode to look at the predominant ions from electron bombardment of H_2O, namely H_2O^+ (ion 18) and O^+ (ion 16). Its calibration was established before the beginning of the test. It is seen from figure 5 that the concentration of water vapor in the cell as determined by the GC/MS gradually increased to an equilibrium level of about 200 ppm in a time of roughly 16 h. During this time the probe reading was found to be too low, and only after about 22 h did it begin to give a true reading of water vapor content.

This test indicates that the hygrometer probe has a long response time for low levels of moisture (below 300 ppm). This probe, therefore, would not be suitable as an accurate monitor of trace moisture content in situations where fairly rapid variations are expected such as might happen during electrical discharge activity. Of course, there are other reasons for excluding such probes in this case, especially for gases like SF_6, in which, as shown above, highly reactive and polar gaseous decomposition species like HF are generated. These species can be absorbed by the probe and attack the probe material, thus adversely affecting its performance. Care was taken so that the probes used to calibrate the GC/MS for the measurements described here were never exposed to gas which had been decomposed in electrical discharges.

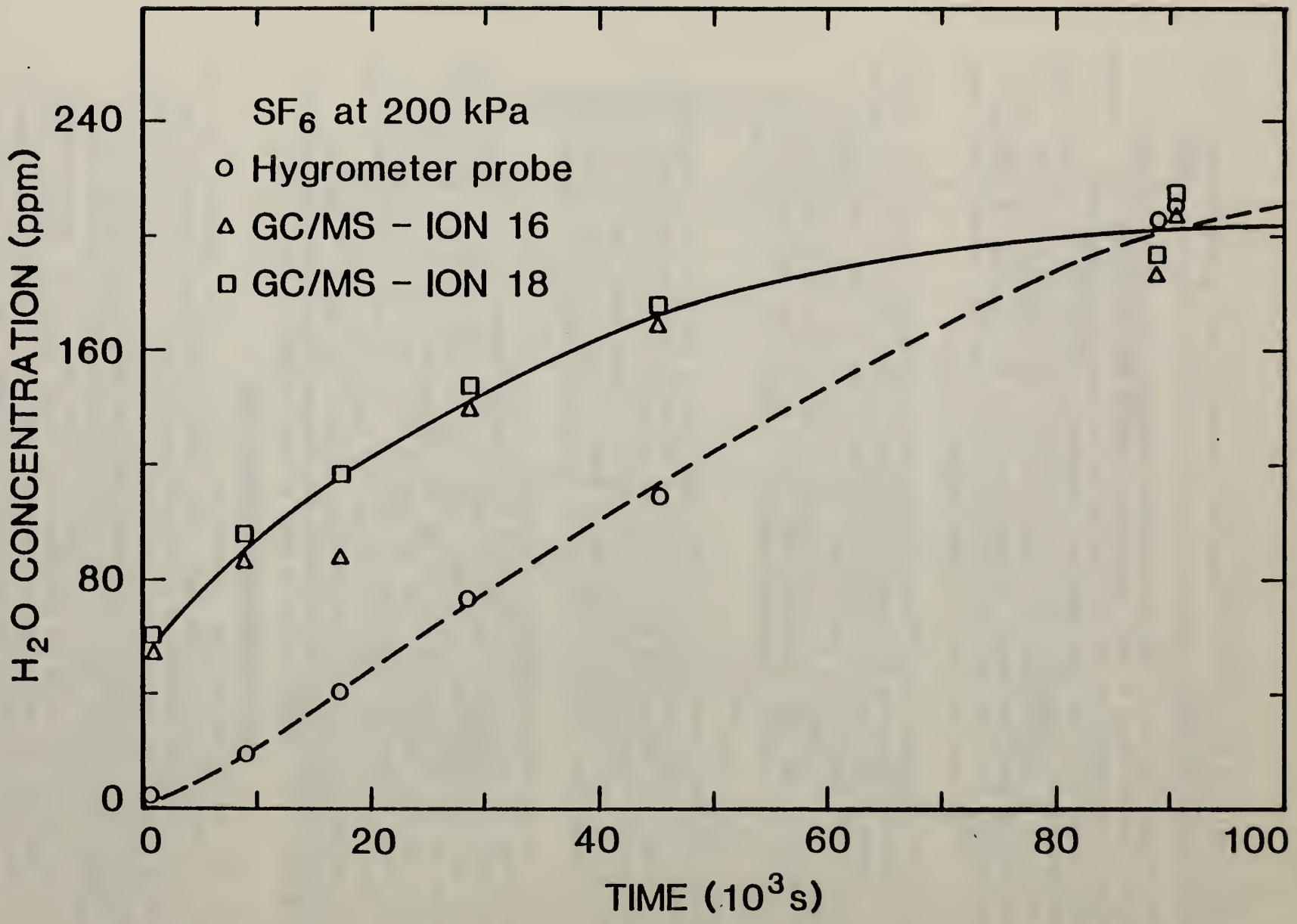

Figure 5. Comparison GC/MS and hygrometer probe responses for detection of trace water vapor in SF_6 at 200 kPa.

It should finally be mentioned that the thin-film aluminum oxide probes which we tested tend to exhibit an initial fast response to sudden increases in water vapor content. This type of behavior has previously been noted by others [5]. An example of such behavior is shown in figure 6 which corresponds to a test in which 4 μl of liquid H_2O were injected into a 4 l vessel under vacuum followed by the introduction of SF_6 at a pressure of 200 kPa. The initial response of the probe indicated a moisture level which was considerably higher than the maximum predicted on the basis of the quantity of liquid introduced. In this case, the system (probe plus vessel) seemed to require more than 5 h to reach equilibrium. Results that we have obtained thus far suggest that the response times of the probes increase with decreasing water vapor concentration. Further tests will be required to verify this trend.

During the next quarter, at least one manuscript, describing our results on production of oxyfluorides in SF_6 corona discharges, will be prepared and submitted for publication. The first draft of a complete bibliography on electrical breakdown data in gases will be compiled and submitted for review to members of the IEEE Technical Committee on Gaseous Dielectrics. It is anticipated that this bibliography will also be prepared for publication in the form of a special NBS report.

More measurements will be performed to evaluate the response time and accuracy of the thin-film aluminum oxide hygrometer method for measuring water vapor content in SF_6. Measurements on the production rates of oxyfluorides in SF_6 and SF_6/H_2O mixtures should be completed and, in this connection, a new method for calibrating the GC/MS for quantitative determination of SOF_4 concentrations in SF_6 will be examined. It is also anticipated that preliminary measurements can be performed to identify the predominant stable gaseous decomposition species generated by corona discharges in SF_6/N_2 mixtures.

For further information contact Dr. R. J. Van Brunt, (301) 921-3121.

4. OPTICAL MEASUREMENTS FOR INTERFACIAL CONDUCTION AND BREAKDOWN IN INSULATING SYSTEMS
Subtask No. 04

The objectives of this investigation are to develop apparatus and appropriate procedures for the optical measurements of interfacial electric field and space-charge density in materials for electric power equipment and systems, to understand the interfacial prebreakdown and breakdown processes in specified insulating systems, and to demonstrate the applicability of the developed instrumentation and the procedures in the development and design of future systems.

The results reported last quarter showed that the field enhancement due to space charge in transformer oil increased with increasing field and increasing temperature. The maximum enhancement was on the order of 30% over the geometrical field $E_u = V/d$, where V is the applied voltage to parallel plates with plate-separation d. The space charge is largest next to the anode having a magnitude of order -30 nC/cm^3 -- heteropolar space charge. The data suggests that the space charge was not dependent upon the presence of water or conducting carbon particles, but was dependent upon the chemical nature of the oil.

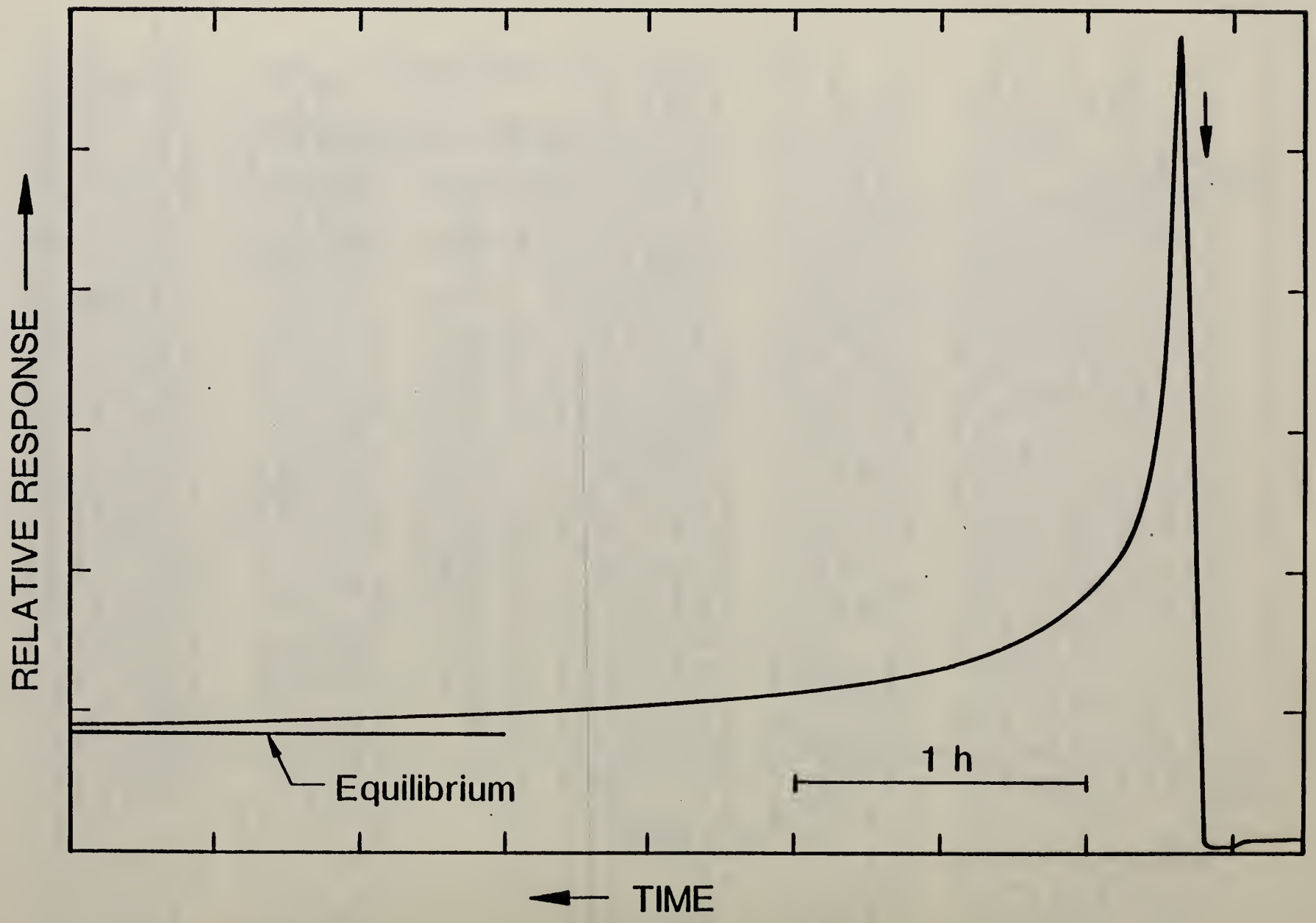

Figure 6. Typical response curve for a thin-film aluminum oxide hygrometer corresponding to a sudden increase in water vapor concentration. Vertical arrow indicates time at which water vapor concentration is increased.

The Conference on Interfacial Phenomena in Practical Insulating Systems was held this quarter (September 19-20, 1983) at NBS. Approximately 40 people participated in the conference with representatives from government, university, and industry coming from several countries. In addition to organizing the conference, the NBS contribution consisted of two papers: "Interfacial Phenomena -- An Overview" by R. E. Hebner, and "The Measurement of the Electric Field in the Vicinity of an Oil-Pressboard Interface Parallel to the Field" by E. F. Kelley and R. E. Hebner. Several conclusions were drawn at the conference. One was that there is not one simple phenomena which can explain the interfacial breakdown problems for all composite insulation systems. Another was that it is not reasonable to perform terminal measurements upon a system without accompanying optical observations. Almost all the papers presented optical observations to clarify the processes under study.

Three important results obtained this quarter are:

1. A correlation is observed between the lowering of the breakdown voltage of transformer oil and the space charge induced field enhancement.

2. Different oils have different space-charge characteristics. Two oils can exhibit substantially different field enhancements under the same conditions.

3. If a pressboard interface is placed between and in contact with parallel plates so that its surface is perpendicular to the plates, no surface charge is detected on the oil-pressboard interface which modifies the electric field in the vicinity of the interface by more than 5%.

In all cases presented, the transformer-oil samples are prepared so that a minimum of water and oxygen remain in the oil. The procedure is to bubble dry nitrogen through the oil for a minimum of 48 hours. A sintered glass filter is used to produce fine bubbles which circulate through the oil. The pressboard is cut to size and then baked at 125°C in a vacuum oven. After a period of not less than 48 hours, degassed, dehydrated, deoxygenated oil is added under vacuum so that the oil covers the pressboard. The oven is then allowed to cool, and the pressboard remains under vacuum until used in the experiment. In all cases, the electrodes are parallel plates with separation d which is 1 cm or less. At one point, two different brands of commercially available transformer oil are compared. These will be referred to as type 1 or type 2 oil.

The average breakdown field ($E_B = V_B/d$) of type 1 oil as a function of temperature is presented in figure 7. Included on this plot is the maximum relative field enhancement due to space charge as a function of temperature. Recall that the fields reported are measured relative to what they would be without space charge in the oil -- the geometric, unperturbed field $E_u = V/d$. The maximum field is produced at the anode due to heteropolar space charge with the application of dc fields. The maximum relative field enhancement is then E_{anode}/E_u, and the field enhancement is measured at fields which are approximately 90% of the breakdown field. These results are preliminary and it is expected that further measurements will provide smaller error bars and increased accuracy in the field measurements. A trend is seen in these data. As the temperature increases, the field enhancement increases and the breakdown field decreases. Whether or not the lowering of the breakdown field is due to

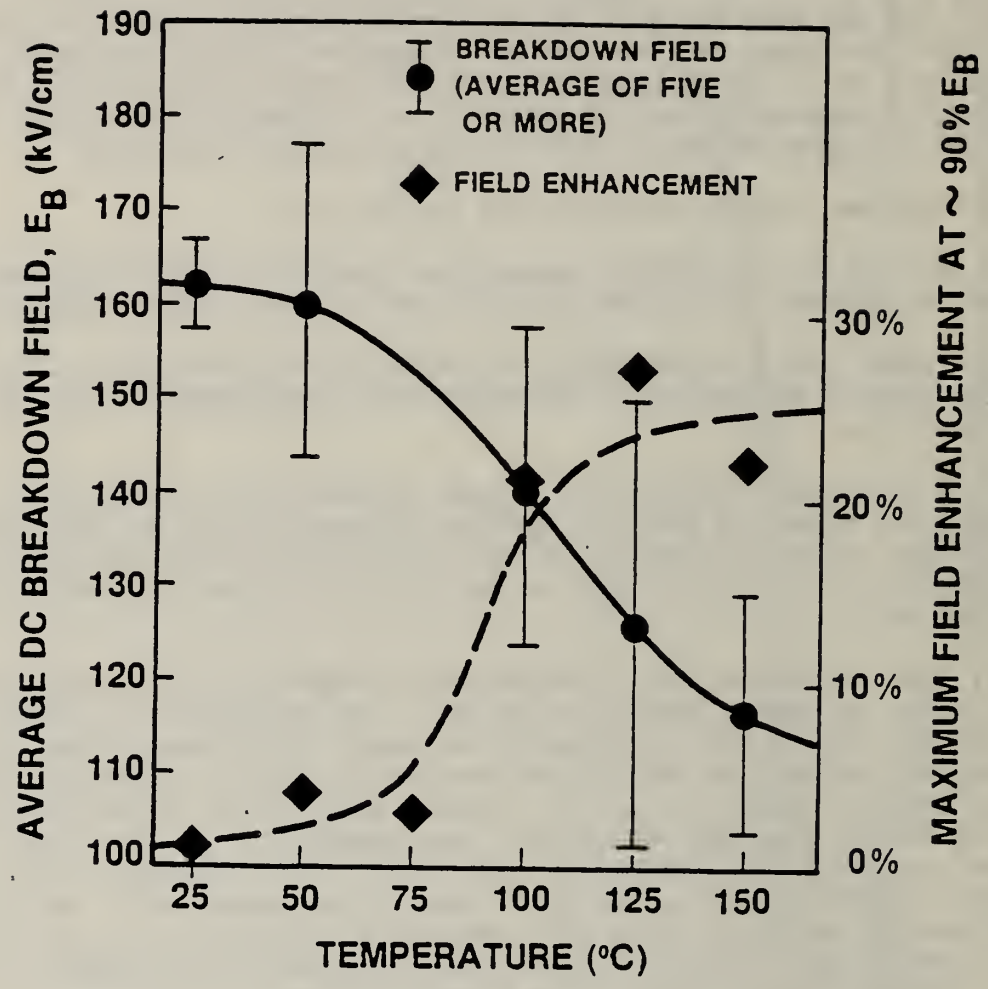

Figure 7. The average breakdown field and maximum field enhancement vs temperature. The average breakdown field E_B is defined as the breakdown voltage divided by the parallel plate separation. Under the application of dc voltage the maximum field enhancement is found at the anode due to heteropolar space charge accumulation in its vicinity. The maximum field enhancement uncertainty is estimated to be ±3%.

the field enhancement is not established by these data. Only by removing the space charge from the oil can the effects of the enhancement be distinguished from the effects of temperature by itself. These additional measurements will be attempted in the future.

Figure 8 shows the temporal development of the electric field in the two types of oil studied. The data are taken at 120°C and each polarity of dc voltage is applied. Type 1 oil initially showed less than a 10% field enhancement due to space charge, but after 18 hours field enhancement of about 25% is observed. In the type 2 oil, the field enhancement remains 10% or less even after four days. Although the influence of the field enhancement upon the breakdown voltage remains to be more firmly established, if a strong correlation is found (as expected) then the measurement of the field enhancement may be an important parameter in future specifications of liquids used in high-voltage apparatus.

To study interfacial phenomena, a pressboard interface was held between parallel plates and in contact with each plate so that its surface is parallel to the geometrical field direction (see inset of figure 9). The electro-optical detector monitors the electric field between the plates in two places: near the surface of the interface and about one gap length away from the surface of the interface. Figure 9 shows the comparison of the relative electric field at both positions for positive applied voltages. The case for negative voltage presents a similar picture with the enhancement following the anode for dc voltages. Note that for a large range of dc voltages, the field enhancement near the interface is the same as the field enhancement away from the interface to within the ±3% precision of the measurement. This measurement shows that the interfacial surface confines insufficient surface charge to produce macroscopic changes in the electric field distribution in the liquid. That is, field enhancement arising from surface charges on the pressboard-oil interface parallel to the field cannot be invoked to explain the lowering of the breakdown voltage of such a system. This statement assumes that the breakdown voltage is directly related to the field found at the electrode surfaces. It may, therefore, be wise to consider microscopic conditions and contaminants as offering a more probable cause for failure of interfaces parallel to the field in pressboard-oil systems. The case for the surface of the interface perpendicular to the field will be investigated at a later date.

There is a confounding factor in the electro-optical detection system which must be minimized before field measurements can be completed for the pressboard-oil system with the interface perpendicular to the field direction. Measurements must be made over an extended region of the inter-electrode area. The difficulty is that the windows presently used are birefringent. Normally for most Kerr-effect measurements, the small birefringence would be ignorable. But since the accuracy of these measurements depends upon low-level, light-intensity measurements, a nonuniform birefringence makes measurements very difficult. Thus, one of the important changes needed is to obtain better windows for the tank and cell. Then measurements of interfacial fields can be made with an estimated sensitivity of 5 kV/cm. Provided such windows can be obtained, the case with the pressboard perpendicular to the field will be investigated.

Measurements of the effects of particles on streamer propagation will be completed next quarter with better documentation of the particulate content and range of particle sizes. The results will be compiled in a monograph.

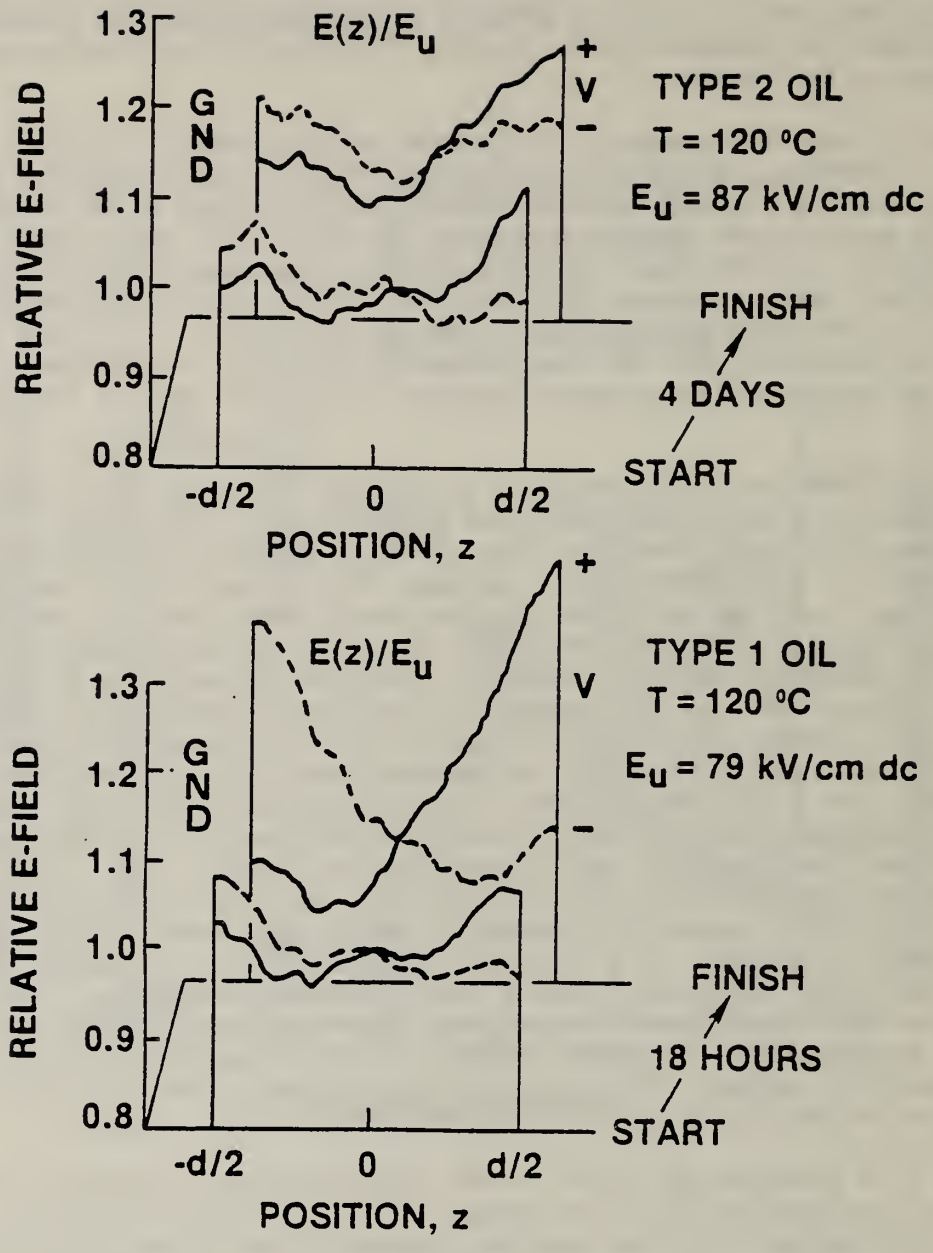

Figure 8. The relative field as a function of position at different times for the two types of oil used. The applied voltage is dc, and is 55 kV for type 2 oil, 50 kV for type 1 oil; the gap spacing is 0.635 cm. Type 2 oil shows essentially no change in time, however, type 1 oil shows great changes in a relatively short time. All data are taken at 120°C. The solid lines show the field when the high voltage electrode is positive and the dashed lines show the field when the high voltage electrode is negative.

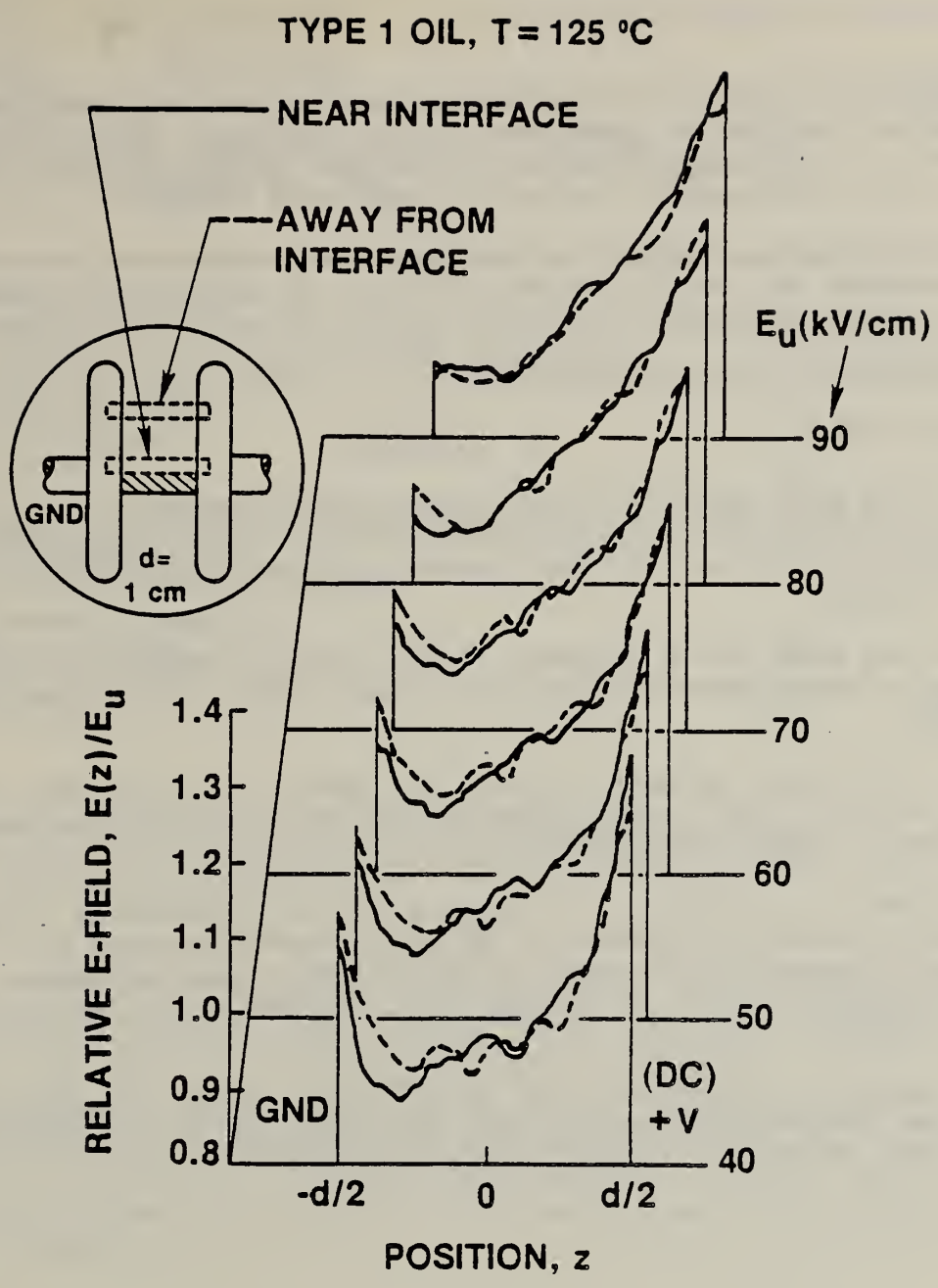

Figure 9. Relative electric field between parallel plates near and away from a pressboard-oil interface parallel to the field. The inset shows the view from the detector looking into the light beam. The light travels parallel to the long plates between which a long pressboard interface is placed. The detector sees the edge of the system and monitors the electric field in the two regions specified. The detection system is only sensitive to extended perturbations of the electric field. Small changes in the local electric field around a void or a particle would not be noticed. The small fluctuations in the field profiles arise from the localized nonuniformities in the light beam as well as "waves" of small thermal gradients in the heated oil tank enclosing the cell. These measurements are averages made over 10 s to 20 s intervals. Dashed lines denote the field away from the interface while the solid lines denote the field near the interface.

Further measurements of the breakdown voltage and field enhancement near breakdown as functions of temperature will be attempted. Efforts will be made to remove the space-charge from the oil in order to separate space-charge effects (field enhancement) from purely temperature effects.

The temperature dependence of the breakdown voltage with and without a paper interface held parallel to the field will be completed. Such data will help to isolate the controlling factors in such interfacial breakdown.

For further information contact Dr. E. F. Kelley, (301) 921-3121.

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This report documents the progress on three technical investigations sponsored by the Department of Energy and performed by the Electrosystems Division, the National Bureau of Standards. The work described covers the period from July 1, 1983 to September 30, 1983. The report emphasizes the measurement of the 60-Hz electric and magnetic field in biological exposure facilities, the measurement of water vapor, the production rates of oxyfluorides in SF_6 corona discharges, and in the measurement of space charge in transformer oil.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

cables; composite insulation; electric fields; high voltage; incipient fault; insulation; liquid breakdown; SF_6; space charge; transformer oil

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