EVALUATION, DESIGN, DEVELOPMENT
AND DELIVERY OF A 1200 kV
PROTOTYPE TERMINATION

Third Technical Progress Report
Covering the Period From
May 1, 1979, to August 31, 1979

September 1979

MASTER

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Evaluation, Design, Development and Delivery
of a 1200 kV Prototype Termination

Third Technical Progress Report

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Preparation Date: September 25, 1979

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Evaluation, Design, Development and Delivery
of a 1200 kV Prototype Termination

Third Technical Progress Report

September 25, 1979

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1.0 ABSTRACT

Detailed analytic and model studies of various termination concepts underway during the present period are described. Reduced scale models are being constructed for the electrostatic and the mechanical studies. Sample tests on a glass fiber reinforced insulating material show promise of an improved shatter-resistant weathercase material. Thermal analysis show that most of the termination designs being considered appear to have acceptable thermal profiles. Optimal materials, configurations, and fabrication plans are expected to be determined upon completion of these studies.

2.0 INTRODUCTION

This is the Third Technical Progress Report on the Evaluation, Design, Development and Delivery of a 1200 kV Prototype Termination. The SF₆ gas bushing termination will be integrated into a gas insulated sub-station. The produced design will be economically attractive and will exhibit improved electrostatic performance, acceptable temperature gradients, and better mechanical integrity when compared with the gas/air termination of typical ratings built with conventional technology.

The project is divided into nine tasks which include the evaluation of innovative and novel concepts and materials uses, thorough paper and model studies of the electrical, thermal and mechanical characteristics of the most promising configurations, designs, production and testing of a full scale prototype and finally delivery of a prototype termination to an appropriate field site.

3.0 TASK 2 - ELECTROSTATIC STUDIES

3.1 Shield Effectiveness

See Section 6.1, Model Studies, for progress on this subtask.

3.2 Resistive Grading Study

In order to test the suitability of stress-grading silicon-carbide paints for the 1200 kV termination, we are fabricating model bushings which will be coated and tested at an appropriately scaled stress. The models will be as shown in Figure 3-1. The section under test will be a 23 cm long cast epoxy tube, which will be coated on its inner surface with the stress-grading paint under test. A conducting rod 1.3 cm in diameter will simulate the bushing stud. The outside of the bushing model will be in air, while the inside of the tube and the tank at the bottom will contain SF_6 at 300 to 400 kPa. Test voltage will be applied between the stud and the ground flange (the latter is part of the metallic tank).

The anticipated test voltage levels will be scaled on the basis of an actual bushing length of 5.5 meters minimum. We assume full-scale test voltages of 1200 kV RMS 60 Hz for 1 minute; 2175 kV, $1.2 \times 50 \mu\text{sec}$ impulse (three without failure or six with one failure); and 1800 kV, $250 \times 2500 \mu\text{sec}$ switching surge, wet (series of three). Scaled down to a 23 cm length, these become 50 kV RMS 60 Hz, 1 min; 90 kV, $1.2 \times 50 \mu\text{sec}$ impulse; and 75 kV, $250/2500 \mu\text{sec}$ switching surge. Calculation of the field distribution between the rod of the model and the surrounding ground flange yields a value of about 123 kV/cm for the maximum field for SF_6 at 45 psig. is over 200 kV/cm for uniform field conditions, and an even higher maximum field would be necessary here to

FIGURE 3-1 SCHEMATIC DRAWING OF BUSHING MODEL
FOR STRESS-GRADING TESTS

initiate breakdown because of the electrode curvature, so that the electric strength of the rod-to-ground-flange gap is quite adequate for the highest test voltage. The most critical region will, in fact, be the rod-to-tube inner wall near the ground flange, but even here the maximum field will be less than 160 kV/cm at an applied voltage of 90 kV. If internal flashover proves to be a limiting factor, the test specimens will be shortened so that the desired test stresses will be reached at lower applied voltages.

Samples of several different silicon carbide paints will be tested in this fashion. It is expected that at least some of these will be satisfactory; if not, the experimental results should point the way to modifications of the paint which will be adequate.

3.3 Field Plotting

In the next reporting period, electrostatic field plots will be made of all of the configurations to be tested in the shield effectiveness study. Predictions will be made from the plots of the test results to be expected. Verification of the predictions will enable confident plotting of the full size 1200 kV termination and prediction of its capabilities.

Field plots of the reduced scale model may also show that additional configurations should be tested besides those already planned.

4.0 TASK 3 - THERMAL TRANSPORT STUDY

4.1 Configurations Being Studied

Several different designs were considered for the thermal network analysis including:

1. Thin film condenser design
2. Semiconducting stress grading coating design
3. Sulphur hexafluoride (SF_6) filled design
 - a. Large conductor (28 cm dia.)
 - b. Small conductor (15.2 cm dia.)

In order to obtain a general estimate of performance of the above design, calculations were made using techniques developed from extensive experience in the design, development and manufacture of both SF_6 gas and solid insulation condenser bushings. These general calculations show the design to be feasible if not practical and all merit further analysis from the thermal aspects. Although an in depth study and actual tests are planned, the initial analysis and calculations are presented in the following paragraphs.

4.2 Losses

The heat generated in a typical termination is a sum of losses due to three sources: The I^2R losses in the conductor, losses in the solid insulation, and the resistive losses in semiconducting coatings if used. It is important to determine these losses in order to calculate the temperatures which the termination construction materials reach in order that temperature limitation on these materials not be exceeded; additionally, lower losses provide improved efficiency of power system operation.

4.2.1 I^2R Losses in the Conductor

I^2R losses produce the most significant amount of heating in most bushings. The resistance of the conductor varies with diameter and wall thickness. Usually, the current is specified, so the choice of conductor material is critical. The most commonly used conductor materials are aluminum and copper. The best aluminum DC conductivity practical is 55 percent. The best copper is over 100 percent although most commonly used copper corresponding to the 55 percent aluminum is 98 percent conductivity copper. Aluminum has the advantage of being lighter in weight and less expensive. Although it does not have a direct current conductivity equal to copper, aluminum compensates by having greater current penetration at 60 Hz. For example, a 10 cm diameter copper conductor with a 1.3 cm wall has a resistance of about 6.6 microhms per meter and the same size aluminum (6101-T6) has a resistance of about 10 microhms per meter. This corresponds to a 60 Hz conductivity of 66%.

The 60 Hz resistance of copper and aluminum are given in Figures 4-1 and 4-2. Note, that increasing the wall thickness on the aluminum tubing from .6 cm to 1.3 cm reduces the 60 Hz resistance considerably but increasing the wall thickness to 1.9 cm decreases the 60 Hz resistance very little. At 60 Hz there is very little advantage in using a conductor with more than 1.3 cm wall thickness. Skin effect similarly affects copper.

Since a number of different conductor diameters are under consideration for this 1200 kV termination, a plot of I^2R losses at 6000 amps was made for quick reference when calculating the temperature rise of the alternate configurations as shown in Figure 4-3. It assumes 1.3 cm wall thickness of type 6101-T6 aluminum.

60 HERTZ RESISTANCE OF COPPER TUBE
(98% Conductivity)

Source: "Chase Copper Bus Conductor Handbook," Chase Brass Co., Cleveland, Ohio, 1964.

FIGURE 4-1

60 HERTZ RESISTANCE OF ALUMINUM TUBE

#6101-T6

(55% Conductivity)

Source: "ALCOA Aluminum Bus Conductor Handbook,"
Aluminum Company of America, Pittsburgh, PA, 1957.

FIGURE 4-2

CALCULATED I^2R LOSSES OF ALUMINUM CONDUCTOR
6106-T6 AT 6000 AMPERES

FIGURE 4-3

4.2.2 Losses in Film Insulation

The use of SF₆ impregnated polypropylene film in a condenser bushing is an attractive alternative to the conventional liquid impregnated paper insulation. Polypropylene was chosen because of this high dielectric strength, low dielectric loss and good thermal and mechanical properties. Impregnated polypropylene has been used in the manufacture of power capacitors and extra high voltage power cables and has been used experimentally in condenser bushings.¹

From Figure 4-4 the following parameters were used to calculate the watts loss in the SF₆ film condenser:

Applied Voltage L-G	639 kV	Frequency	60 Hz.
Ground Foil Diameter	67 cm	Rated Cont. Current	6 kA
Lead Diameter	28 cm		
Lead Condenser Length	860 cm		
Ground Foil Length	200 cm		
Polypropylene Dielectric Constant (k)	2.2		
Polypropylene Power Factor	0.0003		
Polypropylene Thermal Conductivity (K)	1.84 milliwatts/°C-cm		
Permittivity of Free Space (E ₀)	0.0886 pF/cm		

Since the stress on the condenser varies with the distance from the center conductor, the capacitance can better be approximated by dividing the condenser into three sections: inner, center, and outer. These sections have the following parameters:

¹H. Dietz, M. Ermel, "A Condenser Bushing with SF₆ Impregnated Plastic Film Insulation," August 1979, CIGRE Third International Symposium of High Voltage Engineers, Milan.

SF₆ IMPREGNATED FILM CONDENSER TERMINATION

FIGURE 4-4

Inner: Inside Diameter 28 cm
 Outside Diameter 40.9 cm
 Average Length $(\frac{860 \text{ cm} + 638 \text{ cm}}{2}) = 749 \text{ cm}$

Center: Inside Diameter 40.9 cm
 Outside Diameter 53.8 cm
 Average Length $(\frac{639 \text{ cm} + 420 \text{ cm}}{2}) = 529.5 \text{ cm}$

Outer: Inside Diameter 53.8 cm
 Outside Diameter 66.8 cm
 Average Length $(\frac{420 \text{ cm} + 200 \text{ cm}}{2}) = 310 \text{ cm}$

Using these parameters the capacitance for each section can be calculated using the formula:

$$C = \frac{2\pi E_o k l}{\ln \frac{D_o}{D_i}}$$

When: E_o is the permittivity of free space (.0886 pF/cm)
 k is the dielectric constant of polypropylene (2.2)
 l is the average length in cm
 D_o is the outside diameter of the condenser in cm
 D_i is the inside diameter of the condenser in cm
 C is the capacitance in picofarads

$$\text{Thus: } C(\text{inner}) = \frac{2\pi \times .0886 \times 2.2 \times 749}{\ln(\frac{40.9}{28})} = 2421 \text{ pF}$$

$$C(\text{Center}) = \frac{2\pi \times .0886 \times 2.2 \times 529.5}{\ln(\frac{53.8}{40.9})} = 2366 \text{ pF}$$

$$C(\text{Outer}) = \frac{2\pi \times .0886 \times 2.2 \times 310}{\ln(\frac{66.8}{53.8})} = 1754 \text{ pF}$$

Total capacitance of the condenser can then be calculated as follows:

$$C \text{ Total} = \frac{1}{\frac{1}{C(\text{Inner})} + \frac{1}{C(\text{Center})} + \frac{1}{C(\text{Outer})}} = \frac{1}{\frac{1}{2427} + \frac{1}{2366} + \frac{1}{1754}} = 712 \text{ pF}$$

The watts loss in the polypropylene can be calculated:

$$\text{Watts} = \frac{2\pi f C V^2}{1000} (\text{power factor})$$

$$= 2\pi \times 60 \times 712 \times 10^{-12} (693 \times 10^3)^2 \times 0.0003 = 38.6 \text{ watts}$$

Where: f is the system frequency in Hz
 C is the bushing capacitance in farads
 V is the system voltage line to ground RMS
 Power factor is the power factor of polypropylene

Since this is a distributed loss throughout the polypropylene and small with respect to the I^2R loss in the conductor it will be disregarded in further calculations.

The temperature rise throughout the polypropylene can be calculated by the formula:

$$\Delta t = \frac{Q \ln \frac{D_o}{D_i}}{K 2\pi l}$$

Where: Δt is the temperature rise through the polypropylene in $^{\circ}\text{C}$
 Q is the watts loss in the conductor (from Fig. 4-3 this is 1.18 W/cm)
 D_o is outside diameter of the polypropylene in cm
 D_i is the inside diameter of the polypropylene in cm
 K is the thermal conductivity of polypropylene in watts per cm - $^{\circ}\text{C}$
 l is the length in cm of a condenser section being considered.

$$\text{Then: } \Delta t = \frac{1.18 \ln \left(\frac{67}{28} \right)}{1.84 \times 10^{-3} \times 2\pi \times 1 \text{ cm}} = 89 \text{ } ^\circ\text{C}$$

This represents the approximate temperature rise through the polypropylene film condenser with the 28 cm outside diameter aluminum conductor carrying 6000 amperes. It should be noted here, however, that we have found values of thermal conductivity (k) for polypropylene film varies somewhat, depending upon the reference, 1.89×10^{-3} watts/ $^\circ\text{C}$ -cm to 1.15×10^{-3} watts/ $^\circ\text{C}$ -cm. Using the lower value of thermal conductivity can result in a temperature rise Δt of 142.5°C . A temperature rise of 142.5°C would not be acceptable for a condenser design of polypropylene since its maximum use temperature is 120°C .

The temperature rises stated above can be used as design approximations with the assumptions made of constant temperature through the small gas insulating section and negligible temperature rise due to convection through the porcelain.

4.2.3 Losses in Semiconducting Coating

Semiconducting coatings have been used on the external surfaces of bushings and insulators for a number of years as a means for reducing radio interference. One of the proposed 1200 kV bushing termination designs would use a semiconducting coating on the inside of the weathercasing in order to divide the voltage for improved voltage grading. Being resistive, this coating does require power which is lost in the form of heating. The semiconducting coating must be carefully chosen to prevent thermal runaway. Normally the coating resistance is specified as ohms per square where a square is defined as a cylindrical height equal to pi times the diameter of the cylindrical surface to which the coating is applied. This coating was considered to

be applied to the weathercase in Figure 4-5 which is a straight porcelain weathercase with an inside diameter of 84 cm and a length of 530 cm. This length is equivalent to $\frac{530}{84 \times \pi}$ or two squares. The various voltages and waveshapes applied to the termination and 530 cm long weathercase are as follows:

Voltage	Type of Waveshape	kV/cm of length
2175 kV Crest	Impulse 1.2 x 50 μ sec	4.1 Crest
1800 kV Crest	Switching Impulse 200 x 2500 μ sec	3.4 Crest
1200 kV RMS	60 Hz 1 min. withstand	2.3 RMS (3.2 Crest)
693 kV RMS	60 Hz rated max continuous Voltage	1.3 RMS (1.8 Crest)

As stated in the Second Technical Progress Report, May 1979, Section 4.2.1, the resistive losses should be lower, if possible, than .015 watts per cm^2 at continuous operating voltage and .15 watts per cm^2 at the low frequency one minute withstand level to prevent thermal runaway and substrate damage. These two limit points are plotted on Figure 4-6. The approximate capacitance of the gas filled bushing can be calculated as:

$$C = \frac{2\pi E_o k l}{\ln \frac{D_o}{D_i}}$$

Where: C is the capacitance in picofarads

E_o is the permittivity of free space .0886 pF/cm

l is the length of the bushing in cm

k is the dielectric constant of SF_6 (1.0)

D_o is the outside diameter of the gas insulation in cm

D_i is the inside diameter of the gas insulation in cm

$$C = \frac{2 \pi .0886 \times 10^{-12} \times 1.0 \times 530}{\ln \left(\frac{84}{28} \right)}$$

STRAIGHT WEATHERCASE TERMINATION

FIGURE 4-5

FIGURE 4-6 SEMICONDUCTING GLAZE CHARACTERISTICS

This approximation assumes, however, that the conductor and weathercase are coaxial conducting cylinders for the entire 530 cm length which is not exactly the situation. Another approximation would be to ratio this calculated value of capacitance by the length of the conducting throat shield to the overall bushing length.

$$C = \frac{61 \text{ cm}}{530 \text{ cm}} \times 268 \text{ pF} = 31 \text{ pF}$$

An additional method to determine capacitance has been described in a technical paper.* This paper describes the calculation of approximate capacitance of a vertical toroid to ground using the formula:

$$C = 2\pi E_o l_e$$

Where: C is approximate capacitance in pF
 E_o is the permittivity of free space
 0.0886 pF/cm

$$l_e \text{ is } \frac{a + b + c}{3}$$

Where: a = horizontal length in cm
 b = horizontal width in cm
 c = height in cm

for a toroid a = b

$$\text{then } l_e = \frac{a + b + c}{3} = \frac{28 + 28 + 530}{3} = 195 \text{ cm}$$

$$\text{and } C = 2\pi E_o l_e = 2\pi \times .0886 \times 195 = 108.5 \text{ pF}$$

*"Capacitance Calculations for Some Basic High Voltage Electrode Configurations," by P.S. Maruvada and N. Hylten-Cavallius, IEEE Transactions Paper T75 202-7.

Considering the three capacitances calculated from the three different approximating methods above it was decided at this point to assume a capacitance of 100 pF for further calculations:

Capacitive reactance at 60 Hz can be calculated as

$$X_c = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 60 \times 100 \times 10^{-12}} = 26.5 \times 10^6 \text{ ohms (@ 60 Hz.)}$$

For a switching impulse waveshape which reaches crest voltage in 200 microseconds the frequency approximates 1250 Hz

$$X_c = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 1250 \times 100 \times 10^{-12}} = 1.27 \times 10^6 \text{ Ohms (Sw.Imp.)}$$

For an impulse waveshape which reaches crest voltage in 1.2 microseconds the frequency approximates 208.3 kHz.

$$X_c = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 208.3 \times 10^3 \times 100 \times 10^{-12}} = 7640 \text{ Ohms (Imp.)}$$

These last reactance values are plotted on Figure 4-6.

Using the points now plotted on Figure 4-6 the resistance characteristics of an appropriate semiconducting coating can now be chosen. This is shown as the curve on Figure 4-6. Next it is important to determine under which condition (60 Hz continuous, 60 Hz-1 min. withstand, switching impulse or impulse voltage) will cause the most heating of the semiconductive coating.

The impulse wave shape is sketched below:

In order to determine the heating or watts loss for this wave-shape the RMS value of this waveshape must be determined. This calculation can be facilitated by breaking the configuration up into two parts:

From t_0 to t_1 ,

Let the time from t_0 to $t_1 = T$

The equation for the line can be written as $V = \frac{V_{\max}}{T} t$

$$\begin{aligned} \text{Then } V_{\text{rms}} &= \sqrt{\frac{1}{T} \int_0^T (t)^2 dt} = \sqrt{\frac{1}{T} \int_0^T \left(\frac{V_{\max}}{T} t \right)^2 dt} \\ &= \sqrt{\frac{V_{\max}^2}{T^3} \frac{T^3}{3} \Big|_0^T} = \frac{V_{\max}}{\sqrt{3}} \end{aligned}$$

From t_1 to t_2

Let the time from t_1 to $t_2 = T$

The equation for the line can be determined as $V = mt + b$

$$\text{Where } m = \frac{V_{\max} - \frac{1}{2} V_{\max}}{0 - T} = \frac{V_{\max}}{-2T} \text{ and } b = V_{\max}$$

$$\text{Then } V = \frac{V_{\max}}{-2T} t + V_{\max}$$

$$\begin{aligned} \text{and } V_{\text{rms}} &= \sqrt{\frac{1}{T} \int_0^T \left(\frac{V_{\max}}{-2T} t + V_{\max} \right)^2 dt} \\ &= \sqrt{\frac{1}{T} \left(V_{\max}^2 t^3 \right) \Big|_0^T - \frac{(V_{\max})^2}{2T} t^2 \Big|_0^T + \frac{1}{T} (V_{\max})^2 t \Big|_0^T} \\ &= \sqrt{\frac{7}{12} (V_{\max})^2} = 0.764 V_{\max} \end{aligned}$$

Using the solutions to these equations the energy loss due to impulse and switching impulse waveshapes can be calculated.

For an impulse waveshape:

$$\text{Watts loss} = \frac{(V_{\text{rms}})^2}{R}$$

Using the curve in Figure 4-6 R is determined as approximately 1×10^3 ohms per square for an impulse waveshape or 2×10^3 for a coated weathercase 2 squares in length.

For the initial part of the waveshape from t_0 to t_1 (1.2 $\mu\text{sec.}$)

$$\begin{aligned} \text{Watts loss } t_0 - t_1 &= \frac{(V_{\text{rms}})^2}{R} = \frac{\left(\frac{V_{\text{max}}}{\sqrt{3}}\right)^2}{R} = \frac{\left(\frac{2175 \text{ kV}}{\sqrt{3}}\right)^2}{2 \times 10^3} \\ &= \frac{1.58 \times 10^{12}}{2 \times 10^3} = 790 \times 10^6 \text{ watts} \end{aligned}$$

$$\text{Energy Loss} = 790 \times 10^6 \text{ watts} \times 1.2 \times 10^{-6} \text{ sec.} = 948 \text{ w-sec}$$

For the final part of the waveshape from t_1 to t_2 (48.8 $\mu\text{sec.}$)

$$\begin{aligned} \text{Watts loss } t_1 - t_2 &= \frac{(V_{\text{rms}})^2}{R} = \frac{(.764 V_{\text{max}})^2}{R} = \frac{(.764 \times 2175 \text{ kV})^2}{2 \times 10^3} \\ &= \frac{2.76 \times 10^{12}}{2 \times 10^3} = 1380 \times 10^6 \text{ watts} \end{aligned}$$

$$\text{Energy Loss} = 1380 \times 10^6 \times 48.8 \times 10^{-6} \text{ sec} = 67,344 \text{ w-sec.}$$

Total energy loss for an impulse waveshape of 2175 kV crest is then

$$67344 + 948 \approx 68,3 \text{ Kilowatt Seconds}$$

For a switching impulse waveshape:

R is determined from Figure 4-6 to be approximately 1×10^4 ohms per square for a switching impulse waveshape or 2×10^4 for a coated weathercase 2 squares in length.

For the initial part of the waveshape from t_0 to t_1 (200 μ sec)

$$\text{Watts loss } t_0 - t_1 = \frac{(V_{\text{rms}})^2}{R} = \left(\frac{V_{\text{max}}}{\sqrt{3}} \right)^2 = \left(\frac{1800 \text{ kV}}{\sqrt{3}} \right)^2 = 54 \times 10^6 \text{ w}$$

$$\text{Energy Loss} = 54 \times 10^6 \text{ watts} \times 200 \times 10^{-6} \text{ sec} = 10,800 \text{ w-sec}$$

For the final part of the waveshape from t_1 to t_2 (2300 μ sec)

$$\text{Watts loss} = \frac{(V_{\text{rms}})^2}{R} = \frac{(.764 V_{\text{max}})^2}{R} = \frac{(.764 \times 1800 \text{ kV})^2}{2 \times 10^4} =$$

$$94.6 \times 10^6 \text{ watts}$$

$$\text{Energy Loss} = 94.6 \times 10^6 \times 2300 \times 10^{-6} = 217,580 \text{ Watt sec}$$

Total energy loss for a switching impulse waveshape of 1800 kV crest is then $217,580 + 10800 = 228.4$ kilowatt sec.

For a 60 Hz 1 minute withstand test:

$$\text{Watt loss} = \frac{(V_{\text{rms}})^2}{R} \text{ where } R \approx 10^6 \text{ ohms per square or}$$

2×10^6 ohms for a coated bushing 2 squares long.

$$\text{Watt loss} = \frac{(1200 \text{ kV})^2}{2 \times 10^6} = 0.72 \times 10^6 \text{ watts}$$

$$\text{Energy loss} = .72 \times 10^6 \times 3600 \text{ sec} = 2592 \text{ megawatt sec}$$

For a continuously applied 60 Hz voltage:

$$\text{Watts loss} = \frac{(V_{\text{rms}})^2}{R} \text{ where } R \approx 10^8 \text{ ohms per square or } 2 \times 10^8 \text{ ohms for a coated bushing 2 squares long}$$

$$\text{Watts loss} = \frac{(693 \text{ kV})^2}{2 \times 10^8} = 0.0024 \times 10^6 \text{ watts}$$

The results of these calculations are tabulated below:

<u>Applied Voltage</u>	<u>Semiconducting Watts Loss</u>	<u>Coating Energy Loss</u>
2175 kV 1.2 x 50 μ sec Impulse Waveshape	2170 x 10 ⁶ watts	68.3 kW-sec
1800 kV 200 x 2500 μ sec. Switching Impulse Waveshape	148.6 x 10 ⁶ Watts	228.4 kW-Sec
1200 kV rms 1 Min. 60 Hz Withstand	0.72 x 10 ⁶ watts	2592000 kW-Sec
693 kV rms Line to Ground Continuously	0.0024 x 10 ⁶ watts	---

From the calculations and above tabulation it is expected that the 60 Hz 1 minute withstand test will provide the most severe duty for the semiconducting coating.

4.3 Temperature Rise Due to Convection

For a typical SF_6 gas filled high voltage termination, where the gas is the primary insulation, heat transfer must be considered in four areas:

1. Convection from conductor into gas
2. Convection from gas into weathercase
3. Conduction through the weathercase
4. Convection from weathercase to the air

It can be safely assumed that radiation losses are negligible and that the temperature rise due to conduction through the porcelain is small in relation to the temperature rise due to convection. Since the bushing hot spot is located at mid top porcelain, the end effects caused by termination axial heat conduction from that spot in the lead are negligible. Additionally it is assumed that the SF_6 gas is at the constant temperature throughout. The heating due to application of semiconducting glaze is not included in these calculations. A quick approximation of the temperature rise in the lead can be determined by calculating the three remaining convection temperature differences.

4.3.1 Convection from Conduction Into Gas

The characteristic heat transfer calculations from conductor to SF_6 gas are well known. A technical paper published in 1970* describes methods for determination of this convection temperature rise as a function of gas pressure and heat in the lead. A curve has been extracted from this paper and is shown in Figure 4-7. For example, assume an aluminum conductor O.D. of 15.2 cm with a 1.3 cm wall thickness.

* "Calculated Heat Transfer Characteristics of Air and SF_6 ," by H.C. Doepkin, IEEE Paper No 70TP 173-PWR.

FIGURE 4-7

Resistance of this lead is 6.2 micro ohms per meter as taken from the curve in Figure 4-2.

At 6000 amperes continuous

$$p = I^2 R = (6000)^2 \times 6.2 \times 10^{-6} = 223 \text{ watts/meter}$$

The surface area of 1 meter of 15.2 cm dia. conductor is 4788 cm². Thus heat generated at the conductor is $\frac{223}{4788}$ or .047 w/cm².

From Figure 4-7 the temperature rise from the conductor into the SF₆ is 23°C. Next the effect of the heat transfer from SF₆ gas into the weathercase will be considered.

4.3.2 Convection from SF₆ Gas to Porcelain

The surface area of 1 meter of a 84 cm I.D. porcelain is

$$\pi \times D \times 100 \text{ cm} = 26390 \text{ cm}^2$$

The same 223 w/m from the conductor must be transferred through the gas to porcelain.

Thus heat generated as a function of the area of the inside porcelain is $\frac{223}{26390} = 8.45 \text{ milliwatts/square cm.}$

From Figure 4-7 an approximation of the temperature rise from the gas to porcelain can be determined as 6.5°C.

4.3.3 Convection from Porcelain to Air

Assuming an outer diameter of porcelain to be 89 cm. Neglecting the surface area of the irregularly shaped weathersheds and assuming the convective dissipation of porcelain to be 1.24 milliwatts/square centimeter - °C

The surface area of 1 meter of porcelain is

$$\pi D \times 100 \text{ cm} = \pi \times 89 \times 100 = 27960 \text{ square centimeters}$$

with 225 watts/meter in the conductor, the above area yields 8 milliwatts/square centimeter. At the stated convection disipation this gives $\frac{8}{1.24} = 6.5^\circ\text{C}$ temperature difference.

Now the total temperature rise of the conductor can be determined by adding these three conductive temperature rises:

$$\begin{aligned}\Delta t_{\text{total}} &= \Delta t_1 + \Delta t_2 + \Delta t_3 \\ &= 23^\circ\text{C} + 6.5 + 6.5 = \underline{\underline{36^\circ \text{ Rise}}}\end{aligned}$$

As proof that the temperature drop through the porcelain is small and can be neglected, consider:

$$\Delta t = \frac{Q}{K} \frac{\ln \frac{D_o}{D_i}}{2 \pi l}$$

Where: Δt is the temperature rise in degrees C due to conduction through the porcelain

K is the thermal conductivity of porcelain which is equal to 14 mw/cm °C

Q is the watts per cm length of the 84 cm I.D. porcelain. At 6000 amperes, 225 watts/meter of the 15.2 cm diameter conductor is generated or 2.25 watts per cm length.

l is the length of the section being considered or 1 cm in this case.

D_o is the outside diameter of the porcelain in cm.

D_i is the inside diameter of the porcelain in cm.

Then:

$$\Delta t = \frac{2.25 \ln \frac{89}{84}}{2\pi \times .014 \times 1} = 1.5^{\circ}\text{C}$$

A convenient tool for estimating the temperature rise of an SF₆ gas termination is shown in Figure 4-8. This figure can be used as in the example just calculated to give a rapid estimation of the conductor temperature rise. Assumptions made in constructing the curve are:

- a. The mean diameter of the porcelain is equal to three times the conductor diameter. Many bushing designs follow this criteria since it optimizes voltage stress on the inner conductor and outer shield. See Figure 4-2 of the Second Technical Progress Report - May 1979.
- b. Thermal dissipation of the porcelain to air interface is 3.15 mw/cm² - °C.

Temperature Rise of SF₆ Gas Bushings at 4 to 5 Atmospheres Pressure

NOTE: SF₆ convection characteristics determined from IEEE Paper #70TP173 "Calculated Heat Transfer Characteristics of Air and SF₆," by H.C. Doepkin, Jr. Additional assumptions include inner porcelain diameter three times the conductor diameter and dissipation to atmosphere 15.5 mw/cm² - °C

- c. End effects caused by terminations are negligible. That is to say that no axial conduction occurs in the conductor.
- d. Radiation losses as well as conduction through the porcelain insulator are neglected.

The curve is temperature rise in °C vs. watts per square centimeter of conductor surface.

As further proof of validation of the curve of Figure 5, points of a number of actual temperature rise tests performed at the laboratories of the Westinghouse Electric Corporation, Power Circuit Breaker Division, have been plotted and show close correlation with the curve.

4.4 SUMMARY OF HEAT TRANSFER CALCULATIONS

The determination of approximate performance of the various 1200 kV designs proposed is tabulated in Table 4-1.

For the semiconducting coating design, the coating should be selected to have resistance characteristics for various voltage stresses as outlined in Figure 4-6. These characteristics will provide grading for all voltage waveshapes with minimum heating without damage to the substrate or thermal runaway.

Of importance is that various reference sources give differing values of thermal conductivity for polypropylene. These variations have a considerable effect on the calculated rise through the insulator.

Approximate Performance of the Various

1200 kV Designs Proposed

Parameter	Thin Film Polypropylene Condenser Design 28 cm Dia.Al Cond	Semiconducting Coating Design 28 cm Dia.Al Cond	SF ₆ Filled Design	
			28 cm Dia.Al Conductor	15.3 cm Dia.Al Conductor
6000A I ² R Loss in the Conductor	118w/m	118w/m	118w/m	223w/m
Temperature Rise Thru Insulation (neglecting heating due to semiconducting glaze if used)	88.9°C	16°C*	16°C*	36°C
I ² R Loss in Semiconducting Coating- Continuously Energized	-	2400 Watts	-	-
Approximate Capacitance to Ground	711 pF	100 pF	100 pF	
Capacitive Reactance @ 60 Hz		26.5 x 10 ⁶ Ω	26.5 x 10 ⁶ Ω	
Capacitive Reactance @ Switching Impulse		1.27 x 10 ⁶ Ω	1.27 x 10 ⁶ Ω	
Capacitance Reactance @ Impulse		7640 Ω	7640 Ω	
Coating Watts Loss - Impulse	-	2170 x 10 ⁶	-	-
Coating Energy Loss - Impulse	-	68.3 kW-Sec.	-	-
Coating Watts Loss - Switching Impulse	-	148.6 x 10 ⁶	-	-
Coating Energy Loss - Switching Impulse	-	228.4 kW-Sec.	-	-
Coating Watts Loss - 60 Hz-1 Min Withstand	-	.72 x 10 ⁶	-	-
Coating Energy Loss - 60 Hz-1 Min Withstand	-	2592 kW-Sec.	-	-
Coating Watts Loss - 60 Hz Continuous	-	.0024 x 10 ⁶	-	-

*From Curve Figure 4-8

TABLE 4-1

A curve has been presented (Figure 4-8) that will facilitate estimating the temperature rises for SF₆ insulated termination designs. Existing termination designs conform closely to this calculated curve. The curve is ideal for quickly estimating temperature rise performance of various proposed designs.

4.5 WORK TO BE UNDERTAKEN IN THE NEXT PERIOD

The calculations presented in this section on thermal transport are approximate estimates of performance of the various designs proposed. All of the designs proposed appear to be worthy of further consideration from the thermal aspect. Additional work to be performed will include:

1. A thorough determination of temperature rises at critical areas such as gaskets. Westinghouse Research and Development will assist with this thermal analysis to include axial conduction in the conductor, radiation and convection from the conductor to the enclosure through the insulating gas, conduction through the weathercase enclosure and radiation and convection from the external surface to ambient. The effects of the top terminal and grounded throat hardware will also be considered as well as heating due to semiconducting coating.
2. Suggestions for design modifications will be made for problem areas encountered.

5.0 TASK 4 - MECHANICAL STUDIES

5.1 SHATTER RESISTANT WEATHERCASE

5.1.1 Material Tests

Testing was done to determine the characteristics and effectiveness of a fiberglass mesh cast into epoxy. The tests were performed by breaking bars of epoxy containing a mesh cast near the surface of one edge. Three different epoxy formulations and three meshes were used and broken as in Figures 5-1 through 5-5. Results for the tests are shown in Table 5-1. The mesh sizes used are shown in Figure 5-6 and the epoxy characteristics are shown in Table 5-2.

The results of this test agreed very well with predicted results based on stress considerations. As load is applied to the bar of epoxy, the break characteristic is dependent upon the relative flexibilities and tensile strength of the epoxy and fiberglass and the epoxy-fiberglass bond shear strength.

Define:

- R_b = Fiber Bundle Radius
- L_1 = Partial Length of Fiber
- W = Bar Width
- N = Number of Fibers in a Bundle
- R = Fiber Radius (each filament)
- σ_e = Epoxy Tensile Stress

Epoxy Bar Break Test

FIGURE 5-1

TABLE 5-1

<u>Test No.</u>	<u>Epoxy Type</u>	<u>Fiberglass Mesh</u>	<u>Initial Break (kg)</u>	<u>Final Break (kg)</u>	<u>Comments</u>
1	53841TK	None	-	742	Clean Break In Middle.
2	53841TK	101CRX	742	424	Cracks Near Center. Mesh Did Not Break.
3	53841TK	301CRX	721	181	Axial & Longitudinal Cracks. Mesh Did Not Break.
4	53841TK	525CRX	671	390	Crack In Center. Mesh Broke After Initial Break.
5	53841MC	None	-	689	Clean Break In Middle.
6	53841MC	101CRX	544	594	Axial & Longitudinal Cracks. Mesh Did Not Break.
7	53841MC	301CRX	556	408	Axial & Longitudinal Cracks. Mesh Did Not Break.
8	53841MC	525CRX	590	445	Clean Break In Middle, First Epoxy, Then Mesh.
9	53841VC	None	-	621	Clean Break In Middle.
10	53841VC	101CRX	655	735	Center Break. Mesh Did Not Break But Began To Fray & Slip.
11	53841VC	301CRX	585	644	Center Break. Mesh Did Not Break But Began To Fray & Slip.
12	53841VC	525CRX	558	413	Center Break, Then Mesh Slipped Until Breaking.

TESTING MACHINE

SETUP BEFORE
BREAK

REMAINS OF
SAMPLES

FIGURE 5-2

EPOXY 53841TK

MESH 101CRX

MESH 301CRX

MESH 525CRX

FIGURE 5-3

EPOXY 53841MC

MESH 101CRX

MESH 301CRX

MESH 525CRX

FIGURE 5-4

EPOXY 53841VC

MESH 101CRX

MESH 301CRX

MESH 525CRX

FIGURE 5-5

101 CRX-

END
VIEW

301 CRX-

END
VIEW

525 CRX-

END
VIEW

FIGURE 5-6

TABLE 5-2

Epoxy Characteristics

	<u>53841 TK</u>	<u>53841 MC*</u>	<u>53841 VC</u>
1. Tensile Strength, psi at 25°C	4200		3340
2. Tensile modulus, 100°C	1×10^6		0.44×10^6
3. Flexural Strength at 24°C	9300		-
4. Flexural modulus, 25°C	1.0×10^6		1×10^4
5. Compressive strength at 25°C	20,000		10,000
6. Izod impact strength ft-lb/in Notch	0.7		0.3
7. Dielectric constant, 60 Hz, 105°C	5.5		6.7
8. % power factor, 1 kV Hz, 25°C	2.0		2.6
9. Specific gravity	1.70		1.68

*Characteristics intermediate between 53841 TK and 53841VC; not yet precisely determined.

σ_f = Fiber Tensile Stress

f_l = Load on Fiber at Break Point

σ_B = Bend Stress in Bar

σ_g = Epoxy Shear Strength

f_s = Fiber Slip Load

For the glass fibers to slip as the epoxy breaks, the allowed fiber tensile stress load must be greater than the epoxy-fiberglass shear bond strength.

$$f_l = N\sigma_f(\pi R^2)$$

$$f_s = \pi R_b L \sigma_g$$

If f_l/f_s is greater than one, the fiber mesh will slip when the epoxy breaks.

$$f_l/f_s = \frac{NR^2\sigma_f}{R_b L \sigma_g} \quad \text{Equ. 5-1}$$

Typical values for the parameters are:

R = 0.003 to 0.012 mm

σ_f = 300,000 to 500,000 psi (2.17 to 3.5 GPa)

R_b = 0.381 mm to 1.1 mm

L = 305 mm

σ_g = 500 to 4000 psi (3.4 to 27.6 MPa)

N = assume as average of best and worst packing.

This gives an f_1/f_s range of 0.08 to 3.17. This says that the small bundle diameter mesh will probably break and the large bundle diameter mesh will slip when the epoxy breaks. This was the result found in general. The small bundle mesh 525 CRX broke each test, although the epoxy failed before the mesh. The larger bundle mesh slipped in the epoxy but in no case did they break. This slip condition is the desired characteristic of the mesh imbedded in a cylindrical insulator, allowing gas release cracks to form but not allowing massive mechanical failure and projectile creation.

The bulk strength, S_B , of the mesh can be calculated by:

$$S_B = \frac{(\text{Load}) L}{(\text{Mesh Width}) 4b} \quad (\text{All mesh pieces were 101 mm wide})$$

The test results give strengths for each mesh of:

Mesh Designation	Minimum Strength kg/mm width	Maximum Strength kg/mm width	Supplier Quote Strength kg/mm width
101 CRX	29.1	-	28.3
301 CRX	25.5	-	28.3
525 CRX	16.3	17.6	15.5

The needed strength for a cylindrical insulator can be estimated and for a 762 mm diameter insulator at 65 psig gas pressure it is 17.3 kg/mm. This strength will hold the insulator together even if a crack should form. This means that meshes 101 CRX and 301 CRX should be sufficient to bind an epoxy insulator of a 1200 kV size range without disastrous failure. The 525 CRX will be suitable for smaller insulators. Mesh 301 CRX bonded more uniformly and allowed less epoxy to break loose in the flat bar tests. It is also easier to handle in production. Because of this, 301 CRX will be used for the scale model tests and is planned for use in the 1200 kV insulator if the mesh model tests results are satisfactory.

Mesh 525 CRX will be used in the scale model tests because it is a more proper size and strength for the smaller, lower stressed epoxy and will provide good comparison data.

Epoxy 53841 VC, the weakest formulation tested, will not be used for future models because it is very flexible and not suitable for the durable insulator desired. Epoxy 53841 TK is the strongest and least flexible and is considered to be the most brittle acceptable grade of epoxy. Epoxy 53841MC will probably be the most useful formulation, having a good combination of toughness, flexibility and tensile strength.

5.1.2 Model Design

A test model was designed to determine the effectiveness of a fiberglass mesh cast into a conical epoxy insulator, Figure 5-9.

5.1.3 Work to be Done

Five epoxy insulators, Figure 5-9, will be made.

1. Epoxy 53841 MC with no mesh.
2. Epoxy 53841 MC with mesh 301 CRX.
3. Epoxy 53841 MC with mesh 525 CRX.
4. Epoxy 53841 TK with mesh 301 CRX.
5. Epoxy 53841 TK with mesh 525 CRX.

Missing materials data will be obtained.

FIGURE 5-7 DELETED TO PROTECT WESTINGHOUSE AND DEPARTMENT
OF ENERGY PATENT RIGHTS ON SUBJECT MATERIAL.

FIGURE 5-8 DELETED TO PROTECT WESTINGHOUSE AND DEPARTMENT OF
ENERGY PATENT RIGHTS ON SUBJECT MATERIAL.

SHATTER RESISTANT INSULATOR MODEL

FIGURE 5-9

These will be pressurized and mechanically failed in a test fixture, Figure 10, to gain performance data. The 1200 kV insulator will be designed based on these tests if a reinforced epoxy model is chosen.

Thermal studies will be conducted on test slabs of epoxy with the mesh cast in to determine mesh-to-epoxy adhesion after temperature cycling. Sufficient samples will be tested to develop a statistical prediction of performance.

Study will also begin to develop an epoxy joining technique to connect several epoxy insulators together.

5.2 REINFORCING LINER

5.2.1 Model Design

Design effort was reduced in this quarter due to the need for test data from the lined porcelain explosion tests in process. Two additional designs were considered. Figure 5-11 shows a possible flanged bushing design. Mechanical load on the porcelain is low because the liner resists most of the pressure load and can give lateral support at the plug-contact interface. This design is less complex and more reliable than a spring loaded bushing and still greatly reduces porcelain stress and explosion danger while allowing large manufacturing tolerances.

Figure 5-12 shows a simplified spring loaded design using a large sliding seal to isolate the liner-insulator gas gap. During normal operation, there is no pressure difference across the seal. If the weathercase fails mechanically, the seal will limit gas energy available to the insulator, yet retain the gas inside for a long period of time, although the seal is not intended for long term SF₆-to-atmosphere integrity. This design is also much simpler and less expensive than previous work.

FIGURE 5-10

SHATTER RESISTANT INSULATOR--EXPLOSION TEST ASSEMBLY

FIGURE 5-11

FIGURE 5-12

5.2.2 Work to be Done

Testing of the lined and unlined porcelain insulator, Figure 5-13, will be completed and the data compared with the computer predictions of particle scatter. The computer program will be modified if necessary to provide accurate prediction of a 1200 kV size bushing.

Drafting layout will be done to develop sketches of the most promising bushing designs sufficient to make cost estimates of each. This will lead to one eventual cost advantage design for 1200 kV.

5.3 CLAMPING AND FASTENING

5.3.1 All work accomplished this Quarter is described in previous sections.

5.3.2 Work to be Done

Design will begin to develop the lower attachment of an epoxy weathercase, clamped porcelain or lined porcelain. Layout will begin to develop cost analysis sketches and stress design analysis.

FIGURE 5-13

LINED PORCELAIN INSULATOR--EXPLOSION TEST ASSEMBLY

6.0 TASK 5 - MODEL STUDIES

6.1 Shield Effectiveness

6.1.1 Model Construction

Manufacturing is nearly complete on the parts for the shield effectiveness model. The design is built around a 242 kV flanged porcelain weathercasing purchased by Westinghouse for another project. As shown in Figure 6-1, the metal parts were designed to allow for several variations of key parameters. One of three different inner conductor diameters may be screwed into a receptacle inside the porcelain cavity. Four different throat shields will be available for attachment to the flange adapter. Three throat shield heights and two throat shield radii are the parameters being varied. The effectiveness of voltage control outside the porcelain weathercasing due to internal shielding in a simple gas termination will be tested using these parts. An optional top shield extension was also included to determine the effectiveness of vertical cylindrical shielding.

6.1.2 Tests To Be Performed

To investigate the effect of conductor diameter, throat shield height, and top shield, tests will be performed as outlined on Table 6-1. During the tests the test models will be pressurized with SF₆ gas at approximately .50 MPa.

Tests 1 through 5 will be made as 60 Hz rapid rise tests with the voltage increased to the point where visible corona is observed along the porcelain. From past experience it is expected that the locations of this corona will be at approximately the throat shield height. External flashovers on this test series will not be attempted as damage to the porcelain shell could occur.

SHIELD EFFECTIVENESS MODEL
FIGURE 6-1

TABLE 6-1 SHIELD EFFECTIVENESS MODEL TESTS

<u>Test Series</u>	<u>Type Test</u>	<u>Conductor Diameter-cm</u>	<u>Throat Shield Height-cm</u>	<u>Top Shield</u>
1	60 Hz Corona Start	20.3	20.3	Standard
2	60 Hz Corona Start	20.3	40.6	Standard
3	60 Hz Corona Start	15.2	20.3	Standard
4	60 Hz Corona Start	15.2	40.6	Standard
5	60 Hz Corona Start	7.5	30.5	Standard
6	Lightning Impulse	7.5	30.5	Standard
7	Lightning Impulse	7.5	30.5	Extension
8	Switching Impulse Wet	7.5	30.5	Standard
9	Switching Impulse Wet	7.5	30.5	Extension
10	Lightning Impulse	20.3	30.5	Standard
11	Lightning Impulse	15.2	30.5	Standard

On test series 6 the external withstand of the test model equipped with the standard terminal will be determined for lightning impulse waves (1.2/50 μ s.)

The test will start at about 800 kV and the voltage increased in 50 kV steps until flashover occurs. The statistical withstand level will then be determined using the 3/3 series. These tests will be made at both positive and negative polarity.

Test series 7 will be performed the same as series 6 except that the test model will be equipped with the shield extension.

Test series 8 and 9 will be performed in the same manner as 6 and 7 except that the switching impulse wave (250/2500 μ s.) will be used and the starting level will be 650 kV.

Test series 10 and 11 are intended to investigate the possible failure mode of the test model equipped with large diameter conductors.

The lightning impulse wave (1.2/50 μ s.) will be applied starting at about 300 kV and increased in 50 kV steps until flashover occurs. This level will be compared to the results of test series 6. In making these tests extreme caution will be required as the possibility of porcelain rupture exists.

6.2 Mechanical Models

Parts have been received for the lined porcelain test assembly shown in Figure 5-13. Preparations are underway to perform the controlled explosion tests. Special efforts are being made to conduct the tests in a safe manner.

The assembly jig and test fixture for the reinforced epoxy model shown in Figure 5-10 have been ordered. Models are expected to be built and tested during the next period.

The test series for the mechanical models is shown in Table 6-2. The test layout is shown in Figure 6-2.

1200 kV WEATHERCASE MODEL TEST PLAN

Porcelain Series:

1. Standard, Unlined Porcelain Pressurized To 65 psig SF_6 .
2. Standard, Unlined Porcelain Pressurized To 5 psig SF_6 .
3. Lined Porcelain; Pressurized To 65 psig In The Porcelain-Liner Gap.
4. Lined Porcelain; Pressurized To 5 psig In The Porcelain-Liner Gap.

Reinforced Epoxy Series:

1. Unreinforced Epoxy Bushing Pressurized To 65 psig SF_6 . Epoxy 53841MC.
2. Reinforced Epoxy, Mesh 301CRX, Pressurized To 65 psig SF_6 . Epoxy 53841MC.
3. Reinforced Epoxy, Mesh 525CRX, Pressurized To 65 psig SF_6 . Epoxy 53841MC.
4. Reinforced Epoxy, Mesh 301CRX, Pressurized To 65 psig SF_6 . Epoxy 53841TK.
5. Reinforced Epoxy, Mesh 525CRX, Pressurized To 65 psig SF_6 . Epoxy 53841TK.

FIGURE 6-2

7.0 TASK 9 - REPORTING

Under this task the following reports were prepared and submitted to DOE during the reporting period:

<u>Quantity</u>	<u>Report Title</u>
4	Project Status Reports
4	Contract Management Summary Reports
4	Cost Management Reports
1	Conference Record
1	Technical Progress Report

7.1 Program Status

The progress of each individual subtask is shown in the program schedule Figure 7-1. This same schedule will be incorporated in each quarterly report as a means of showing clearly the technical progress on the project.

7.2 Manpower Status

With regard to the manpower utilization in the project, the key personnel have been committed to carrying out this project in an efficient and timely manner.

<u>Key Personnel</u>	<u>Hours Worked During Reporting Period (5-1-79 to 8-31-79)</u>
J. S. Billings	322 Hours
Z. Neri	122 Hours
C. F. Cromer	126 Hours
R. W. Crookston	6 Hours

Total manhours Worked Druing the Reporting Period (Including Key Personnel):

Task 1	88 Manhours	Task 4	165 Manhours
Task 2	218 Manhours	Task 5	74 Manhours
Task 3	297 Manhours	Task 9	184 Manhours

SCHEDULE FOR 1200 kV TERMINATION

TASK 1 - CONCEPTUAL DESIGN AND MATERIAL STUDY

- 1.1 PROBLEM DEFINITION
- 1.2 INNOVATIVE CONCEPTS
- 1.3 MATERIALS INVESTIGATION
- 1.4 FABRICATION TECHNIQUES

TASK 2 - ELECTROSTATIC STUDIES

- 2.1 SHIELD EFFECTIVENESS
 - 2.1.1 CONCEPT STUDY AND MODEL DESIGN
 - 2.1.2 ESTABLISH TEST OBJECTIVES
 - 2.1.3 DATA EVALUATIONS & RECOMMENDATIONS
- 2.2 RESISTIVE GRADING
 - 2.2.1 GRADING OBJECTIVES & CRITERIA
 - 2.2.2 DESIGN MODELS
 - 2.2.3 ESTABLISH TEST OBJECTIVES
 - 2.2.4 DATA EVALUATIONS & RECOMMENDATIONS
- 2.3 FIELD PLOTTING

TASK 3 - THERMAL STUDIES

- 3.1 THERMAL TRANSPORT STUDY
- 3.2 HEAT PIPE STUDY

TASK 4 - MECHANICAL STUDIES

- 4.1 SHATTER-RESISTANT WEATHERCASE
 - 4.1.1 CONCEPT STUDY, MODEL DESIGN, AND TEST CRITERIA
 - 4.1.2 DATA EVALUATIONS & RECOMMENDATIONS
- 4.2 REINFORCING LINERS
 - 4.2.1 CONCEPT STUDY, MODEL DESIGN, AND TEST CRITERIA
 - 4.2.2 DATA EVALUATIONS & RECOMMENDATIONS
- 4.3 CLAMPING AND FASTENING

TASK 5 - MODEL STUDIES

- 5.1 SHIELD EFFECTIVENESS
- 5.2 RESISTIVE GRADING
- 5.3 SHATTER RESISTANT WEATHERCASE
- 5.4 REINFORCING LINER

TASK 6 - DESIGN OF A PROTOTYPE

- 6.1 FINALIZE DESIGN PARAMETERS
- 6.2 MAKE ENGINEERING DRAWINGS
- 6.3 REVIEW AND EVALUATE

TASK 7 - PRODUCTION AND THE TESTING OF A PROTOTYPE

- 7.1 QUALITY ASSURANCE & PREPARATIONS FOR TEST
- 7.2 PROCUREMENT OF SPECIAL TOOLING AND COMPONENT PARTS
- 7.3 FABRICATING THE WEATHERCASE AND ASSEMBLING THE PROTOTYPE
- 7.4 ELECTRICAL DESIGN TESTS
- 7.5 OTHER DESIGN TESTS
- 7.6 REVISE & FINALIZE DRAWINGS
- 7.7 DISASSEMBLY PROTOTYPE
- 7.8 MODIFY PROTOTYPE
- 7.9 REASSEMBLE PROTOTYPE
- 7.10 COMPLETE TESTS

TASK 8 - DELIVERY OF THE PROTOTYPE AND MONITORING PERFORMANCE

TASK 9 - REPORTS & RECOMMENDATIONS

FIGURE 1

8.0 SUMMARY

Parts have been recieved for the model assembly for the Electrostatic Shield Study (Task 2.1). Tests are expected to be completed in the next quarter. A model has been designed and the Resistive Grading Study (Task 2.2) will be underway in the next period. Field maps (Task 2.3) will be made as needed.

Preliminary calculations made by the Thermal Transport Study (Task 3.1) showed that the film-SF₆ condenser will be at best marginal at 6000 amperes without cooling, so a Heat Pipe Study (Task 3.2) may be required. Further studies will be performed in the next quarter.

Samples of epoxy weathercase materials containing various fiberglass meshes were broken and the design parameters for the Shatter Resistant Weathercase (Task 4.1) were refined. Construction and test equipment for model tests are being made and tests are expected to be made in the next quarter. Parts have been received for the Reinforcing Liner (Task 4.2) Models to be tested in the next period. Several new top end configurations were drawn up as part of the clamping and fastening study (Task 4.3).

All studies were delayed by the two week shutdown and seven week strike at the Trafford Plant.