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MASTER

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

Fifth Technical Progress Report for the Period
December 1, 1979—February 29, 1980

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

Fifth Technical Progress Report

Reporting Period: December 1, 1979 to February 28, 1980

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of a 1200 kV Prototype Termination

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1.0 ABSTRACT

Detailed analytic and model studies of various 1200 kV termination concepts underway during the present period are described. Test results are reported for the electrostatic field enhancement and the shatter-resistant weathercase studies. Optional materials, configurations, and fabrication plans are expected to be determined upon completion of these studies.

2.0 INTRODUCTION

This is the Fifth 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 substation. 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 the prototype termination to an appropriate field site.

3.0 TASK 2 ELECTROSTATIC STUDIES

3.1 Shield Effectiveness Study

As described in Section 4.1 of the Second Technical Progress Report an external flashover in a simple gas bushing is the result of either insufficient strike distance or the high gradient that can exist at the bottom of the bushing. In a condenser bushing the external flashover is always the result of the insufficient strike distance (which we may call top to bottom failure, as the field is basically uniform along the weathercasing. To investigate the effect of conductor size and top shielding on the performance of a simple gas bushing a Shield Effectiveness Model was constructed (see Figure 3-1).

3.1.1 Top to Bottom Capability

The strike distance of the test bushing is 1750 mm. From past experiences it can then be estimated that the maximum voltage withstand of the bushing will be approximately as follows:

A.	Lightning Impulse 1.2/50 μ s	1050 kV
B.	Switching Impulse Wet 250/2500 μ s	700 kV
C.	60 Hz Dry	60 kV rms

The above values would be expected if the failure is top to bottom and not caused by excessively high gradients at the bottom of the bushing.

Figure 3-1

242kV Test Bushing with 3.3 X 3.3 m Ground Plane

3.1.2 Tests Conducted

The original proposed tests are outlined on Table 3-1. Test series 1, 2 and 10 (20.3 cm conductor) could not be made because with this configuration internal flashover preceeded external flashover. On the configurations with the 15.2 cm and 7.5 cm conductors all tests consisting of 60 Hz, lightning impulse and wet switching impulse were taken to external flashover. Selected tests were made with a 3.3m x 3.3m ground plane installed at the bottom of the bushing as shown on Figure 3-1.

3.1.3 Test Methods and Results

During the test series over 350 individual tests were made. A resume of test methods and results will be outlined in the following sections.

3.1.3.1 Lightning Impulse with 7.5 cm Conductor

Tests were made using the 3/3 test series with an impulse wave of 1.2/50 μ s to determine the maximum external withstand of the specified configuration. Tests were made with both the standard top shield and the shield extension. Selected (low values omitted) test results are shown on Table 3-2.

3.1.3.2 Lightning Impulse With 15.2 cm Conductor

Test procedure described in 3.1.3.1 was followed. Test results are shown on Table 3-3.

TABLE 3-1 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

SHIELD EFFECTIVENESS MODEL

7.5 cm CONDUCTOR

LIGHTNING IMPULSE PERFORMANCE

<u>Top Shield</u>	<u>Test Voltage kV and Results</u>	
Standard	+ Polarity	- Polarity
	1059 O.K.	1085 O.K.
	1054 O.K.	1080 O.K.
	1059 O.K.	1080 O.K.
	1090 F.O. Ext.	1121 F.O. Int.
	1080 O.K.	1111 F.O. Int.
	1080 O.K.	
	1075 F.O. Ext.	
Extension	1023 O.K.	1023 O.K.
	1023 O.K.	1023 O.K.
	1013 O.K.	1023 O.K.
	1044 F.O. Ext.	1070 F.O. Int.
	1044 F.O. Ext.	1059 O.K.
		1069 F.O. Int.

Table 3-2

SHIELD EFFECTIVENESS MODEL

15.2 cm CONDUCTOR

STANDARD TOP SHIELD LIGHTNING IMPULSE PERFORMANCE

Test Voltage (kV) and Results

+ Polarity	- Polarity
786 O.K.	817 O.K.
786 O.K.	817 O.K.
876 O.K.	821 O.K.*
811 O.K.	837 O.K.
811 O.K.	837 O.K.
811 O.K.	837 O.K.
848 O.K.	879 O.K.
848 O.K.	879 F.O. Ext.
868 F.O. Ext.	868 F.O. Ext.
868 F.O. Ext.	863 O.K.*
	863 O.K.
	863 O.K.

*These were partial flashovers with streamers at bottom part of the porcelain.

Table 3-3

3.1.3.3 Wet Switching Impulse with 7.5 cm Conductor

Tests were made using the 3/3 test series with an impulse wave of 250/2500 μ sec. Tests were conducted up to external flashover. The simulated rain had a rate of 0.5cm/min and a resistivity of 17,500 ohm-cm. Test results are shown on Tables 3-4 and 3-5.

3.1.3.4 Wet Switching Impulse with 15.2 cm Conductor

Test procedure described in 3.1.3.3 was followed. Test results are shown on Table 3-6 and 3-7.

3.1.3.5 60 Hz Performance

One minute withstand tests were made. The voltage was raised in approximately 25 kV steps until flashover was experienced. The results for the various configurations tested are given on Table 3-8.

3.1.3.6 Lightning Impulse with Ground Plane at Bottom of Porcelain

For the configuration with the extension on the top shield and using the 15.2 cm conductor, a short series of lightning impulse tests was made with a 3.3 x 3.3 m ground plane installed at the bottom of the bushing as shown on Figure 3.1. On positive polarity external flashover was experienced at 925 kV and at 1050 kV on negative polarity.

SHIELD EFFECTIVENESS MODEL

7.5 cm CONDUCTOR

STANDARD TOP SHIELD SWITCHING IMPULSE PERFORMANCE

Test Voltage (kV) and Results

+ Polarity	- Polarity
655 O.K.	703 O.K.
687 O.K.	708 O.K.
687 O.K.	708 O.K.
724 O.K.	739 O.K.
724 O.K.	734 O.K.
724 F.O. Ext.	729 F.O. Ext.
760 F.O. Ext.	770 O.K.
760 O.K.	760 F.O. Ext.
760 O.K.	770 F.O. Ext.
775 F.O. Ext.	
775 F.O. Ext.	
775 F.O. Ext.	

Table 3-4

SHIELD EFFECTIVENESS MODEL

7.5 cm CONDUCTOR

EXTENSION ON TOP SHIELD SWITCHING IMPULSE PERFORMANCE

Test Voltage (kV) and Results

+ Polarity	- Polarity
713 F.O. Ext.	703 O.K.
713 O.K.	703 O.K.
713 F.O. Ext.	703 O.K.
689 O.K.	734 O.K.
698 O.K.	734 O.K.
698 O.K.	734 O.K.
734 F.O. Ext.	770 F.O. Ext.
734 F.O. Ext.	770 O.K.
734 F.O. Ext.	770 F.O. Ext.

Table 3-5

SHIELD EFFECTIVENESS MODEL

15.2 cm CONDUCTOR

STANDARD TOP SHIELD SWITCHING IMPULSE PERFORMANCE

<u>Test Voltage (kV) and Results</u>	
+ Polarity	- Polarity
667 O.K.	670 F.O. Ext.
667 O.K.	670 F.O. Ext.
677 O.K.	512 O.K.
693 F.O. Ext.	506 O.K.
693 O.K.	512 O.K.
693 F.O. Ext.	553 O.K.
	553 O.K.
	548 O.K.
	563 F.O. Ext.
	568 O.K.
	574 O.K.
	605 O.K.
	605 O.K.
	599 O.K.
	625 O.K.
	625 O.K.
	625 F.O. Ext.
	625 F.O. Ext.

Table 3-6

SHIELD EFFECTIVENESS MODEL

15.2 cm CONDUCTOR

EXTENSION ON TOP SHIELD SWITCHING IMPULSE PERFORMANCE

<u>Test Voltage (kV) and Results</u>	
<u>+ Polarity</u>	<u>- Polarity</u>
651 O.K.	512 O.K.
651 O.K.	506 O.K.
651 F.O. Ext.	506 O.K.
625 O.K.	548 O.K.
625 O.K.	548 O.K.
625 O.K.	548 O.K.
677 F.O. Ext.	584 O.K.
677 O.K.	579 O.K.
677 F.O. Ext.	579 O.K.
	615 O.K.
	605 O.K.
	605 O.K.
	636 O.K.
	636 F.O. Ext.
	636 F.O. Ext.

Table 3-7

SHIELD EFFECTIVENESS MODEL

60 Hz PERFORMANCE

<u>7.5 cm Conductor</u>	<u>Test Voltage kV rms</u>	<u>Time</u>	<u>Result</u>
1. Standard Top Shield	529	60 Sec.	O.K.
	552	60 Sec.	O.K.
	575	1 Sec.	F.O. Ext.
2. Extension on Top Shield	529	60 Sec.	O.K.
	552	60 Sec.	O.K.
	575	60 Sec.	O.K.
	598	1 Sec.	F.O. Ext.
3. Extension on Top Shield + 3.3 x.3.3 m Ground Plane at Bottom of Bushing	506	60 Sec.	O.K.
	483	60 Sec.	O.K.
	506	60 Sec.	O.K.
	529	1 Sec.	F.O. Ext.
<u>15.2 cm Conductor</u>			
1. Extension on Top Shield	437	60 Sec.	O.K.
	460	60 Sec	O.K.
	483	60 Sec	O.K.
	506	-	F.O. Ext.

Table 3-8

3.1.4 Discussion of Results

3.1.4.1 Effect of Conductor Size

The test data confirms the postulation that conductor size has a marked influence on the external performance of a simple gas bushing. With the 7.5 conductor, withstands on all tests (60 Hz, switching impulse, lightning impulse) achieved the maximum levels that could be expected with 1750 mm strike as described in section 3.1.1.

With the 15.2 cm conductor on all of the types of tests the external withstand was approximately 20 percent lower than with the 7.5 cm conductor. The actual difference in bottom end withstand may have been greater but the top to bottom capability limited the test level with the 7.5 cm conductor. The failures for the 15.2 cm conductor initiated by the high gradients at the bottom of the bushing are clearly shown on Figure 3-2b which is a photo of streamers emanating from the bottom of the porcelain on a partial breakdown on negative polarity. Figure 3-2a shows the oscillogram of this test.

3.1.4.2 Effect of Top Shielding

The addition of the extension to the top shield did not improve the top to bottom capability as was hoped. The reason for this can be understood by observing the growth of corona on photographs, Figure 3-3. The discontinuity between inner conductor, top bushing flange, and extension, is great enough that the extension could not act as an effective shield.

a) Oscillogram

b) Photograph

Figure 3-2

Partial Flashover-Negative Polarity
15.2cm Conductor

a) 506 kV

b) 552 kV

c) 598 kV

Figure 3-3

60-Hertz Corona Growth with
7.5 cm Conductor and Top Shield

3.1.4.3 Effect of Ground Plane at Bottom of Bushing

With the 7.5 cm conductor (top to bottom failures) the addition of the 3.3 x 3.3 m ground plane at the bottom decreased the 60 Hz flashover from 598 kV to 506 kV. A reduction was to be expected because the top-bottom configuration was changed from approximately rod-rod to rod-plane.

With the 15.2 cm conductor the addition of the ground plane increased the bottom-top flashover on lightning impulse tests from approximately 850 kV to 900 kV.

3.1.5 Work to be Undertaken in the Future

It is unfortunate that only one conductor size (15.2 cm) resulted in bottom to top external flashovers. The tests with the 20 cm conductor resulted in internal flashovers. It is doubtful if much additional data could be obtained without complete redesign of the shield effectiveness model. No additional testing will be done on the model. Flux plotting of the model will determine the electric fields that existed at the time of flashover, so that the theoretical hypotheses may be confirmed.

3.2 Resistive Grading

Switching surge tests are underway on the small model (see Section 3.2 of the Fourth Technical Progress Report) and will be reported on in the next progress report. Tests will also be made up to flashover with and without stress-grading coatings, to determine quantitatively how much improvement results from the stress grading. Work will also start on the design and test of a larger scale model with stress grading coating.

3.3 Field Plotting

Plots of the configuration used in the shield effectiveness model (see Section 3.1) will be made and analyzed in the next period. Plots may also be made in support of the SF₆-film condenser study (see Section 3.4).

3.4 SF₆-Film Condenser

3.4.1 Review of the State of the Art

In order to determine the validity of the radial and longitudinal stress gradient assumptions made earlier in the project, a similar concept was analyzed as reported by Meswandler Bau¹ in August 1979. Although the dimensions published in the paper are rather incomplete it was possible to determine that the maximum radial stress in the polypropylene film in their 420 kV bushing was probably slightly more than 100 kV/cm. The maximum longitudinal stress along the surface of the film was apparently about 10 kV/cm. These values agree well with the assumptions of 100 kV/cm and 8 kV/cm made in this project.

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

3.4.2 Calculation of Possible 1200 kV Design

Since the major cost of making a condenser is the labor to wind it, the design should minimize the amount of labor required. This is most easily accomplished by winding the condenser from full length sheet rather than from narrow strips. If we assume that the largest sheet winding machine available has a capacity of 180 inch wide sheet, then a 450 cm (177 inch) long condenser is the maximum size to consider.

Since a condenser influences the voltage gradient in air primarily at the bottom end of the weathercasing, the condenser does not need to extend to the top of the weathercase. For an average radial gradient of 100 kV/cm, the radial build must be $1200 \text{ kV} / 100 \text{ kV/cm} = 12 \text{ cm}$. Thus the outside diameter of a condenser with a cylindrical conductor diameter of 28 cm will be $28 + 2 \times 12 = 52 \text{ cm}$.

For an axial gradient of 10 kV/cm as in the Messwandler design, then the lower end length will be $1200 \text{ kV} / 10 \text{ kV/cm} = 120 \text{ cm}$. To allow for a little margin, a length of 125 cm will be used. Earlier calculations indicated that the length of the ground layer of the condenser should be approximately equal to the length of the bottom end of the condenser. This leaves 200 cm for the top end of the condenser. A sketch of the configuration is shown in Figure 3-4. The volume of film required to wind this structure, if all from the same width sheet, would be

$$L \pi (D_o^2 - D_i^2) / 4 = (450 \text{ cm}) (\pi) [(52 \text{ cm})^2 - (28 \text{ cm})^2] / 4 \\ = 6.8 \times 10^5 \text{ cm}^3$$

(L = Length, D_o = Outer Diameter, and D_i = Inside Diameter of Condenser)

Figure 3-4 1200 kV Polymer Film Condenser

However, narrower sheet is usually used as the condenser tapers out, so only 60 percent or $4.1 \times 10^5 \text{ cm}^3$ is required. Polypropylene film has a density of .907g/cm and the fill factor of the film assumed is .8 so the total amount of the film required would be

$$(.907 \text{ g/cm}) (.8) (4.1 \times 10^6 \text{ cm}^3) = 295 \text{ kg (651 lb)}$$

At approximately \$4.40/kg (\$2/lb), the cost of material for the condenser would be about \$1300.

3.4.2 Design of Reduced Scale Model Condenser

For analysis purposes, an attempt was made to design a reduced scale SF_6 -film condenser. The General Electric Company in Hudson Falls, N.Y. was contacted. Their facility produces polypropylene in a maximum of 152 cm (60 inch) width. Thus a design was built around this dimension using roughly the same proportions as the 1200 kV design. As shown in Figures 3-5, 5 cm of radial build is wrapped on a 15.24 cm (6 inch) diameter conductor. A condenser was then calculated using the split foil concept (see 3.1.5 of the Second Technical Progress Report. The lengths are adjusted for equal capacitance between conductive layers and constant radial steps. See Table 3-9 for the dimensions of the capacitive layers. This design would use

$$(150 \text{ cm}) \pi [(25.24 \text{ cm})^2 - (15.24 \text{ cm})^2] / 4 = 47700 \text{ cm}^3$$

or

34.6 kg (76.2 lb) of film.

Figure 3-5 242 kV Scale Polymer Film Condenser

LAYER	DIAMETER	LENGTH	THICKNESS	CAPAC.	KILOVOLTS	GRADIENT
1	15.74 cm	72.602 cm	.25 cm	2249 pF	25	100 kv/cm
2	16.24	70.332	.25	2249	25	100
3	16.74	68.199	.25	2249	25	100
4	17.24	66.192	.25	2249	25	100
5	17.74	64.299	.25	2249	25	100
6	18.24	62.512	.25	2249	25	100
7	18.74	60.821	.25	2249	25	100
8	19.24	59.219	.25	2249	25	100
9	19.74	57.7	.25	2249	25	100
10	20.24	56.257	.25	2249	25	100
11	20.74	54.884	.25	2249	25	100
12	21.24	53.576	.25	2249	25	100
13	21.74	52.33	.25	2249	25	100
14	22.24	51.14	.25	2249	25	100
15	22.74	50.003	.25	2249	25	100
16	23.24	48.915	.25	2249	25	100
17	23.74	47.874	.25	2249	25	100
18	24.24	46.876	.25	2249	25	100
19	24.74	45.919	.25	2249	25	100
20	25.24	45	.25	2249	25	100
TOTAL CAPACITANCE = 112.451247						

Table 3-9

242 kV Scale Polymer Film Condenser

4.0 TASK 3 THERMAL STUDIES

Further thermal analysis will be made as required as progress is made in the other study areas. Review of the Messwandler-Bau paper² cited in Section 3.4 indicates that natural thermosiphon convection cooling of all of the termination designs may limit temperatures to acceptable levels. A heat pipe is probably not necessary even for the SF₆-film design, provided the termination is oriented vertically.

²Ibid.

5.0 TASK 4 - MECHANICAL STUDIES

5.1 Shatter-Resistant Weathercase

5.1.1 Test Results

The epoxy insulator models for failure testing were completed and three were tested. The six models are:

<u>Test</u> <u>Number</u>	<u>Epoxy Type</u>	<u>Reinforcing</u> <u>Mesh Type</u>	<u>Tested</u> <u>To Date</u>
1	53841TK	None	Yes
2	53841TK	301CRX	Yes
4	53841MC	525CRX	No
5	53841MC	None	No
3	53841MC	301CRX	Yes
6	53841MC	525CRX	No

Each of the three insulators tested were pressurized to 65 psig SF₆ gas (550 kPa) and impacted with a stud gun nail. Each failed but the reinforcement exhibited a considerable ability to bind the epoxy insulator together during failure. The insulator without a reinforcement mesh, Test #1, exploded freely as the porcelain insulators have done in previous testing. Table 5-1 shows the measured projectile throw distances over a half-circle of the explosion. An analysis of the results gives the results:

Failure Test Results - Test #1
Unreinforced Insulator 531F080HO6 with Epoxy 53841TK

Size (cm)	Mass (kg)	Throw Distance (Meters)
18 x 20	1.8	0.9
36 x 18	4.1	2.7
38 x 9	2.3	2.7
23 x 8	0.7	2.7
48 x 13	3.2	3.7
36 x 13	2.7	6.4
15 x 10	6.8	6.4
25 x 8	1.4	7.3
25 x 18	2.3	8.2
15 x 8	0.7	10.8
41 x 13	3.2	10.1
25 x 15	1.8	10.1
33 x 13	2.4	10.1
33 x 20	3.2	12.8
36 x 30	5.7	12.8
33 x 20	3.9	13.7
28 x 8	1.1	13.7
28 x 23	4.5	14.6
18 x 13	1.0	14.6
18 x 13	0.9	15.8
20 x 15	1.4	16.8
18 x 8	0.7	16.8
41 x 30	11.9	17.7

(Largest Piece in Circle - 16.4 kg, 56 x 41 cm at 12.8 meters)

Table 5-1

Total insulator mass	-	116 kg	(256 lbs)
Total measured mass	-	59 kg	(130 lbs)
Maximum throw distance	-	17.7 m	(58 ft)
Maximum projectile mass	-	16.4 kg	(36 lbs)
Average throw distance	-	11.3 m	(37.2 ft)
Average projectile mass	-	2.6 kg	(5.7 lbs)
Avg. proj. size (cube)	-	11.2 cm	(4.4 inch)

The /JMBUSH/ computer program was modified to compare its prediction with the above test results. The insulators tested previous to this test have been straight. The epoxy insulators are tapered and the unequal distribution of epoxy mass and gas volume along the length of the insulator affects the projectile scatter. The program was improved to account for the diameter change by incorporating a piecewise integration of the insulator along its length and assuming that the gas does not move axially during the insulator failure. The new program listing is shown in the Appendix.

The program results, Table 5-2, are:

Average throw distance	-	16.3m	(53.5 ft)
Maximum throw distance	-	18.4m	(60.5 ft)

The predicted average throw distance is 44 percent higher than the test results, indicating significantly more gas was lost through the cracks between the pieces than expected. Apparently due to the larger average size of epoxy fragments, more pressure energy was dissipated in this manner than in the porcelain failure tests.

Failure Test Results--Test #2
301CRX Reinforced Insulator 1657B82

With Epoxy 53841TK

(1/2 Circle Nearest Stud Gun Measured)

Size cm	Mass (kg)	Throw Distance Meters
33 x 10	1.4	0.9
29 x 8	0.7	1.8
30 x 13	1.1	1.8
36 x 10	1.5	2.7
20 x 10	8.0	2.7
20 x 8	0.7	3.7
51 x 8	2.0	4.6

(Largest piece in circle = 3.3 kg, 53 x 13 at 6.1 meters)

Table 5-2

The maximum predicted throw distance (which had been low for the porcelain tests) was very accurate for the epoxy tests. This result was probably due to the greater initial gas loss for the epoxy insulators. The non-uniform probabilistic scatter (which the computer analysis does not account for) may contribute further to this effect. The non-uniform scatter increases the actual maximum throw distance and the computer program normally predicts lower than the test results. The high gas energy loss apparently reduced the maximum throw distance in the test and brought the results down to the computer prediction.

Test #2, the most brittle epoxy reinforced with the coarse mesh fiberglass weave was failed. The stud gun nail pierced through both sides of the epoxy insulators causing epoxy from both sides to break out and be thrown a short distance away. The detailed results are in Table 5-3. The failure pattern is evident in photographs in Figure 5-1. The epoxy did not adhere well enough near the puncture areas to resist the gas pressure. Due to the brittleness of the material, the axial cracks propagated without restraint. As predicted, the mesh was not ruptured.

Test #5, the medium brittle and presently preferred epoxy with the coarse mesh was pressurized and failed. Figure 5-2 shows the local cracking that occurred near the stud gun nail. No significant material was expelled and the cracks did not propagate the full length or circumference of the insulator. This behavior is what was expected and is the desired characteristic for the eventual 1200 kV size termination insulator. When the insulator was failed the gas leaked out safely and no dangerous explosion resulted.

Test #1

1)PORCELAIN OR 2) EPOXY (PRINT NO.)?2
 AMBIENT TEMPERATURE T1 (F DEG)=42
 LINER THICKNESS T & HOLE AREA A (INCH)=.5,1
 LINER OD TOP & BOTTOM (INCH)= 5,15.5
 INSULATOR INNER DIA, TOP & BOTTOM (INCH)=6.06,16.5
 INSULATOR AVERAGE THICKNESS (INCH)=1.95
 INSULATION & LINER PRESSURES (PSIG)=65,65
 INSULATOR LENGTH (INCH)=51.38
 GAS VOLUME IN ATTACHED BUS (CU IN)=0
 PROJECTILE SIZE (INCH)=4.4
 HEIGHT ABOVE GROUND, LOWER AND UPPER (INCH)=14,65.38

INIT HT (INCH)	WITH LINER *****		WITHOUT LINER *****	
	INIT VEL (FT/SEC)	SCATTER (FT)	INIT VEL (FT/SEC)	SCATTER (FT)
14.00	131.92	34.80	158.46	41.63
26.85	129.82	47.07	147.40	53.25
39.69	124.54	54.66	135.46	59.28
52.54	116.22	58.54	122.37	61.53
65.38	104.77	58.86	107.73	60.47

TIME AFTER FAILURE= 1.00 SECONDS

14.00	131.92	34.80	158.46	41.63
26.85	129.82	47.07	147.40	53.25
39.69	124.54	54.66	135.46	59.28
52.54	116.22	58.54	122.37	61.53
65.38	104.77	58.86	107.73	60.47

TIME AFTER FAILURE= 2.00 SECONDS

TIME CONSTANT OF ORIFICE= 2.54 SECONDS
 ENERGY REDUCTION RATIO= 0.541
 AVERAGE THROW WITHOUT LINER (FT)= 53.5
 AVERAGE THROW WITH LINER (FT)= 48.6

 MODIFY ANY PARAMETER? NO
 STOP

Table 5-3

a) Nail Entrance Side

b) Nail Exit Side

Figure 5-1

Photographs of the 53841TK Epoxy Insulator reinforced with 301CRX mesh, showing also the fragment scatter following Test #2

a) Stud Gun Nail
Puncture Point

b) View from inside
at Puncture Point

Figure 5-2

Photographs of 53841MC Epoxy Insulator reinforced with
301CRX mesh following test #5

5.1.2 Work to be Done

The remaining three insulators will be failed and the results compared with the above reported tests. The overall results will then be used to select and design a possible 1200 kV size reinforced epoxy insulator.

5.2 Reinforcing Liner

5.2.1 Conclusions

The tests (as reported in the Fourth Technical Progress Report) of lined and unlined porcelains and the recent tests of epoxy insulators have shown that the explosion characteristics of pressurized insulators can be predicted with useful accuracy. The analysis technique will be used in the final design of a 1200 kV termination. Also, the tests have shown that a liner can considerably reduce the danger level and area in the event of an insulator failure, especially if the liner can be used as a mechanical support to inhibit vertical motion of insulator and bushing pieces. State of the art pressurized insulators do present a considerable danger and much can be done to reduce the danger level of these designs. Reducing internal pressure, increasing porcelain mass, decreasing available gas volume, and shielding from possible projectiles at damage sensitive locations near the termination may result in safety improvements, but at least a small cost penalty is associated with each. Also available are recently developed high strength porcelains that would greatly reduce the probability of failure due to their greater toughness as compared to commonly used porcelain. The cost to the overall termination design will determine, to great extent, which will be chosen as the best design.

6.0 TASK 5 MODEL STUDIES

6.1 Electrostatic Models

Testing of the shield effectiveness model has been completed and is reported upon in Section 3.1. Testing is continuing on the resistive grading model. Manufacture of a larger scale model should commence in the next period.

6.2 Mechanical Studies

All of the insulators for the shatter resistive weathercase study have been manufactured and are ready for test. Completion of the tests are expected early in the next period. See Section 5.0 for further information on the mechanical model studies.

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>
3	Project Status Reports
3	Contract Management Summary Reports
3	Cost Management Reports

7.1 Program Status

The progress of each individual subtask is shown in the program schedule Figure 7-1. This same schedule is 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 following 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 (Fifth Quarter)</u>
J. S. Billings	212 Hours
Z. Neri	56 Hours
C. F. Hofmann	65 Hours
R. W. Crookston	0 Hours

Total manhours worked during the reporting period (including Key Personnel).

TASK 1 - 13 Manhours	TASK 4 - 119 Manhours
TASK 2 - 146 Manhours	TASK 5 - 245 Manhours
TASK 3 - 76 Manhours	TASK 9 - 144 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 7-1

8.0 SUMMARY

Tests on the electrostatic shield effectiveness model were completed, preliminary analyses were completed and preliminary analyses were presented. The results will now be compared with computer field plots to verify the theoretical postulations. The first results of the successful tests on the shatter-resistant weathercase models were reported. Calculated results were compared with the experimental data.

Most of the study phase of this project is expected to be completed during the next period. Each of the concepts studied will then be evaluated, and the final combination of concepts will be selected. Design of the full scale prototype 1200 kV termination will then commence.

APPENDIX

REVISED WEATHERCASE FAILURE ANALYSIS PROGRAM

```
*****
*THIS PROGRAM MODELS VARIOUS ASPECTS OF A HIGH VOLTAGE GAS BUSHING
*DURING A CATASTROPHIC FAILURE. VARIOUS DESIGNS ARE CONSIDERED:
* 1) STANDARD DESIGN, VARIABLE PRESSURE.
* 2) BUSHING WITH INNER LINER
* 3) BUSHING WITH INNER LINER WITH GAP HAVING LOWER PRESSURE.
*
* ENERGIES, DEBRIS SCATTER & TIME CONSTANTS ARE CALCULATED AND OUTPUT
*****
```

```
REAL B1,B2,T,Y1,A,D3,D4,F,P1,P2,L,D1,D2,V1,V2,V3,V4,D5,D6,T9,
REAL T2,K,K1,C1,E1,A4,A1,T4,E2,C,K2,R1,T3,Z,V0,V8,X0,X1,L1,T5
REAL E5,E6,B3,B5,B6,D8,D9
INTEGER N,I,M,O
STRING H
```

```
WRITE(1,100)
WRITE(1,131)
U=0
1 ACCEPT$1)PORCELAIN OR 2) EPOXY (PRINT NO.)?$,B
  IF (O.EQ.1) GO TO 15
2 ACCEPT$AMBIENT TEMPERATURE T1 (F DEG)=$,T1
  IF (O.EQ.1) GO TO 15
3 ACCEPT$LINER THICKNESS T & HOLE AREA A (INCH)=$,T,A
  ACCEPT$LINER OD TOP & BOTTOM (INCH)=$,D2,D1
  IF (O.EQ.1) GO TO 15
4 ACCEPT$INSULATOR INNER DIA, TOP & BOTTOM (INCH)=$,D3,D4
5 ACCEPT$INSULATOR AVERAGE THICKNESS (INCH)=$,F
  IF (O.EQ.1) GO TO 15
6 ACCEPT$INSULATION & LINER PRESSURES (PSIG)=$,P1,P2
  IF (O.EQ.1) GO TO 15
8 ACCEPT$INSULATOR LENGTH (INCH)=$,L
9 ACCEPT$GAS VOLUME IN ATTACHED BUS (CU IN)=$,V4
10 ACCEPT$PROJECTILE SIZE (INCH)=$,Z
11 ACCEPT$HEIGHT ABOVE GROUND, LOWER AND UPPER (INCH)=$,Q1,Q2
```

```
15 WRITE(1,131)
   WRITE(1,135)
   WRITE(1,160)
   WRITE(1,130)
   WRITE(1,180)
   WRITE(1,131)
```

```
IF (B.EQ.1) GO TO 20
B1=0.0019
GO TO 25
20 B1=0.0031
25 C=.6
30 C1=113.6*32.2
   K=1.12
```

```

K2=(K+1)/(K-1)
K1=(K-1)/K
G=(D4-D1)/2
V3=0.262*L*D4*D4*(1+D3/D4+(D3/D4)^2)
V2=0.262*L*(D1-2*T)^2*(1+(D2-2*T)/(D1-2*T)+((D2-2*T)/(D1-2*T))^2)
V1=V3-0.262*L*D1*D1*(1+D2/D1+(D2/D1)^2)
D5=(0.0278*(F1-5)+.53)/1728/32.2
D6=(0.0278*(F2-5)+.53)/1728/32.2
T2=(14.7/(F1+14.7))^K1*(T1+459.7)-459.7
T5=(14.7/(F2+14.7))^K1*(T1+459.7)-459.7
A1=C*A*(32.2/(10.6*(T1+459.7)))**K*(2/(K+1))^K2^0.5
T3=D5*V2/(F1*A1)*32.2
T9=T3
IF (A.EQ.0) T3=0.5
IF (T3.GT.1) T3=1
D0=50 N=1,2
B3=0
B5=0
B6=0
IF (A.EQ.0) N=2
T4=T3*N
E4=-P1*A1*T4/(D5*V2)/32.2
E1=C1*D6 *V1*(T1-T5)*(V2/V1*D5/D6*(1-2.7183^E4)+1)
E2=D5*V3*C1*(T1-T2)
K1=E1/E2
K2=.000045/32.2
D0=40, I=0.4
D8=(5*D4-(D4-D3)*(T+1))/((5*D4-(D4-D3)*T)
D9=(5*D1-(D1-D2)*(I+1))/((5*D1-(D1-D2)*I)
E5=E2*.0524*L/V3*(D4-(D4-D3)*I/5)^2*(1+D8+D9^2)
E6=E5-E5*.0524*L/V3*(D1-(D1-D2)*I/5)^2*(1+D9+D9^2)
B2=(D4-(D4-D3)/10*(2*I+1))* .6283*L*F*B1
V0=(E5^2/B2)^.5
V8=(E6^2/B2)^.5
L1=Q1+I*(Q2-Q1)/4
T8=(2*L1/(32.2*12))^0.5
X0=B1*Z*.139/R2*ALOG(V0/R2*T8*.72 / (B1*Z)+1)
X1=B1*Z*.139/R2*ALOG(V8/R2*T8*.72 / (Z*B1)+1)
B3=B2+B3
B5=B5+X0*B2
B6=B6+X1*B2

40  WRITE(1,132) L1,V8,X1,V0,X0
    WRITE(1,140) T4
    WRITE(1,131)
50  CONTINUE
    IF (A.EQ.0) GO TO 51
    WRITE(1,120) T9
51  WRITE(1,170) R1
    B5=B5/B3
    B6=B6/B3
    WRITE(1,185) B5
    WRITE(1,190) B6
    WRITE(1,100)
55  ACCEPT$MODIFY ANY PARAMETER? $,H
    IF (H.EQ.'YES') GO TO 60
    IF (H.EQ.'NO') GO TO 200
    DISPLAY$WRONG INPUT DUMMY! TRY AGAIN, YES OR NO$
    GO TO 55
60  DISPLAY$MATERIAL-1, TEMP-2, LINER-3, INSUL SIZE-4, PRESSURE-6, PROJECTILE-10$
    ACCEPT$ PRINT NUMBER- $,M
    Q=1
    IF (H.EQ.1) GO TO 1
    IF (H.EQ.2) GO TO 2

```

```

IF (M.EQ.3) GO TO 3
IF (M.EQ.4) GO TO 4
IF (M.EQ.5) GO TO 6
IF (M.EQ.15) GO TO 10
WRITE(1,100)

```

```

100  FORMAT(72($$$))
120  FORMAT($TIME CONSTANT OF ORIFICE=,F6.2,$ SECONDS$)
130  FORMAT($ INIT HT $, $ INIT VEL$,7X,$SCATTER$,7X,$INIT VEL$,6X,$SCATTER$)
131  FORMAT(//)
132  FORMAT(F7.2,4X,F7.2,8X,F7.2,7X,F7.2,8X,F6.2)
135  FORMAT(17X,$WITH LINER$,17X,$WITHOUT LINER$)
140  FORMAT($TIME AFTER FAILURE=,F5.2,3X,$SECONDS$)
150  FORMAT(I2X,25($$$),5X,25($$$))
160  FORMAT(11X,22($$$),6X,22($$$))
170  FORMAT($ENERGY REDUCTION RATIO=,F6.3)
180  FORMAT($ (INCH) $,$ (FT/SEC)$,7X,$(FT) $,6X,$(FT/SEC)$,6X,$(FT)$)
185  FORMAT($AVERAGE THROW WITHOUT LINER (FT)=,F6.1)
190  FORMAT($AVERAGE THROW WITH LINER (FT)=,F6.1)
200  END
*
```