DEVELOPMENT OF A LOW LOSS MAGNETIC COMPOSITE UTILIZING AMORPHOUS METAL FLAKE

Second Semi-Annual Progress Report

For the Period

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NOTICE

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Evaluation, Design, Development And Delivery Of A 1200 kV Prototype Termination

First Technical Progress Report

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Preparation Date: February 22, 1979

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1.0 ABSTRACT

The conceptual design and material study, Task 1 of this project is nearing completion. The primary objective of problem definition, in the form of a preliminary design specification, is complete. Several innovative concepts are being explored and compared. By the end of Task 1, the many alternative concepts will be narrowed considerably so that model studies of the most promising candidates may commence.

2.0 INTRODUCTION

This is the first technical progress report on the evaluation, design, development, and delivery of a 1200 kV prototype termination. The SF_6 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 terminations 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, design, production, and testing of a full scale prototype, and finally delivery of a prototype termination to an appropriate field site.

The scope of the work to be performed in this project is described in the following work statement from the contract:

2.1 STATEMENT OF WORK

A. Objective: The objective of this project is to design, develop and deliver a 1200 kV prototype air to SF_6 gas bushing termination for integration into an insulated substation. The produced design must be economically attractive and it must exhibit improved electrostatic performance, acceptable temperature gradients, and better mechanical integrity when compared with the gas/air terminations of typical ratings built with conventional technology.

B. Background: The Electric Energy Systems Division of the Department of Energy has structured and initiated a program for the development of a 1200 kV gas insulated transmission line and associated terminal equipment to be integrated into a compact substation. At some juncture in the development of these components (transformers, reactors, circuit breakers, surge arresters, instrumentation systems) a reliable termination for a transition from the compressed gas environment to open air will be needed.

It is recognized that the air to gas transition for a 1200 kV system is not a simple task, because in addition to meeting all the station or line dielectric requirements, the external insulation components must withstand wet switching transients as well as airborn contamination effects.

A major problem with the design of any air to gas termination is to decide the permissible value of electrostatic field gradients to withstand the low frequency overvoltages and the impulse and switching transients during factory performance tests. Preliminary calculations have shown that it is desirable to limit the conductor and the external field gradients to 10 kV/cm per 1000 kV standard impulse transient for a 1200 kV termination design. It must be emphasized, however, that gradient calculations alone cannot produce the optimized design of a gas to air termination but can only provide general design guidelines. For this reason, high voltage testing is essential to verify calculated designs.

In addition to reliable electrostatic performance of the termination, high ampacity requirements without exceeding the permissible thermal gradients and proper precautions against catastrophic failures are essential criteria for this development effort.

C. Project Tasks: The research and development effort under this program is to be directed towards novel design concepts which will provide acceptable electrostatic and thermal performance and proper mechanical stability and bursting strength. The prototype unit as delivered shall be compatible with other EES developments for SF_6 gas insulated substation equipment. It is also anticipated that the developed technology will be readily applicable to terminations rated at voltages lower than 1200 kV.

As a minimum, the required project tasks are as follows (not limited to nor in order of importance).

Task 1. Conceptual Design and Material Study: The project efforts under this task shall be directed towards the technical feasibility study of novel and conceptual designs. Also, identify and explore new materials, investigate new applications of proven materials, and examine fabrication techniques emphasizing performance and reliability.

Task 2. Electrostatic Study: While considering the electrostatic performance, efforts must be made and considerations must be given to:

2.1 minimizing ionization gradients which may be detrimental to the insulating system,

2.2 insulating withstand capability against impulse transients as well as the dry and the wet switching transients and,

2.3 the prediction of long term a.c. performance of the insulating system based on models of the physical mechanism of flashover and volume breakdown.

The required insulating withstand capability and the levels of protective margin shall be coordinated with the volt-time characteristics of the corresponding surge arrester. The basic device characteristics as planned are as follows:

Using 980 kV as a per unit base $\frac{(1200 \times \sqrt{2}\ kV)}{\sqrt{3}}$ the 100% protective characteristics are:

maximum front of wave sparkover	-- 1725 kV crest
maximum standard impulse sparkover	-- 1650 kV crest
maximum switching impulse sparkover	-- 1570 kV crest
maximum 30 kA discharge voltage	-- 1650 kV crest
maximum switching impulse discharge voltage	-- 1570 kV crest
recovery voltage rating	-- 1400 kV (approx.)

<u>Task 3</u>. <u>Thermal Study</u>: Proper assessment of temperature gradients and the requirements for cooling shall be investigated,

3.1 studies shall be made to assess I^2R and eddy current loss at 5000 amps. and at 6000 amps. rated current,

3.2 calculate the dielectric loss associated with the termination system and its impact on the thermal performance,

3.3 the maximum design temperature profile shall be dictated by the thermal properties of the insulating materials, current density distribution, dielectric losses, momentary short-circuit current carrying capacity and the cooling mechanism,

3.4 heating of flanges, clamping mechanism and shields shall be controlled within the permissible temperature limits.

Note: (i) Self-cooled bushing designs are required.

(ii) For a unified coordination among different substation components and gas insulated bus sections, it is recommended that the nominal outside diameter of the center conductor is 28 cm. having 1.3 cm. wall thickness.

Task 4. Mechanical Performance Study:

4.1 an effective clamping mechanism must be developed,

4.2 design considerations must be made to minimuze harmful mechanical excursions during shipment and also during operation against earthquake and wind loadings,

4.3 design precautions shall be taken to guard against catastrophic failure,

4.4 since the developed termination shall be applicable to a variety of terminal equipment in a gas insulated substation, it must withstand momentary short circuit currents without ill effects.

Task 5. Model Studies: It is anticipated that for proper technical feasibility study and in evaluating performance, various models will be conceived and they will be tested at different intervals in the program. Certain models and/or combinations of components shall be investigated for the combined effects of electrostatic and thermal gradients and mechanical stresses.

Task 6. Design Of A Prototype: Upon successful completion of the model studies, finalize the best possible design of a 1200 kV prototype unit. This design shall be reviewed and evaluated prior to production.

Task 7. Production And The Testing Of A Prototype: Investigate and make recommendations for quality assurance and the acceptable test program for the proposed design concept. The contractor shall then perform the design as well as the routine factory tests on the prototype termination prior to delivery.

Note: The acceptance tests shall be coordinated with any applicable IEEE-NEMA-ANSI standards and with the station requirements.

Task 8. Delivery Of The Prototype And Monitoring Performance: The contractor shall take full responsibility for a safe delivery of the prototype unit to a substation site which may be located anywhere within the continent and as selected by EES/DOE. The contractor shall provide the required assistance and instructions for proper field installation, operation, and maintenance of the prototype unit.

Task 9. Reports And Recommendations: The overall reporting requirements shall be in accordance with the guidelines provided with the proposal. The contractor shall also report on the technology transfer to the designs of lower voltage class units.

Note: The pertinent technical data and requirements for the engineering design are presented as follows:

Pertinent Technical Data And Information

a)	Rated termination voltage 1.0 p.u.	1200 kV/$\sqrt{3}$ L-G, rms
b)	Rated nominal current	5000 amps., for buried underground cable system 6000 amps., for surface and/or open air system
c)	Basic insulation level (BIL-withstand)	2175 kV crest (internal)
d)	Wet switching surge voltage level (withstand)	1800 kV crest
e)	Power frequency withstand voltage level, phase-ground	1200 kV rms, L-G
f)	Ionization level 800 kV rms, phase-ground	Essentially free as detected with instrumentation having detector sensitivity 2 p.c. and/or 2μ V
g)	Cantilever withstand strength	0.3g earthquake equivalent with simultaneous wind loading of 90 mph
h)	Bursting strength	Guard against catastrophic failure
i)	Momentary current rating	135 kA peak
j)	Short circuit rating	50 kA rms, symmetrical for one second
k)	Shipping requirements, anywhere within the continent of U.S.A.	Withstand railroad shipping shocks without ill effects

3.0 CONCEPTUAL DESIGN AND MATERIAL STUDY (TASK 1)

The primary objectives of this task are to:

1. determine the problems to be solved in the development of a 1200 kV termination,
2. determine which of the many possible alternative configurations and materials appear to best solve those problems, and
3. determine how to best gather the information needed to verify that the solutions will work and arrive at the optimum solution.

3.1 PROBLEM DEFINITION

3.1.1 Design Specification

Based on the performance requirements set forth in the contract, and past experience with the development, and production of bushings, a functional design specification was written (see Appendix A). It is intended to be a preliminary document, defining the problems to be solved and the considerations which should be taken into account during the development of the termination. As the project proceeds, changes will likely be made to improve the definition and provide more detail.

3.1.2 Electrical Considerations

The major electrical considerations were reasonably well detailed in the project proposal and consequently will not be repeated again in this report.

3.1.3 Mechanical Considerations

A preliminary analysis is progressing to determine basic parameters and their interaction in a standard porcelain insulator when a catastrophic failure occurs and porcelain fragments are hurled by the released gas. Approximate calculations of energy available, scatter of varying size fragments, and velocity variations with size and position, forms a basis for relative comparison of various termination designs. Relative energy and danger to men and equipment near the failed termination will provide a basis for decision to devise significantly improved designs.

Gas Energy: $E_t = P_1V_1 \cdot \ln (P_1/P_2)$ Isothermal

$E_a = MC_v \cdot (t_1-t_2)$ Adiabatic

Where $t_2/t_1 = (P_2/P_1) \cdot (k-1)$

Assuming: P_1=4.33 Atmospheres absolute

P_2=1 Atmosphere absolute

K =1.12

C_v=189.4 Joules/kg K°

M =28.1 kg/m^3

T_1=294 K°

Then: E_t (Isothermal) = 657,541 Joules/m^3

E_a (Abiabatic) = 733,917 Joules/m^3

Maximum Average Projectile Velocity: Assuming the gas within the termination is the only source of energy for projectile motion during the shattering of the porcelain, the average initial velocity of the projectiles can be calculated.

Define: L = Initial projectile height above ground level

D_2 = Lower insulator diameter

D_1 = Upper insulator diameter

T = Average insulator thickness

Mass of Porcelain $M_p \cong \rho_p \pi TL \frac{(D_1+D_2)}{2}$

Gas Volume $Vg \cong (D_1+D_2)^2 \frac{\pi L}{8}$

Total Energy $EVg = 1/12\ M_p\ V_o^2$ (V_o = Initial Velocity of Projectile)

Then:

$$V_o = \left[\frac{2\ EV_g}{M_p}\right]^{1/2} = \left[\frac{E\ (D_1+D_2)}{2T\ \rho_p}\right]^{1/2}$$

ρ_p = 2,768.0 kg/m^3

$$V_o \text{ Isothermal} = 118.8 \left[\frac{D_1+D_2}{T}\right]^{1/2} \quad \text{Meter/Second}$$

$$V_o \text{ Adiabatic} = 132.6 \left[\frac{D_1+D_2}{T}\right]^{1/2} \quad \text{Meter/Second}$$

A graph of the above equations, Figure 1, shows the relations above. Practical terminations are in the region of 15 to 25 for $(D_1+D_2)/T$. Thus, maximum average projectile velocity will be about 58 m/s for a 25 ratio value.

Projectile Motion: The insulator fragments will vary in shape, size, initial velocity, initial height above the ground and initial projectile angle. The result of the exploded insulator is surely a probablistic distribution around the original termination location of the insulator fragments. However, the study of the projectile nature with simplified assumptions gives an idea of the basic motion characteristics of a fragment. Assuming a cube shape fragment of side length "Z" at an initial height above ground of "L", an initial horizontal velocity "V" and density ρ_p:

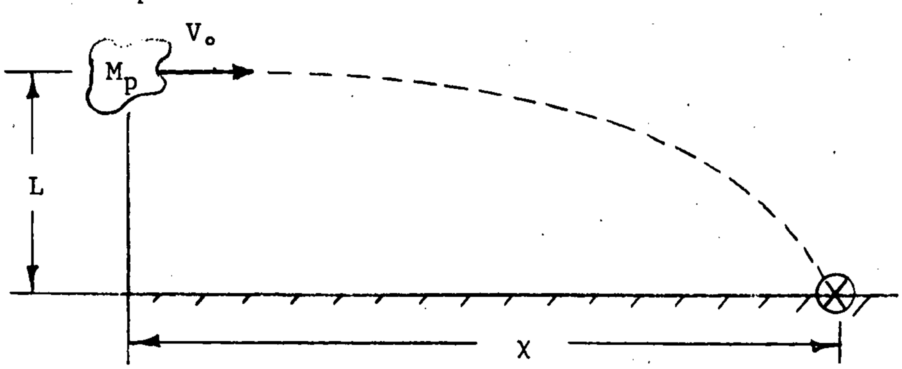


Figure 2

PORCELAIN FRAGMENT INITIAL VELOCITY Vo DUE TO SF6 GAS ENERGY

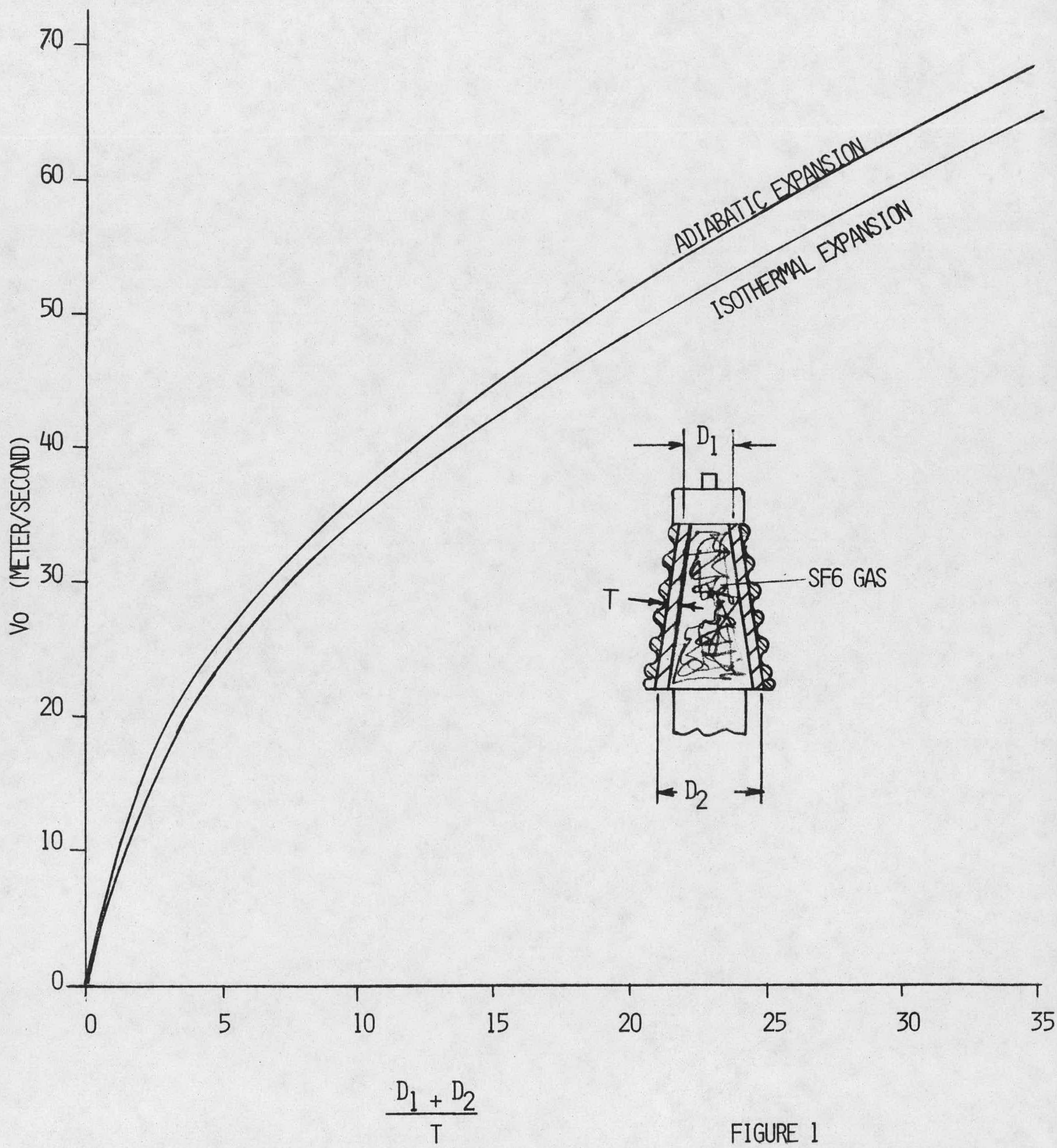


FIGURE 1

Time to ground impact with vertical air resistance negligible is:

$$t = \left[\frac{2L}{g_c}\right]^{1/2}$$

Horizontal Motion Equation is:

$$\frac{d^2\chi}{dt^2} - K\left(\frac{d\chi}{dt}\right)^2 = 0$$

Where:

$$K = \frac{C_2 P_a Z^2}{M_p}$$

$$\chi(0) = 0 \qquad \frac{d\chi}{dt}(0) = V_o$$

C_2 = Drag coefficient = 0.6 (assumed)

ρ_a = Air density = 1.206 kg/m^3

Solution to the above is:

$$\chi(t) = \frac{M_p}{C_2 \rho_a Z^2} \ln\left[\frac{V_o C_2 \rho_a}{M_p} \cdot t+1\right]$$

$$d\chi(t) = V_\circ \cdot \left[\frac{V_\circ C_2 \rho_a Z^2}{M_p} \cdot t+1 \right]$$

From these relations, the fragment horizontal velocity at ground impact, V_h, total velocity at ground impact, V_t, and the total energy at ground impact, E_f, were calculated.

$$V_h = V_\circ \cdot \left[\frac{V_\circ C_2 \rho_a Z^2}{M_p} \cdot \left(\frac{2L}{g_c} \right)^{1/2} +1 \right]^{-1}$$

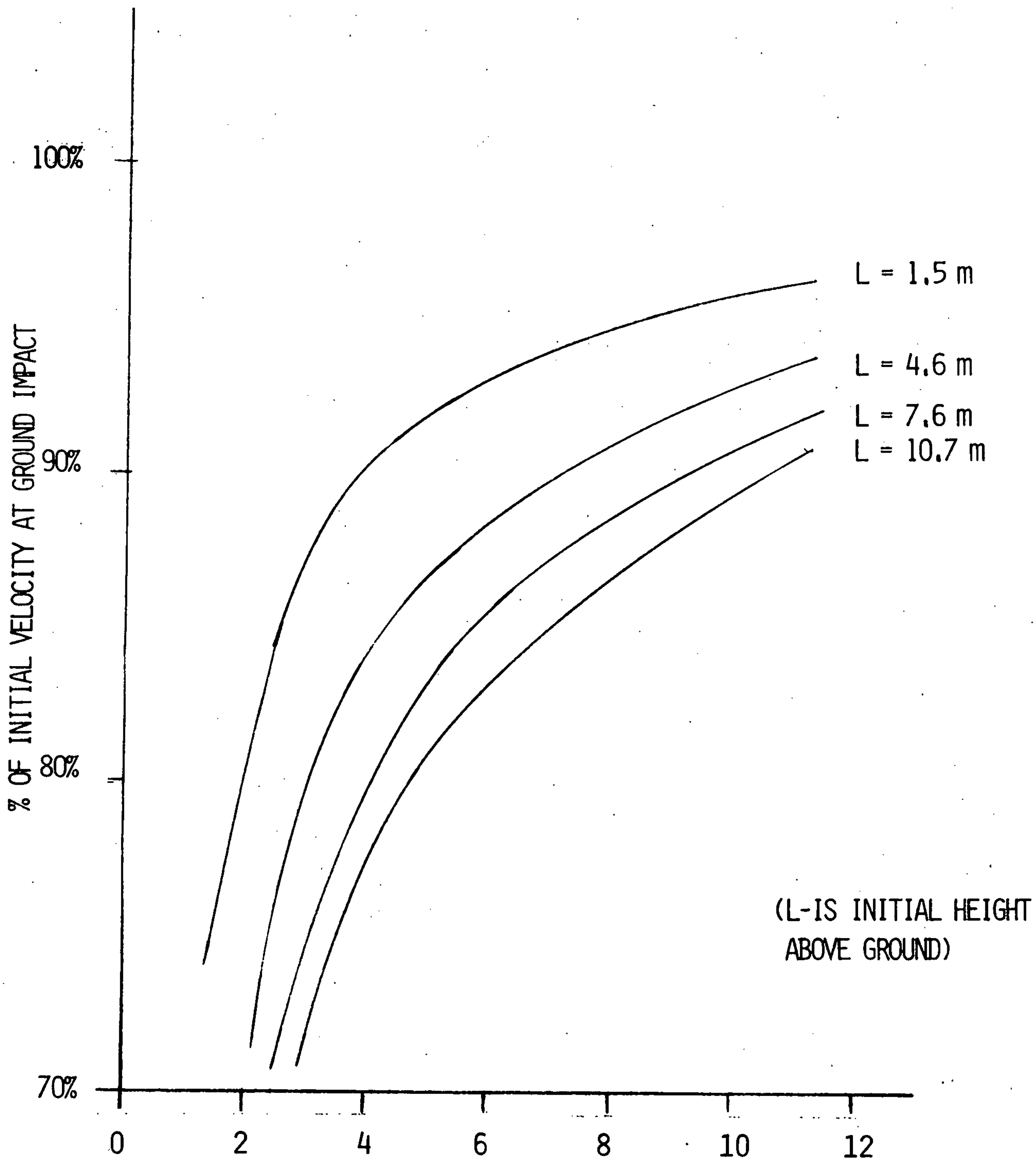
$$V_t = \left[V_h^{\ 2} + 2G_c L \right]^{1/2}$$

$$E_f = 1/2 \ M_p \ V_t^{\ 2}$$

The results of these equations are shown on Figures 3, 4, and 5 respectively. Representative fragment travel distance "χ" is shown on Figure 6. Correlation of these curves suggests that the fragments below 3 cm size will cause small damage and are little danger to people, though these fragments can be thrown quite far if their initial position is near the top of the insulator. Also, fragments about 7 cm and larger have sufficient energy at ground impact to cause considerable danger

HORIZONTAL FRAGMENT VELOCITY

(PERCENT OF INITIAL VELOCITY AT GROUND IMPACT)



Z - FRAGMENT SIZE (cm)

FIGURE 3

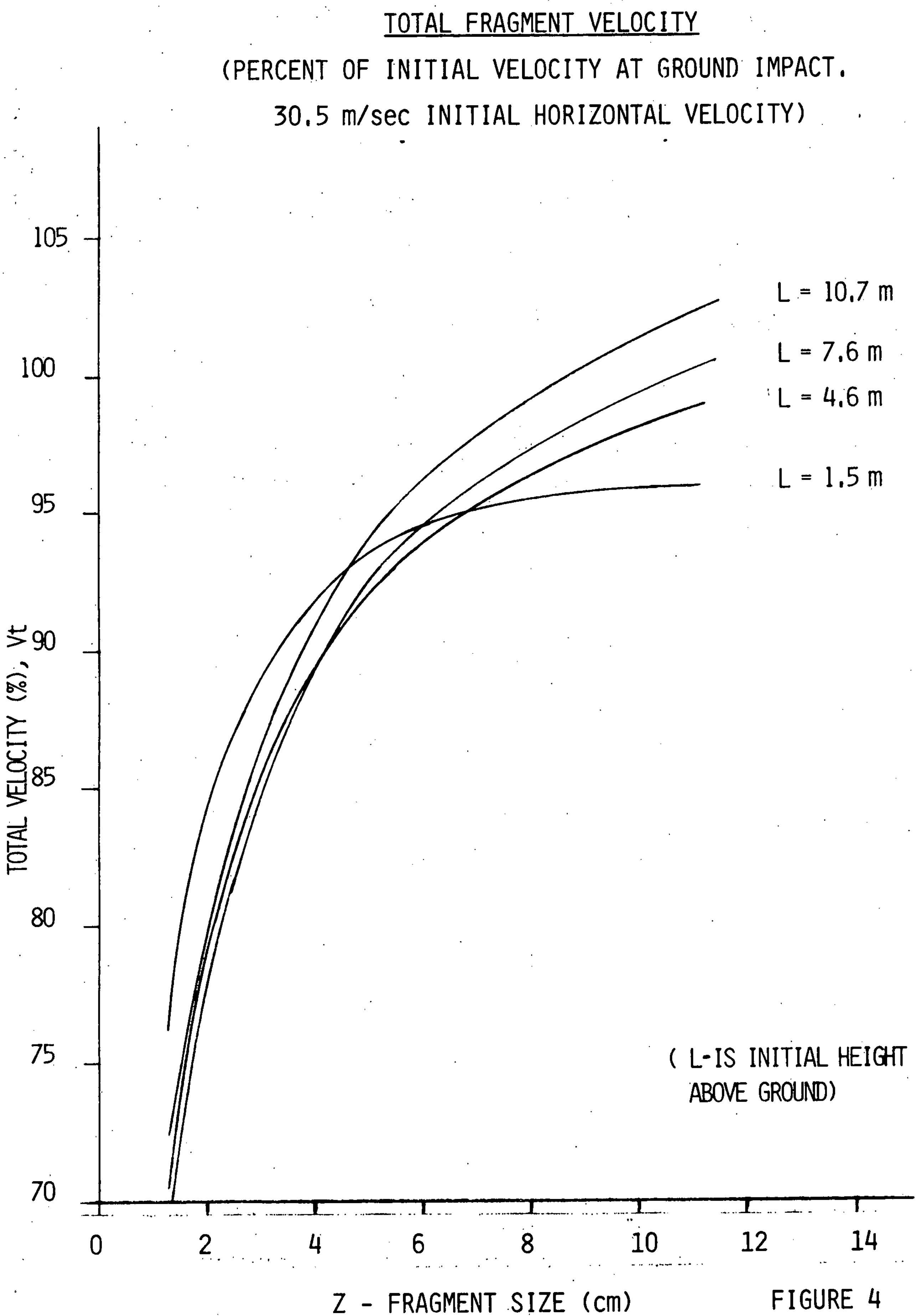

TOTAL FRAGMENT VELOCITY
(PERCENT OF INITIAL VELOCITY AT GROUND IMPACT.
30.5 m/sec INITIAL HORIZONTAL VELOCITY)
105
100
95
90
85
80
75
70
TOTAL VELOCITY (%), Vt
L = 10.7 m
L = 7.6 m
L = 4.6 m
L = 1.5 m
(L-IS INITIAL HEIGHT
ABOVE GROUND)
0
2
4
6
8
10
12
14
Z - FRAGMENT SIZE (cm)

FIGURE 4

FRAGMENT ENERGY AT GROUND IMPACT

(30.5 m/sec)

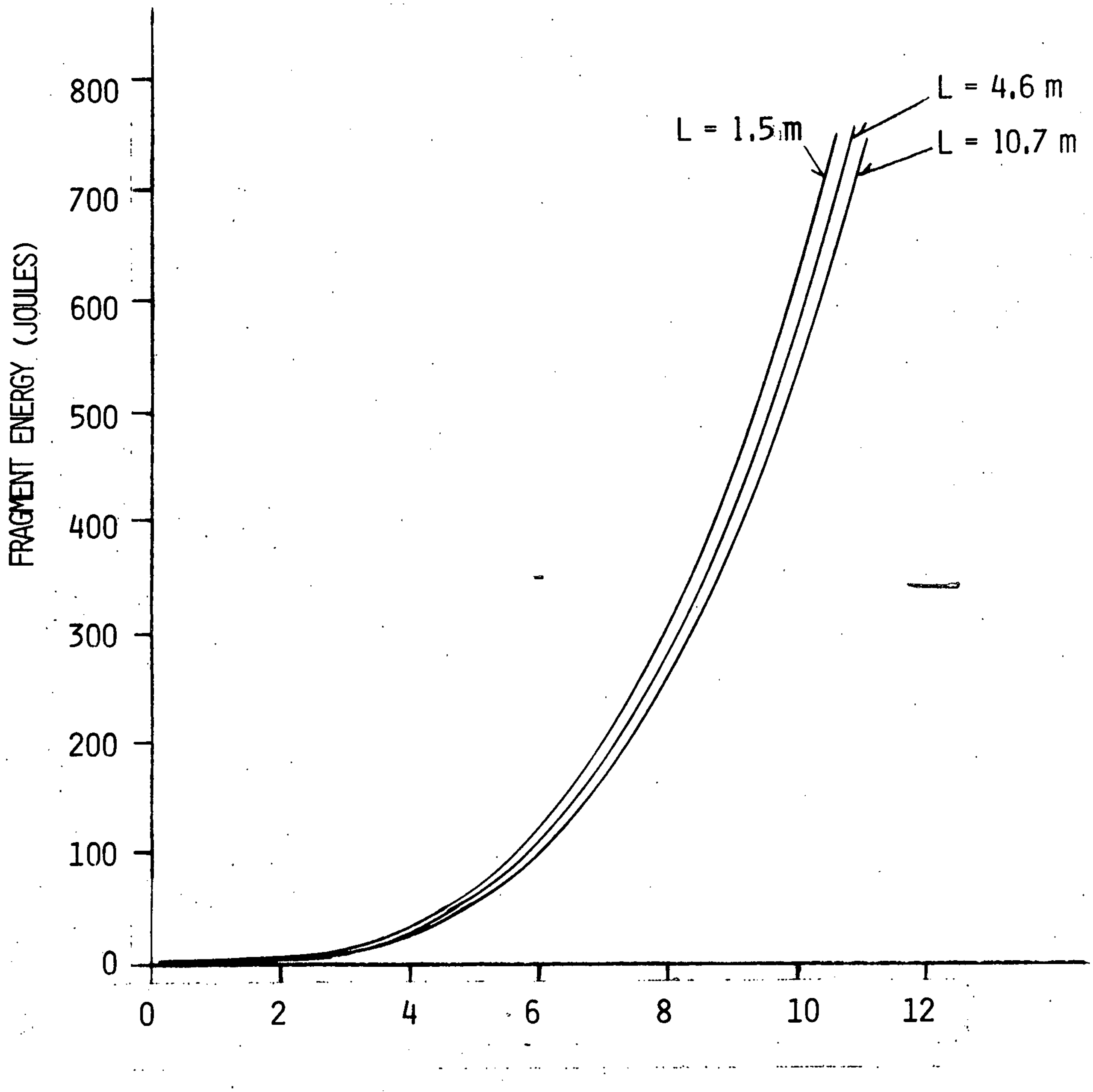
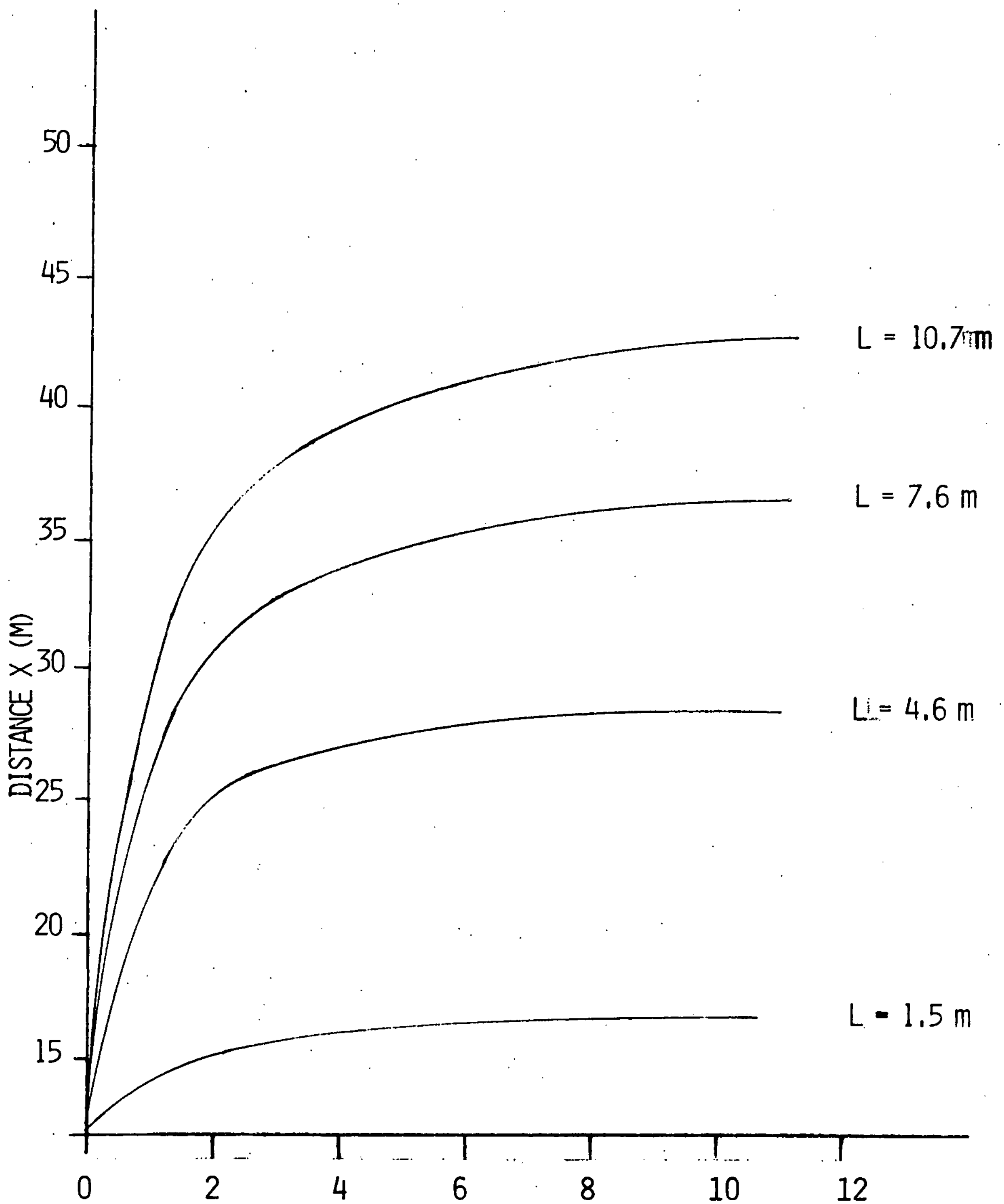


FIGURE 5

FRAGMENT TRAVEL (X) AT GROUND IMPACT

(Vo = 30.5 m/sec)



Z - FRAGMENT SIZE (cm)

FIGURE 6

and damage. The impact energy is not effected seriously by the initial height of the fragment but the travel distance increases with initial height as expected.

Conclusions: The work thus far indicates that the standard design pressurized insulator is capable of doing considerable damage if exploded. A reduction in gas pressure will greatly reduce this danger; a pressure reduction to .133 MPa (1.33 absolute atmospheres) from .433 MPa (4.33 atm) results in a 78% initial energy reduction. Also, insulator designs which allow no fragments or only small fragments to be thrown would reduce the impact danger by an order of magnitude.

3.2 INNOVATIVE CONCEPTS

3.2.1 Metal Banded Weathercase Concept

A standard porcelain weathercase pressurized with SF_6 or a similar insulating medium may shatter explosively when impacted sufficiently by a projectile or if punctured by an electric arc. The gas energy available in the weathercase is sufficient to hurl fragments of porcelain 30 meters or more, the larger fragments being less affected by air resistance and thus able to travel a farther distance than the smaller in general. These large fragments also will cause greater damage to the surroundings due to their higher mass and are, therefore, more dangerous to personnel near the porcelain when it explodes. It is desirable to limit the movement of the large fragments to create a safer bushing design. Most of the proposed designs of this project do this in some manner.

The banded weathercase is simply a conventional design porcelain insulator with relatively small diameter metal rings, one at the base of each shed, which fit loosely around the porcelain. In the event of a porcelain rupture, the bands will delay by entrapment the outward motion of large fragments, allow time for much of the gas to escape harmlessly and use up energy as the bands expand and eventually break in tension. This total effect will thus reduce the total gas energy available to porcelain fragments and reduce the average fragment size. This will make a safer bushing without greatly increasing the bushing cost.

The metal bands will affect the electrical field and this must be evaluated. Also, the attachment of the bands to make a strong and well shaped joint in the band needs to be developed. Energy absorbed by the band before it breaks can be calculated and the bands sized for all the foregoing factors before model testing is necessary. Testing of a small porcelain model will supply sufficient data to determine if the concept will be viable for large high voltage usage.

3.2.2 SF_6 Film Condenser

One possible configuration which may solve several of the problems of a 1200 kV termination is an SF_6 gas impregnated plastic film condenser bushing. Drawing from technology employed in oil-impregnated paper condenser bushings, and plastic film insulated cables, an SF_6-film bushing would probably comprise a conductor, a wound plastic and foil condenser assembly, a close fitting weathercase, lower end support insulator, mounting flange assembly, axial clamping assembly, and appropriate top end shielding.

The condenser would consist of a plurality of alternating concentric foils and dielectric film layers forming a cylindrical capacitor structure. By appropriately sizing and locating the foils, the radial voltage stress in each capacitive layer would be limited to an acceptable level while at the same time considerably reducing the overall diameter of the condenser. By means of the voltage division among the capacitive layers, the axial voltage gradient would also be controlled. By judicial control of the voltage just inside the weathercase, the voltage outside the weathercase would be limited to acceptable levels while reducing the overall length requirements for the weathercase.

Advantages of the SF_6-film condenser bushing include:

1. Reduced diameter and shorter length of weathercase, resulting in
2. less expensive weathercase,
3. lighter weight weathercase, and
4. less enclosed potentially explosive gas volume.
5. Weathercase nearly filled with solid insulation, resulting in
6. less available potential explosive gas volume.
7. Controlled radial voltage stress in the bushing.
8. Improved control of axial voltage stress outside the bushing.
9. Reduced need for ground end external voltage grading rings.

Disadvantages include:

1. Considerable resistive heat loss thermal transport problems away from the conductor.
2. Increased bottom end length.
3. Considerable added expense of winding condenser.

4. Uncertainty as to the effectiveness of the external voltage control.

5. Uncertainty as to the long term stability of the film dielectric.

6. Possible sensitivity to elevated temperatures.

7. Possible difficulty in terminating the foil ends.

One possible configuration for an SF_6-film condenser bushing is shown in Figure 7. The design assumptions employed were as follows:

1. Maximum radial stress (perpendicular to film) = 100 kV/cm

2. Maximum longitudinal stress (average) = 8 kV/cm

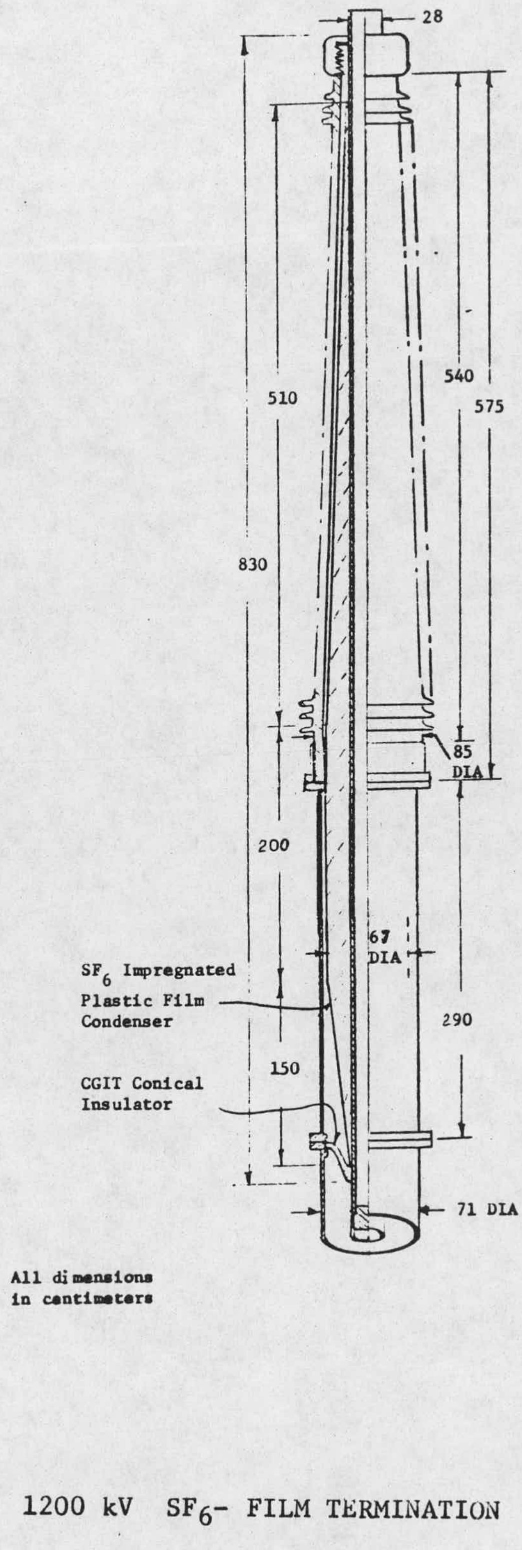
3. Inner conductor diameter = 28 cm

4. Maximum stress ratings apply for 1200 kV rms 1 minute test

5. Foil termination can be achieved without dimension change

6. Minimum allowable capacitive layer thickness = .23 cm

7. 30 capacitive layers are adequate to achieve uniform longitudinal voltage gradient



1200 kV SF_6- FILM TERMINATION

FIGURE 7

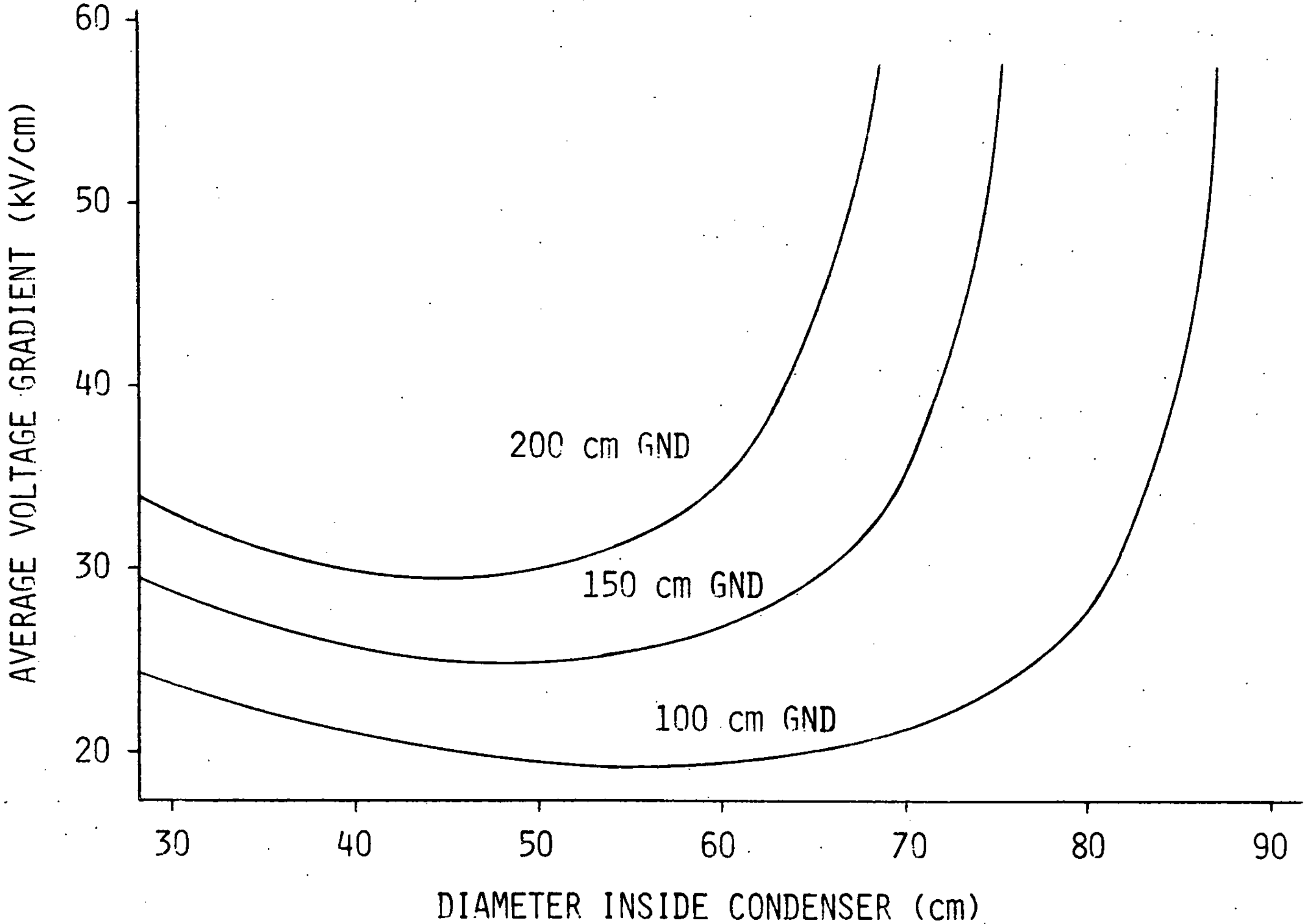
8. CGIT Conical insulator can provide adequate support for bottom end of bushing

9. Dielectric constant for SF_6 - impregnated film = 2.2

The dimensions shown in Figure 7 were based also on equal capacitance in each of 30 layers, thereby insuring a relatively uniform longitudinal gradient along the ends of the condenser. (The lengths of the respective foils were stepped uniformly.) The design calculations ignored the effects of all external capacitance of the condenser structure to the outer bus wall.

Figure 8 displays the average voltage gradient in the SF_6-film dielectric as a function of diameter for three different outside (ground) foil lengths. In order to minimize the outside diameter of the condenser using the equal capacitance design concept, the bushing must be made quite long. Obviously, further reductions in overall diameter would be expected if the voltage gradients in each capacitive layer were made more nearly equal. The smallest theoretical outside foil diameter assuming a constant voltage gradient of $100/\sqrt{3}$ kV/cm and a conductor diameter of 28 cm would be

$$28 \text{ cm} + 2 \cdot \frac{1200/\sqrt{3} \text{ kV}}{100/\sqrt{3} \text{ kV/cm}} = 52 \text{ cm (20.5 in)}.$$



AVERAGE STEADY STATE RADIAL VOLTAGE GRADIENTS INSIDE SF_6-FILM CONDENSER AS LENGTH OF OUTSIDE (GROUND) FOIL LENGTH IS VARIED

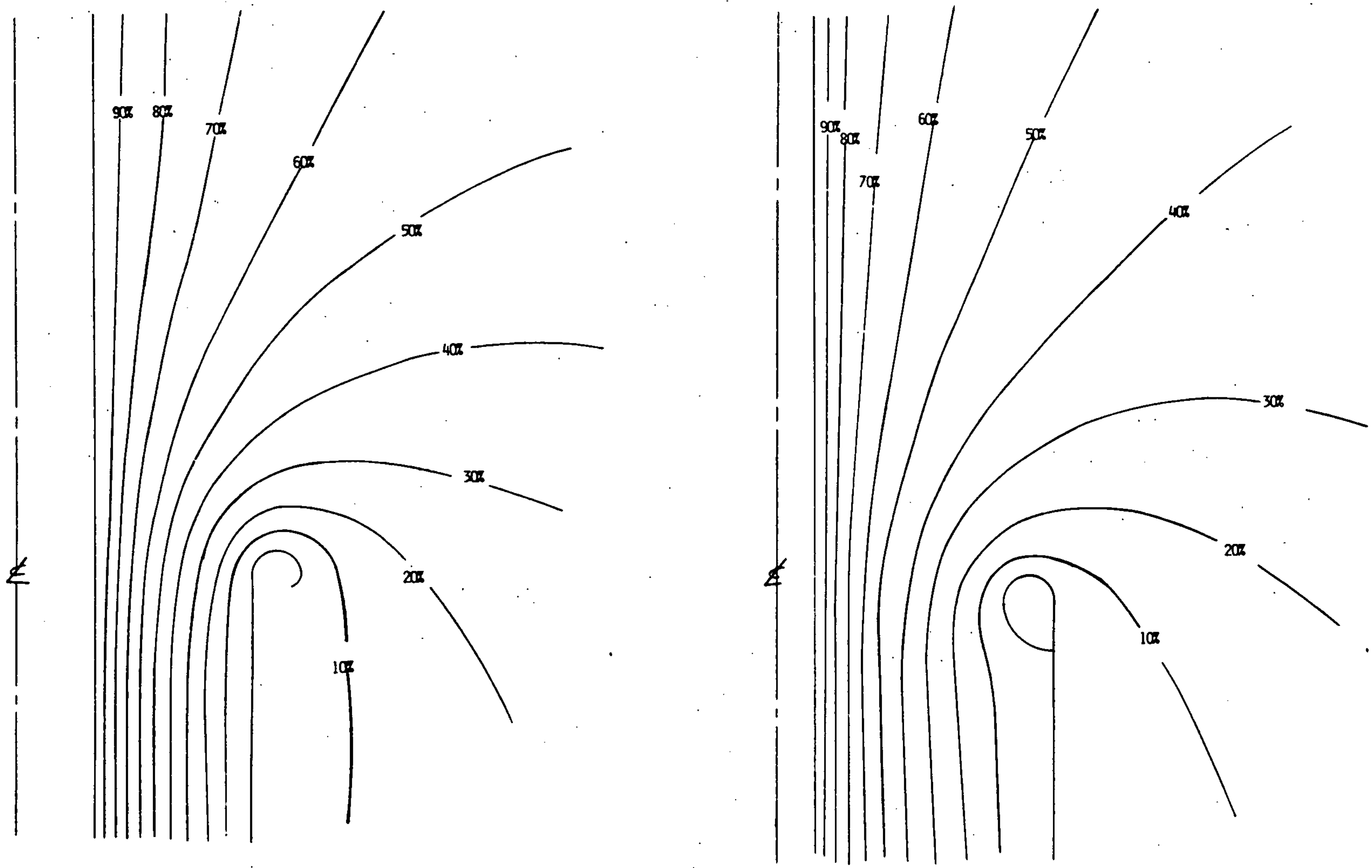
FIGURE 8

Thus, a weathercasing with an inside diameter as small as 60 cm (23.6 in) may be possible. This, in comparison to the approximately 71 cm (28 in) inside diameter of the 1200 kV gas bushing for DOE Project EX-76-C-01-2061 (Prototype UHV Compressed Gas Insulated Transmission System), would be a significant improvement.

Other schemes for placement of foils need to be checked, with the goal of optimal voltage grading both inside and outside the bushing. If the calculations show sufficient improvements in electrical stress control and reductions in weathercasing diameter, the building and testing of SF_6-film condenser models may be warranted.

3.2.3 Conductor Throat Shield Variation

Electrostatic field plots were made of several internal throat shield and conductor diameter configurations. Figure 9 illustrates the relative advantage of a large diameter conductor and outward turned throat shield (a) as compared to a smaller diameter conductor and inward turned throat shield (b). The voltage stress is nearly the same on the conductor in both cases, and the maximum stress on the throat shields varies little, but the electric field outside the bushing is improved substantially with the latter case. The electrostatic studies to be conducted in Task 2 of this project will verify this concept on actual models.



a) Outward Turned Shield

b) Inward Turned Shield

Comparison of Voltage Fields for Two Throat Configurations

Figure 9

3.3 CONCEPTS, MATERIALS, AND FABRICATION TECHNIQUES ANALYSIS

In an attempt to narrow down the list of alternative termination concepts, the characteristics of the 35 concepts in Table 1 were compared. First the relative importance of each characteristic were ranked and weighed in relative significance from 1 to 29 as shown in Table 2. The performance characteristics were judged most important and, therefore, assigned the highest weights. The manufacturability characteristics were judged least significant and, therefore, assigned the lowest weights.

Next, the characteristics of each concept were assigned values from -4 to +4 as shown in Table 3. For example, the one piece flanged porcelain on the first line would have a very high cost so the cost per piece characteristic (#1) was judged very bad or -3, whereas its expected life (#29) was judged excellent or +4. Since the dielectric stresses are more a function of the shielding or grading means than the type of weathercasing, these characteristics (8 to 12) were termed not applicable or 0.

Finally, the characteristic ratings of each concept were multiplied by the respective characteristic weighings and the products totaled for each concept in Table 4. The totals in the far right column can then be used to decide which concepts should be considered further. The higher the total, the better the concept is.

Table 1

CONCEPT

CONCEPT
1-Piece flanged porcelain
Multi-piece flanged porcelain
Unflanged porcelain
Rigid epoxy weathercase
Flexible epoxy weathercase
Reinforced epoxy weathercase
Polysil weathercase
Metal banded weathercase
Present shed configuration
Nonlinear resistive coatings
Conducting fibers
Flanges
Tie rods
Springs
Fiberglass liner
Fiberglass cone
Conical insulator
Frustum (lower end)
Oil-paper condenser
Film-SF_6 condenser
Epoxy condenser
Floating shields in plug
Floating internal shields
Dielectric shields
Throat shields
Large conductor
Small conductor
Heat pipe
Bottom external toroids
Intermediate external toroids
Top external toroids
Top sphere
Segmented sphere
Horizontal cylinder
Vertical cylinder

Table 2

RELATIVE WEIGHINGS OF EACH CHARACTERISTIC

	Characteristic	Weight
1.	Cost/Piece	11
2.	New Facilities	3
3.	Weight	4
4.	Interface	10
5.	Difficulty of Manufacture or Ass'y.	8
6.	Lead Time	2
7.	Storage	1
8.	Int. Diel. Str. at Throat	27
9.	Int. Diel. Str. Elsewhere	23
10.	Ext. Diel. Str. Bottom End	28
11.	Ext. Diel. Str. Intermediate	20
12.	Ext. Diel. Str. Top End	29
13.	R I Limit	13
14.	I^2R Heating	14
15.	Dielectric Loss Heating (Int. only)	12
16.	Flange Heating	9
17.	Other Heating (Weathercases)	17
18.	Heat Transport	22
19.	Material Temperature Limit	24
20.	Clamping Forces	26
21.	Shipping Forces	6
22.	Steady State Gas Pressure	18
23.	Short Circuit Forces	5
24.	Earthquake Forces	15
25.	Wind Load	21
26.	Catastrophic Failure - Probability	25
27.	Gas Energy Available	19
28.	Projectile Size/Danger	16
29.	Life (Established)	7

TABLE 3

CHARACTERISTIC

RUN #1

CONCEPT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
ONE-PC FL. PORC	-3	1	0	0	3	-2	1	0	0	0	0	0	0	0	0	-1	3	2	4	0	0	0	0	0	0	0	0	0	4
MULTI-PC FL. PORC	-1	3	-2	0	1	-1	2	0	0	0	0	0	0	0	0	-1	3	2	4	0	-1	0	-1	-1	0	-1	0	0	4
UNFLANGED PORC	2	4	2	0	1	0	2	0	0	0	0	0	0	0	0	3	3	2	4	2	0	-1	-2	-2	0	0	0	0	3
RIGID EPOXY W.C.	3	-2	2	0	1	3	3	0	0	0	0	0	0	0	0	3	3	2	2	0	1	0	0	0	0	0	0	0	1
FLEX. EPOXY W.C.	3	-2	2	0	1	3	3	0	0	0	0	0	0	0	0	3	3	2	0	0	-1	-2	-2	-2	0	2	0	2	1
REINF. EPOXY W.C.	3	-3	2	0	0	2	3	0	0	0	0	0	0	0	0	3	3	2	1	0	1	1	0	1	0	2	0	2	0
POLYSIL W.C.	0	-3	-1	0	0	0	0	0	0	0	0	0	0	0	0	-1	2	2	2	0	-1	-1	0	-1	0	0	0	0	0
METAL BANDED W.C.	-2	-1	-1	0	1	0	0	0	0	-4	-4	0	-4	0	0	0	0	0	4	0	0	0	0	0	0	0	0	3	1
PRES. SHED CONF.	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	4
NONL. RES. COAT.	-2	-1	0	0	-2	0	-1	0	0	2	2	0	0	0	0	3	-2	2	1	0	0	0	0	0	0	0	0	0	1
COND. FIBERS	-1	-2	0	0	-1	0	-1	0	0	2	2	0	0	0	0	3	-3	3	2	0	1	1	0	1	0	2	0	2	1
FLANGES	1	4	-1	3	3	1	3	0	0	0	-2	0	-2	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0
TIE RODS	1	4	2	2	1	0	2	0	0	0	0	0	-2	0	3	2	0	3	3	2	1	0	1	-1	0	0	0	0	0
SPRINGS	2	4	1	1	1	2	3	0	0	0	0	0	0	0	0	-1	0	0	-1	2	1	-1	-1	-2	0	0	0	0	0
FIBERGL. LINER	-3	2	1	2	-1	0	-1	0	0	0	0	0	-1	0	3	3	0	-1	2	0	-1	0	0	0	0	2	0	3	0
FIBERGL. CONE	-1	2	2	2	1	0	1	0	0	0	0	0	-3	0	3	3	0	-1	2	1	0	3	1	1	0	3	3	3	0
CONICAL INS.	2	4	4	3	2	2	2	0	0	0	0	0	-1	0	4	0	0	3	2	1	0	3	1	1	0	3	3	3	0
FRUSTUM	4	3	4	-1	1	3	2	0	0	0	0	0	-1	0	4	0	0	2	2	1	0	3	1	1	0	3	3	3	0
OIL-PAPER COND.	-3	3	-3	-3	2	3	1	2	0	4	4	0	0	0	-2	0	0	-1	-1	0	-2	0	1	-2	0	3	3	3	2
FILM-SF6 COND	-3	-1	-2	-3	0	3	1	2	0	4	4	0	0	0	-2	0	0	-3	-1	0	-1	0	1	-1	0	3	3	3	1
EPOXY COND.	-3	-4	-2	-1	-1	2	2	2	0	2	2	0	0	0	-2	0	0	-2	-1	0	-2	0	1	-2	0	3	3	3	1
FL. SDS. IN PLUG	-1	-1	3	2	-1	2	1	2	0	2	2	0	-2	0	-2	0	0	-2	-1	0	0	0	0	0	0	0	0	0	3
FL. INT. SHIELDS	-1	2	-1	-1	2	3	2	2	0	2	2	0	0	0	0	0	0	-1	-2	0	0	0	0	0	0	0	0	0	4
DIEL. SHIELDS	-1	-2	2	3	2	3	3	1	1	2	2	0	0	0	2	0	0	1	2	0	0	0	0	0	0	0	0	0	3
THROAT SHIELDS	2	4	4	3	4	3	3	0	0	2	0	0	0	0	4	0	0	2	4	0	0	0	0	0	0	0	0	0	4
LARGE CONDUCTOR	2	4	2	4	4	3	1	4	4	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SMALL CONDUCTOR	3	4	4	3	4	3	1	2	3	3	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HEAT PIPE	-1	-1	2	4	1	2	1	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	2
BOTTOM EXT. TOR.	-2	2	-2	0	2	3	2	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0
INTM. EXT. TOR.	0	2	2	0	3	3	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	-1	-1	0	0	0	0
TOP EXT. TOR	-1	2	-2	0	2	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	-1	0	0	0	0
TOP SPHERE	-3	2	-2	0	2	2	1	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	-2	-2	0	0	0	0
SEG. SPHERE	-2	2	-3	0	1	3	1	0	0	0	0	-4	-4	0	0	0	0	0	0	0	0	0	0	-1	-1	0	0	0	0
HORIZ. CYL.	-1	3	0	0	3	3	2	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	-2	-1	0	0	0	0
VERT. CYL.	2	3	2	0	3	3	2	0	0	0	0	4	4	0	0	0	0	0	0	0	-1	0	0	-1	-1	0	0	0	0

INPUT DATA: RELATIVE EVALUATION OF EACH CHARACTERISTIC AS IT APPLIES TO EACH CONCEPT

TABLE 4

CHARACTERISTIC

>RUN #1

CONCEPT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	TOTAL
ONE-PC FL. PORC	-33	3	0	0	24	-4	1	0	0	0	0	0	0	0	0	-9	51	44	96	0	0	0	0	0	0	0	0	0	28	201
MULTI-PC FL. PORC	-11	9	-8	0	8	-2	2	0	0	0	0	0	0	0	0	-9	51	44	96	0	-6	0	-5	-15	0	-25	0	0	28	157
UNFLANGED PORC	22	12	8	0	8	0	2	0	0	0	0	0	0	0	0	27	51	44	96	52	0	-18	-10	-30	0	0	0	0	21	285
RIGID EPOXY W.C.	33	-6	8	0	8	6	3	0	0	0	0	0	0	0	0	27	51	44	48	0	6	0	0	0	0	0	0	0	7	235
FLEX. EPOXY W.C.	33	-6	8	0	8	6	3	0	0	0	0	0	0	0	0	27	51	44	0	0	-6	-36	-10	-30	0	50	0	32	7	181
REINF. EPOXY W.C.	33	-9	8	0	0	4	3	0	0	0	0	0	0	0	0	27	51	44	24	0	6	18	0	15	0	50	0	32	0	306
POLYSIL W.C.	0	-9	-4	0	0	0	0	0	0	0	0	0	0	0	0	-9	34	44	48	0	-6	-18	0	-15	0	0	0	0	0	65
METAL BANDED W.C.	-22	-3	-4	0	8	0	0	0	0	-112	-80	0	-52	0	0	0	0	0	96	0	0	0	0	0	0	0	0	48	7	-114
PRES. SHED CONF.	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	66	0	0	0	0	0	0	0	0	0	0	28	118
NONL. RES. COAT.	-22	-3	0	0	-16	0	-1	0	0	56	40	0	0	0	0	27	-34	44	24	0	0	0	0	0	0	0	0	0	7	122
COND. FIBERS	-11	-6	0	0	-8	0	-1	0	0	56	40	0	0	0	0	27	-51	66	48	0	6	18	0	15	0	50	0	32	7	288
FLANGES	11	12	-4	30	24	2	3	0	0	0	-40	0	-26	0	0	0	0	0	0	0	0	-18	0	0	0	0	0	0	0	-6
TIE RODS	11	12	8	20	8	0	2	0	0	0	0	0	-26	0	36	18	0	66	72	52	6	0	5	-15	0	0	0	0	0	275
SPRINGS	22	12	4	10	8	4	3	0	0	0	0	0	0	0	0	-9	0	0	-24	52	6	-18	-5	-30	0	0	0	0	0	35
FIBERGL. LINER	-33	6	4	20	-8	0	-1	0	0	0	0	0	-13	0	36	27	0	-22	48	0	-6	0	0	0	0	50	0	48	0	156
FIBERGL. CONE	-11	6	8	20	8	0	1	0	0	0	0	0	-39	0	36	27	0	-22	48	26	0	54	5	15	0	75	57	48	0	362
CONICAL INS.	22	12	16	30	16	4	2	0	0	0	0	0	-13	0	48	0	0	66	48	26	0	54	5	15	0	75	57	49	0	531
FRUSTUM	44	9	16	-10	8	6	2	0	0	0	0	0	-13	0	48	0	0	44	48	26	0	54	5	15	0	75	57	48	0	482
OIL-PAPER COND.	-33	9	-12	-30	16	6	1	54	0	112	80	0	0	0	-24	0	0	-22	-24	0	-12	0	5	-30	0	75	57	48	14	290
FILM-SF6 COND	-33	-3	-8	-30	0	6	1	54	0	112	80	0	0	0	-24	0	0	-66	-24	0	-6	0	5	-15	0	75	57	48	7	236
EPOXY COND.	-33	-12	-8	-10	-8	4	2	54	0	56	40	0	0	0	-24	0	0	-44	-24	0	-12	0	5	-30	0	75	57	48	7	143
FL. SDS. IN PLUG	-11	-3	12	20	-8	4	1	54	0	56	40	0	-26	0	-24	0	0	-44	-24	0	0	0	0	0	0	0	0	0	21	68
FL. INT. SHIELDS	-11	6	-4	-10	16	6	2	54	0	56	40	0	0	0	0	0	0	-22	-48	0	0	0	0	0	0	0	0	0	28	113
DIEL. SHIELDS	-11	-6	8	30	16	6	3	27	23	56	40	0	0	0	24	0	0	22	48	0	0	0	0	0	0	0	0	0	21	307
THROAT SHIELDS	22	12	16	30	32	6	3	0	0	56	0	0	0	0	48	0	0	44	96	0	0	0	0	0	0	0	0	0	28	393
LARGE CONDUCTOR	22	12	8	40	32	6	1	108	92	56	0	0	0	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	405
SMALL CONDUCTOR	33	12	16	30	32	6	1	54	69	84	0	0	0	-14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	323
HEAT PIPE	-11	-3	8	40	8	4	1	0	0	0	0	0	0	0	0	0	0	66	0	0	0	0	0	0	0	0	0	0	14	127
BOTTOM EXT. TOR.	-22	6	-8	0	16	6	2	0	0	0	20	0	13	0	0	0	0	0	0	0	0	0	0	0	-21	0	0	0	0	12
INTM. EXT. TOR.	0	6	8	0	24	6	3	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0	-15	-21	0	0	0	0	24
TOP EXT. TOR	-11	6	-8	0	16	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-30	-21	0	0	0	0	-41
TOP SPHERE	-33	6	-8	0	16	4	1	0	0	0	0	58	26	0	0	0	0	0	0	0	0	0	0	-30	-42	0	0	0	0	-2
SEG. SPHERE	-22	6	-12	0	8	6	1	0	0	0	0	-116	-52	0	0	0	0	0	0	0	0	0	0	-15	-21	0	0	0	0	-217
HORIZ. CYL.	-11	9	0	0	24	6	2	0	0	0	0	58	26	0	0	0	0	0	0	0	0	0	0	-30	-21	0	0	0	0	63
VERT. CYL.	22	9	8	0	24	6	2	0	0	0	0	116	52	0	0	0	0	0	0	0	-6	0	0	-15	-21	0	0	0	0	197
SUM	-55	123	84	230	392	120	52	459	184	644	300	116	-130	14	180	198	255	550	816	234	-30	90	5	-270	-168	625	342	480	280	

OUTPUT DATA: RELATIVE VALUE OF EACH CHARACTERISTIC AS IT APPLIES TO EACH CONCEPT AND TOTAL VALUE OF EACH CONCEPT

The results of this exercise have not been analyzed yet and should not necessarily be considered deciding factors. The consequences of choosing the "best" concepts and the effects of minor changes in the input schedules must first be evaluated. The "best" combination now seems to be a reinforced epoxy weathercase with conductive fiber voltage grading held together with tie rods. The bottom end would be provided by internal throat shields and a vertical cylinder top end shield, although a large diameter inner conductor would be used. Some of these concepts are conflicting, so must be reevaluated.

4.0 REPORTING (TASK 9)

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

Qty.	Report Title
1	Conference Record
1	Topical Report
3	Project Status Reports
2	Contract Management Summary Reports
2	Cost Management Reports

4.1 PROGRAM STATUS

The progress of each individual subtask is shown in the program schedule Figure 10. This same schedule will be incorporated in each quarterly report as a means of showing clearly the technical progress on the project.

4.2 MANPOWER STATUS

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

Key Personnel	Hours Worked During Reporting Period (9/28/79 to 1/3/79)
J. S. Billings	139 Hours
Z. Neri	60 Hours
C. Hofmann	0 Hours
R. Cookston	0 Hours

Total Manhours Worked During The Reporting Period (Including Key Personnel)

Task 1	149 Manhours
Task 9	165 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

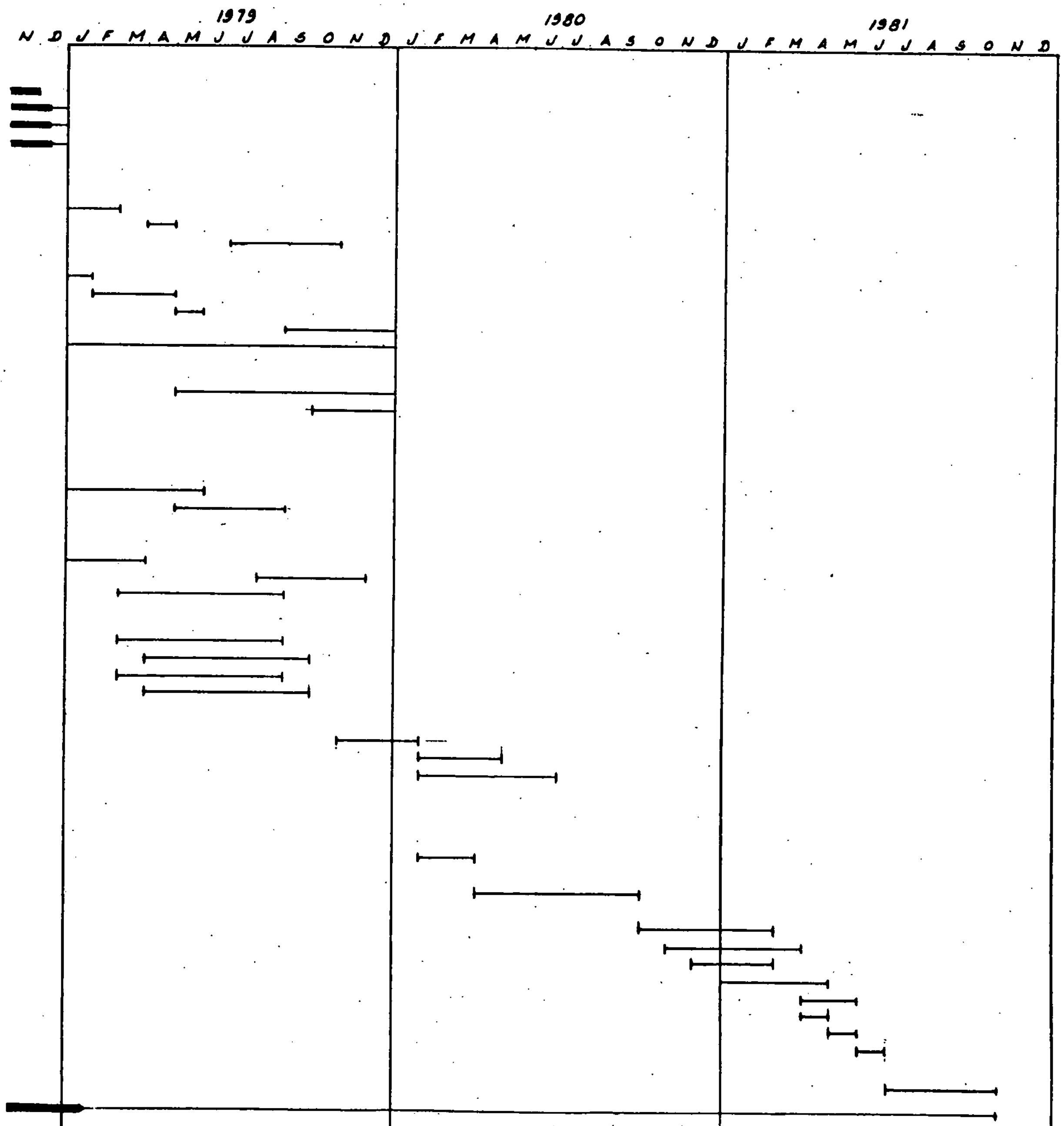


FIGURE 10

5.0 Work To Be Undertaken During Next Reporting Period

5.1 Complete the evaluation of innovative concepts, materials and fabrication techniques.

5.2 Decide which study projects to undertake.

5.3 Design the model for the shield effectiveness study.

5.4 Determine the objectives and criteria for the resistive grading study.

5.5 Start designing the models for the resistive grading study.

5.6 Make electrostatic field plots as needed.

5.7 Start designing the models for the shatter resistant weathercase study.

5.8 Start designing the models for the reinforcing liner study.

5.9 Start the clamping and fastening study.

5.10 Order long lead model parts as needed.

5.11 Prepare monthly reports as required and start on second technical progress report.

DESIGN SPECIFICATION FOR A 1200 kV TERMINATION

1.0 Project Scope

This is a design specification for a 1200 kV air-to-SF_6 termination to be developed as a part of DOE contract No. ET-78-C-01-3107. Innovative concepts, materials, and fabrication techniques are to be investigated. A reasonable design concept will be selected which will most effectively, efficiently, and reliably meet the electrical, thermal, and mechanical requirements as set forth in this specification.

The design will be fabricated and tested and a prototype termination will be delivered at the culmination of this project for field evaluation by DOE. The prototype will include only the termination itself and appropriate adaptors, if necessary, to mate with other 1200 kV equipment supplied by separate contract. Westinghouse will assist with the installation and provide instructions for the operation and maintenance of the termination.

This document is intended to serve only as a guideline for the development and design of the 1200 kV termination and as such should not necessarily constrain the final termination design except where limited by contractual agreement, government regulations or industry standards. Some areas of the specification will likely be revised or refined during the course of the project.

2.0 Applicable Documents

2.1 Reference Standards

2.1.1 ANSI C68.1 - 1968 Techniques for Dielectric Tests

2.1.2 ANSI C37.074 - 1972 Requirements for Switching Impulse Voltage Insulator Strength for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis (362 kV and Above)

2.1.3 ANSI C37.076-1972 Requirements for Pressurized Components of AC High Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

2.1.4 ANSI C37.078-1972 Requirements for External Insulation for Outdoor AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

2.2 Documentation on Associated Projects

2.2.1 ERDA project # E(99-18)-2061 Design, Development, test, and economic analysis of a prototype UHV (1100 kV) Compressed Gas Insulated Cable System.

2.2.2 DOE Project #ET-78-C-01-2870 Development of a Semiflexible 1200 kV Compressed Gas Insulated Transmission System.

2.2.3 DOE Project # DE-AC01-79-ET-29067 Analysis & Design of a 1200 kV Circuit Breaker for a gas insulated substation.

3.0 Requirements

3.1 Function

The function of the termination is to provide an electrical power transmitting interface between SF_6 gas insulated equipment and air insulated equipment. The SF_6 gas equipment may be SF_6 insulated cable, a SF_6 circuit breaker or other SF_6 insulated equipment.

3.2 Major Applications

3.2.1 Configuration

The major expected configurations for application of the termination are as follows:

3.2.1.1 Direct connection to elbow or tee

3.2.1.2 Axial connection to straight bus or cable

3.2.1.3 Direct connection to apparatus

3.2.1.3.1 Circuit breakers

3.2.1.3.2 SF_6 transformers

3.2.1.3.3 SF_6 reactors

3.2.1.3.4 Other apparatus

3.2.2 Expectations of use

This termination is expected to be mounted at any angle (close to vertical likely). Reasonable line hardware and cable may be connected to its air-end terminal, which it must support. Unless otherwise specified, the SF_6-end terminal will consist of a conventional plug-in joint. The terminal will not be expected to independently support circuit breaker interrupters or other massive or active devices.

The termination is expected to effectively seal the SF_6 equipment it terminated; thus it will be exposed on its SF_6 end to the full SF_6 system pressure. It is desirable that the termination should not have an independent SF_6 system.

The termination will be applied in a system with a rated three-phase 60 Hz line-to-line voltage of 1200 kV rms. It is expected to be capable of conducting 5000 Amperes, rms, continuously when connected to buried underground cable or 6000 Amperes, rms, when connected to surface or above ground equipment. The termination is expected to be self-cooled and should not transfer significant heat energy through its terminals to the connected bus or equipment.

Terminations are expected to be installed in electric utility substations not accessible to the general public. Authorized personnel will likely walk or perform tasks in the near vicinity of the termination while it is being operated. Standard utility safety rules for overhead clearance and operating equipment are expected to be practiced.

3.3 Design Requirements

3.3.1 Electrical requirements at minumum SF_6 pressure

3.3.1.1 Continuous Voltage 60 Hz rms $\frac{1200}{\sqrt{3}}$ = 690 kV

3.3.1.2 1 Minute 60 Hz rms withstand 1200 kV

3.3.1.3 Lightning Impulse Withstand (1.2/50 μs) 2175 kV

3.3.1.4 Switching Impulse Withstand (250/2500 μs) (wet and dry) 1800 kV

3.3.2 Mechanical Requirements

3.3.2.1 The termination shall function properly in an environment between the temperatures of -40°C to +40°C.

3.3.2.2 As per standards listed in 2.2.1, the termination shall not exceed the following temperature limits with full rated current applied at 40°C ambient:

105°C Maximum - all silvered current carrying joints

105°C Maximum - all inaccessible external surfaces

70°C Maximum - all accessible external surfaces

3.3.2.3 The termination shall be self-cooled.

3.3.2.4 The termination must withstand an internal vacuum.

3.3.2.5 The termination must withstand a gas pressure of 1.5 times the maximum designed pressure of the vessel. Pressure relief devices shall be provided to limit over-pressure. See 3.3.9 on construction.

3.3.2.6 The terminations shall withstand a cantilever force equal to the total of the wind force, seismic load, and short circuit magnetic force as calculated below plus an appropriate safety factor based on configuration and materials used. (Line pull is not expected to exceed 600 lb.)

3.3.2.6.1 Wind load at 90 mph shall be assumed as turbulent so force equals 20 pounds/FT^2. Area shall be assumed as the envelope of the termination's sillouette. Cantilever force at the terminal shall be assumed as one half the total wind load if the termination sillouette approximates a rectangle. If the sillouette has an irregular shape such as a large sphere at top of termination, the cantilever force shall be assumed equal to the sum of the computed moments of each segment of section of the bushing divided by the termination length.

3.3.2.6.2 The termination must withstand a seismic load of 0.3g. The natural frequency of vibration of the bushing should be greater than 20 Hz to avoid resonance with seismic load. The cantilever force resulting from .3g acceleration shall be assumed to be equal to 0.15 times termination weight.

3.3.2.6.3 The magnetic force at the terminal shall be calculated assuming a short circuit current of 40000 Amperes, symmetrical. In the worst case, terminal-to-terminal separation shall be assumed no less than 110 percent of the bushing strike distance.

3.3.2.7 Complete shipping assemblies and packaged terminations must survive without damage a repeated 15g momentary acceleration in any direction. 20g accelerations have been experienced during normal rail shipments without the use of special cars and should be considered during analysis to predict damage should such an acceleration occur. These high loads are the result of impacts between cars and are limited to the longitudinal axis of the car. Placing the centerline of the termination in a horizontal plane and parallel to the centerline of the car will significantly improve its ability to tolerate this load.

3.3.2.8 The termination design shall allow for differential expansion resulting from the inner conductor operating at a higher temperature and having a different Coefficient of thermal expansion than the outer shell.

3.3.2.9 Fabrication tolerances and sag due to conductor weight should allow no more than a 10 percent eccentricity of the inner conductor relative to outer conductor. This 10 percent eccentricity coupled with the 5 percent due to interphase electrical forces produces a total maximum eccentricity of 15 percent.

3.3.3 SEALS

3.3.3.1 Seals used within the termination and at the joint(s) with the connected apparatus shall limit the loss of SF_6 gas to atmosphere to less than 1% per year of the gas enclosed by the bushing.

3.3.3.2 All seals must be resistant to atmospheric corrosion and remain reliable over a temperature range of -40c to +40c.

3.3.4 RELIABILITY

Service life shall be 20 years with normal maintenance.

The leak rate shall be less than 1% per year of the gas enclosed by the termination.

3.3.5 SERVICE LIFE

Service life shall be 20 years minimum without replacing major components provided normal maintenance is performed.

3.3.6 SAFETY

The termination will be designed to minimize the danger of castastrophic failure from either mechanical or electrical damage. Potential damage to personnel or equipment will be within the limits of conventional SF_6 insulated bushings at 362 kV or below.

3.3.7 ENVIRONMENTAL EFFECTS

The termination must have negligible effect on the environment. All external coatings shall not be detrimental. SF_6 leakage shall be minimized.

3.3.8 ENVIRONMENTAL CONDITIONS

The termination shall function properly in an environment as follows:

- o Ambient temperature range from -40°C to +40°C.
- o Earthquake with 0.3g equivalent acceleration.
- o Repeated 15g momentary acceleration in any direction on shipping assemblies and packaged bushings.
- o Wind load at 90 mph (turbulent) with force of 20 lb/ft^2.

  Area shall be assumed as the envelope of the bushing silhouette.

3.3.9 CONSTRUCTION

3.3.9.1 Should be an axial cylindrical connection to system to minimize or eliminate orientation with system.

3.3.9.2 Should be a suitable size and weight for shipping.

3.3.9.3 Adequate means shall be provided for handling and installing.

3.3.9.4 The design shall not hinder maintenance and repair.

3.3.9.5 The termination shall be readily adaptable to mate with any other component in the system.

3.3.9.6 The termination shall be self-cooled.

3.3.9.7 Each gas compartment of which a termination is a part shall have an overpressure relief device. These should be located on adjacent elbows and tees. Care should be taken to protect maintenance personnel near the device in the event the device is called upon to relieve gas pressure, such as using a baffled cover over the pressure relief exhaust.

Also, the gas compartment should be such that a sufficient gas passage is available from all portions of the compartment to the relief device to allow proper gas flow and limit the localized pressure maximum due to a maximum rated fault in the compartment to less than 2.5 times the maximum design pressure of the vessel. The arc may burn a hole in the vessel wall which will aid in the limiting of internal pressure.

3.3.9.8 The completed assembly should be designed to facilitate shipping and minimize field erection difficulties.

3.3.10 PARTS AND COMPONENTS

The major components of the termination are:

- External insulation (weathershed)
- Conductor
- Internal insulation
- External insulation
- Internal shielding
- Flanges

3.3.11 MATERIALS

3.3.11.1 Electrical insulation shall be one or more of the following:

- Porcelain Westinghouse PDS 46502AA or equivalent
- Epoxy (cycloaliphatic) Westinghouse PDS 53841VA-VF or equivalent with track resistance per:

  ASTM D2302, DWT test; of greater than 8.1 watt minutes and ASTM 2303, Inclined Plane Test, of greater than 400 minutes.
- Reinforced glass epoxy, Westinghouse PDS-44765BG, or equivalent similar material.
- The epoxy may be reinforced with open weave fiber scrim, Westinghouse PDS-41524 SX or equivalent.

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- o Reinforcing fibers such as glass or carbon fibers may be used for composite structures.

The following may be used to supply a conducting and/or a reinforcing function in composite with insulating materials.

- o Metalized glass fiber
- o Graphite fiber
- o SS 304 fiber
- o Amorphous metal ribbon

If insulation material is exposed to arced SF_6, the exposed surfaces shall have a 1000 VDC arced SF_6 resistence in excess of 10,000 M .

3.3.11.2 Contact Material

Internal contacts shall be made of copper based or aluminum based materials. The contacts will be silver plated to increase conductivity.

3.3.11.3 Bolting Hardware

Bolting hardware shall generally be of grade 5 steel.

3.3.11.4 Springs

Springs, if used may be steel or other suitable material.

3.3.11.5 Other Materials

All other materials shall be non-ferrous.

3.3.12 COATINGS AND TREATMENTS

All coatings, platings and treatments applied to terminations shall conform to any standard specifications for station bus, elbows and tees.

Processes shall not employ critical parameters which are difficult to maintain if failure to maintain these parameters might result in a significant deterioration of the properties of the part being coated or treated.

3.3.13 PARTS STANDARDIZATION

Standard components shall be used whenever possible. Since a number of the opportunities for standardization lie in areas controlled by suppliers, standardization of termination parts may prove somewhat difficult. Particular effort will be made to standardize the following:

- o Bolting hardware
- o Terminals and grounding pads
- o Top end seals
- o Top end shields
- o Contacts

The same termination design shall be employed for circuit breakers, gas insulated substations and compressed gas insulated transmission facilities.

3.4 MAINTENANCE CONCEPT AND LOGISTICS REQUIREMENTS

3.4.1 Bushing design shall minimize or eliminate maintenance.

3.4.2 Parts which must be maintained shall be easily accessible.

3.4.3 The need for special tools shall be minimized.

3.4.4 The difficulty of maintenance shall be minimized.

3.5 COST OBJECTIVES

The selling price of the termination should be reasonable in comparison to other 1200 kV equipment. A goal of 60% of the assembled price of the porcelain termination with floating internal metal shields developed as a part of DOE contract No. EC-6-C-01-2061 and no more than the price of the oil condenser bushings * supplied as part of the Waltz Mill 1100 kV project on a constant dollar basis.

*NOTE: The Waltz Mill bushings do not include adaptors to mate with the SF_6 system, are not sealed for use in SF_6 systems, and furthermore are only rated 600 amperes continuous current.

3.6 Project Schedule

EVENT SCHEDULE DOE PROJECT ET-78-R-01-3107 1200 kV TERMINATION WESTINGHOUSE ELECTRIC

1978: N D | 1979: J F M A M J J A S O N D | 1980: J F M A M J J A S O N D | 1981: J F M A M J J A S O

TASK 1 — Concept Design & Material Study
- (1.1) Problem Definition
- (1.2) Innovative Concepts
- (1.3) Materials Investigation
- (1.4) Fabrication Techniques

TASK 2 — Electrostatic Studies
- (2.1.1) Concept Study & Model Design (Shield Effectiveness)
- (2.1.2) Establish Test Objectives
- (2.1.3) Data Evaluations & Recommendations
- (2.2.1) Grading Objectives & Criteria (Resistive Grading)
- (2.2.2) Design Models
- (2.2.3) Establish Test Objectives
- (2.2.4) Data Evaluation & Recommendations
- (2.3) Field Plotting

TASK 3 — Thermal Studies
- (3.1) Thermal Transp... Study
- (3.2) Heat Pipe Study

TASK 4 — Mechanical Studies
- (4.1.1) Concept Study Model Design & Test Criteria (Shatter-Resistant Weathercase)
- (4.1.2) Data Evaluations & Recommendations
- (4.2.1) Concept Study, Model Design & Test Criteria (reinforcing liners)
- (4.2.2) Date Evaluations & Recommendations
- (4.3) Clamping & Fastening Study & Recommendations

TASK 5 — Mechanical Studies
- (5.1) Shield Effectiveness
- (5.2) Resistive Gradings
- (5.3) Shatter-Resistant Weathercase
- (5.4) Reinforcing Liner

TASK 6 — Design of Prototype
- (6.1) Finalize Design Parameters
- (6.2) Make Engineering Drawings
- (6.3) Review and Evaluate

TASK 7 — Production & Testing of a Prototype
- (7.1) Quality Assurance & Preparations for Test
- (7.2) Procurement of Special Tooling & Component Parts
- (7.3) Manufacture Prototypes
- (7.4) Elect. Design Tests
- (7.5) Other Design Tests
- (7.6) Revise & Finalize Drawings
- (7.7) Disassemble Prototype
- (7.8) Modify Prototype
- (7.9) Reassemble Prototype
- (7.10) Complete Tests

Delivery of the prototype and monitoring performance — Task 8

Reports & Recommendations — TASK 9

3.7 CONDITIONS OF USE AND MISUSE IN UNPROTECTED OUTDOOR ENVIRONMENT

3.7.1 Ambient temperatures of -40°C to +40°C

3.7.2 Clean to highly polluted atmosphere

3.7.3 Possible .3g earthquake

3.7.4 Up to 90 mph winds

3.7.5 Possible excessive line pull

3.7.6 Possible mis-use of insulator sheds and shields as a ladder or for lifting

3.7.7 Possible damage due to accidental impacts from tools and falling objects or vandalism

3.7.8 Accidental overpressure or underpressure during operation

3.7.9 Ultraviolet radiation

3.7.10 Possible sandstorms

3.7.11 Lightning induced over-voltages

3.7.12 Switching surge over-voltages

3.8 DESIGN ALTERNATIVES (not necessarily complete)

3.8.1 Conventional procelain shell gas-insulated bushing

3.8.2 Gas insulated bushing with modified internal throat shields

3.8.3 Gas insulated bushing with floating internal shields

3.8.4 Gas insulated bushing with reduced diameter inner conductor

3.8.5 Bushing with solid sphere top corona shield

3.8.6 Bushing with segmented sphere top corona shield

3.8.7 Bushing with toroidal top corona shields

3.8.8 Bushing with horizontal cylinder top corona shield

3.8.9 Bushing with upward bent cylinder top corona shield

3.8.10 Bushing with vertical cylinder top corona shield

3.8.11 Weathershed with nonlinear or resistive coating

3.8.12 Weathershed with conductive fiber filler

3.8.13 Resin weathershed with fiber reinforcement

3.8.14 Weathershed cast directly to conductor at top end

3.8.15 Weathershed cast over fiberglass tube

3.8.16 Weathercase separated from fiberglass liner by sealed gas space

3.8.17 Weathercase separated from perforated fiberglass liner

3.8.18 Flanged weathercase

3.8.19 Spring loaded weathercase

3.8.20 Conical insulator bottom support

3.8.21 Conductor in tension

3.8.22 Tie rods in tension

3.8.23 Heat-pipe cooled conductor

3.8.24 External dielectric shield (thick wall weathercase)

3.8.25 Internal dielectric shield

3.8.26 Cast resin condenser

3.8.27 Oil impregnated paper condenser

3.8.28 SF_6 gas impregnated film condenser

3.8.29 Intermediate length high pressure tube

3.8.30 Metal banded weathercase

3.8.31 Gas insulated bushing with internal dielectric shields

3.9 CRITICAL PARTS

3.9.1 Pressure relief devices

3.9.2 Seals

3.9.3 Attachment devices for weathercase

3.9.4 Weathercase

3.9.5 Primary dielectric

3.10 HIGH RISK AREAS

3.10.1 Lightning impulse capability internally

3.10.2 Wet switching surge capability externally

3.10.3 Shatter resistance

3.11 MAKE OR BUY

All components except "Normal Buy" commodities (i.e., hardware, castings) will be evaluated according to Westinghouse Make or Buy Guide MG-M05.

Make or buy decisions may be used in material selections when one possible material may be made in house and another possible material would be bought outside (as in epoxy vs. porcelain).

Make or buy decisions will not be implemented when contract regulations differ.

4.	<u>PRODUCT INTEGRITY ASSURANCE</u>	
4.1	Design Tests	
4.1.1	60 Hz One Minute Dry Withstand (kV)	1200
4.1.2	Full Wave (1.2/5 μS) Lightning Impulse Withstand (kV)	2175
4.1.3	Switching Impulse (250/5000 μS) Withstand (wet and dry) (kV)	1800
4.1.4	Rated Current Thermal Withstand-(Amperes)	6000
	Ionization Level	Essentially free at 800 kV 60 Hz rms
4.1.5	Hydrostatic Five-Minute	4.25 Times Maximum Operating Pressure
4.1.6	Cantilever and Bow String Tests	Cantilever tests on one bushing assembly will be used to verify 90 mph wind load and .3g earthquake equivalent A bow string test will be made to determine the material frequency of the bushing and the seismic performance will be verified by calculation.
4.1.7	Thermal Cycle Test	The final protype bushing assembly filled with SF_6 gas will be subjected to 10 thermal cycles from -30°C to +40°C ambient
4.1.8	Explosion Resistance	Catastrophic failure will be simulated by firing a 30.06 rifle bullet into a pressurized weather casing.

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4.2 FIELD TESTS

As a part of this project, a prototype termination will be delivered to a suitable field location for connection to other SF_6 gas insulated equipment not included in this project. Field evaluations of the prototype termination are not included in this contract.

4.3 PACKAGING, HANDLING, AND TRANSPORTATION REQUIREMENTS

The termination should be packaged to withstand railroad shipment anywhere within the continent of the U.S.A. See Section 3.3.2.7 for mechanical requirements.

4.4 DOCUMENTATION REQUIREMENTS

Reporting on this contract should be per the uniform Contractor Reporting System Guidelines as included in contract #ET-78-C-01-3107. Form DOE 537 lists which reports are to be made, their frequency, and distribution.

All technical data should be prepared in such a manner that it may be reproduced directly into the quarterly reports and for viewgraph slides whenever possible. All original data and calculations should be properly recorded in permanent record books.