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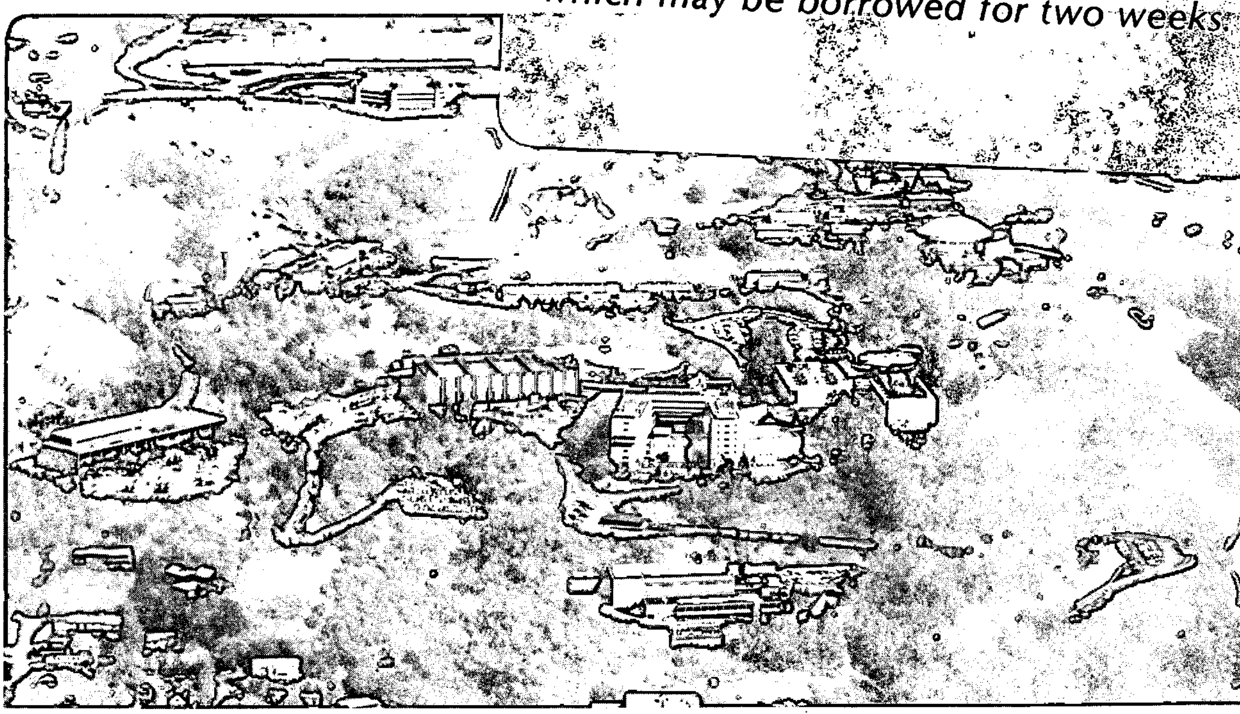

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DEVELOPMENT OF LARGE HIGH-VOLTAGE PRESSURE INSULATORS FOR THE PRINCETON TFTR FLEXIBLE TRANSMISSION LINES

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Specially formulated insulator materials with improved strength and high-voltage properties were developed and used for critical components of the flexible transmission lines to the TFTR neutral beam ion sources. These critical components are plates which support central conductors as they exit the high-voltage power supply and enter the ion source enclosure. Each plate acts both as a high-voltage insulator and as a pressure barrier to the SF_6 insulating gas. The original plate was made of commercial glass-epoxy laminate which limited the plate voltage capacity. The newly developed insulator is made of specially-formulated cycloalphatic Di-epoxide whose isotropic properties exhibit increased arc resistance. It is cast in one piece with skirts which greatly increase the breakdown voltage. This paper discusses the design, fabrication and testing of the new insulator.

1. Introduction

The Princeton Tokamak Fusion Test Reactor (TFTR) has large flexible transmission lines[1/] that carry the arc and filament power from the high-voltage power supplies to the ion sources of the neutral beam injectors. Inside of the transmission lines is a center bundle of cables that carry 6,000 A in a SF_6 environment at 120 kV with respect to the outer cables.

Critical components of these transmission lines are the 25-inch diameter High-Voltage Pressure Insulators at each end of the transmission line. Each insulator supports the central bundle of conductors carrying the current from the power-supply and must act both as a high-voltage insulator and as a pressure barrier to the SF_6 insulating gas.

The original insulators were fabricated of NEMA G-10. The commercially available G-10 shapes required that the insulators be made of several pieces joined together with an adhesive. These G-10 insulators presented several problems. They exhibited directional properties (in the plane of the glass fabric); they did not hold the specified voltage; and there was difficulty in holding the specified gas pressure.

As a consequence of the problems with the G-10, a new insulator had to be developed with specially formulated materials. This paper discusses the special formulation, design, fabrication and testing of the new insulator.

2. Special Insulator Formulation

The search for a new improved insulator material started with certain G-10 basic properties as requirements and then added needed improvement goals. Thus the new material must be as good or better than the G-10 in the following properties:

- arc resistance
- tensile strength
- gas pressure-tightness

The following improvements over G-10 were added as goals:

- the physical properties should be isotropic
- the insulating properties should be enhanced and the fabricating procedures simplified by being able to cast the insulator in one piece
- capability to encapsulate feed-thrus (without cracking)

Fortunately the search for the new insulator material was facilitated by extensive work previously done by R.S. Taylor.[2/] Nevertheless, approximately 70 test specimens with sixteen different formulations were fabricated and evaluated in this search.

The central ingredient in all of the test specimens was Cycloaliphatic Di-Epoxide ERL-4221. It was chosen because it features good electrical loss properties combined with toughness and high heat-distortion temperature. Another important ingredient was Polymeric Diol PCP-0230 which is useful in improving the thermal shock resistance of ERL-4221 in systems having heat distortion requirements below 100 degrees C.

The principal ingredients whose weight-percentage was changed in the test specimens were the filler materials--the C-333 ATH hydrated alumina and the chopped glass fibers (1/8-inch or 1/4-inch length).

Table 2-1 gives the final formulation selected and the casting procedure for the high-voltage pressure insulators.

The following sections describe the design and test of the finished insulators which are installed at the Princeton TFTR.

3. Design Features

The new insulator incorporates a number of design improvements, including the following:

- Cylindrical skirts integrally cast into the flat sections were added to increase the high-voltage creep path.
- The six grid posts were made of stainless-steel and integrally cast into the insulator.

The original G-10 insulator precluded the effective use of cylindrical skirts and of stainless steel grid posts because the attachment of separate skirts and grid posts to the flat G-10 disk would have presented serious breakdown problems.

Before deciding on the final design, the impact of 2, 3 and 4 inch high skirts on the maximum gradient of the equipotential lines was analyzed. It was found that the impact on voltage gradient is negligible. Therefore a skirt height of 4 inches was selected to get the largest creep path across the 200 kV test potential.

After selecting the 4-inch skirt height, the tensile stresses in the insulator were analyzed by considering an annular flat plate with a uniform load over the entire surface under two sets of boundary conditions:

- Outer edge fixed and inner edge free.
- Outer edge simply-supported and inner edge free.

The results of this analysis are shown in Table 3-1.

Table 3-1 shows that the tensile stresses are much higher for a simply-supported than for a fixed outer-edge. Therefore, the goal in the detailed design was to approach the fixed-support condition as closely as possible. This was done by providing large clamping forces at the outer-edge of the insulator.

The calculated stresses in Table 3-1 are for a differential pressure of 60 psi across the insulator. This 60 psi was the acceptance-test pressure for the 42 production insulators. Section 4 below will show that the destructive-test pressure on three prototype insulators provides a comfortable safety margin above the 60 psi acceptance-test pressure.

Sketches and photographs of the fabricated insulators and of their installation in the Princeton TFTR are indicated in the following figures. The insulator cross-section is shown in Figure 3-1 and its installation at the HV Power Supply is shown in Figure 3-2. Figure 3-3 shows the finished insulator (with the cast-in-place grid inserts) being removed from the casting mold. Figures 3-4 and 3-5 show the view of the trans- mission line being installed below the main floor and a closeup of the connection to the HV power supply.

4. Test Results

A total of 42 production insulators (including 10 spares) were fabricated for installation in the Princeton TFTR machine. Three prototype insulators were fabricated for purpose of destructive tests to determine safety margins.

Typical operating conditions for the production insulators installed in the TFTR machine are as follows:

- Operating Voltage . . . . 120 kV
- Operating Pressure Differential . . 30 psi
- Operating Temperature . . . . . . 40 C.

The SF_6 pressures are approximately 4 inches water on transmission-line side of the insulator, 15 psig on the HV ion source side and 30 psig on the HV power supply side.

The basic specifications for the acceptance tests are as follows:

- Breakdown Test Voltage . . . . . . 180 kV
- Test Differential Pressure . . . . 60 psi
  (Must remain gas tight at this pressure)

All of the production insulators passed or exceeded these specifications. Figure 4-1 shows typical voltage holding capability. As shown, the current drain was less the 1 μA at 150 kV and only 5 μA at 200 kV.

Three prototype insulators were tested to destruction to determine their ultimate strength. Figure 4-2 shows typical results of Deflection vs. Differential Pressure. The deflection was measured at the tip of one of the skirts. It is seen that the deflection-load curve is essentially linear until breakage at 220 psi. This breaking load (220 psi) offers a comfortable margin over the acceptance test pressure load (60 psi). Figures 4-3 and 4-4 show photographs of the pressure-load side and of the air-side, respectively, of the broken tested insulator. The circumferential crack on the pressure-load side of the insulator indicates that the tensile strength limit was reached on the skirt. The radial crack on the air-side of the insulator indicates that the tensile strength limit was reached by tangential stresses.

The production insulators have been installed in the Princeton TFTR machine since 1985 and have been operating satisfactorily since installation.

The authors have recommended that a program of testing and monitoring for creep of the insulators be instituted at Princeton. For example, any permanent deflection on the insulator skirts could be periodically monitored. If, during the monitoring, the permanent deflection should approach the 0.045 inches (shown for the 60 psi differential pressure load in Figure 4-2) then evaluation and any necessary corrective action should be instituted.

5. Acknowledgments

The authors acknowledge the contributions of Naseem Munshi and W. Gath to this work.

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6. References

[1] J. Haughian, K. Lou, R. Byrns, E. Fong, J. Carrieri, "Fabrication and Testing of the Flexible Transmission Line to the TFTR Neutral Beam Ion Sources," Proceedings of the 10th Symposium on fusion Engineering, Philadelphia, December 1983.

[2] R.S. Taylor, LLNL, January 6, 1981, Formulation RT-2868.

Table 2-1. Insulator Formulation a/

Item b/	Mixing Temp	WT %	Constituent	Stock No.	Material
A	100F	17.49	Resin	ERL 4221	Cycloaliphatic Di-Epoxide
B	125F	15.99	Resin	PCP 0230	Polymetric Diol
C	100F	19.74	Hardener	ECA 190	Anhydride Mthpa
D	70F	0.27	Catalyst	BDMA	Benzyldimethylamine
E	70F	0.51	Coupling Agent	KR-385	Titanate
F	70F	8.00	Filler	—	1/8-in Chopped Glass Fiber
G	70F	38.00	Filler	C-333	Ath-hydrated alumina
H	70F	25 drops per 100 lbs mix	Defoaming Agent	SAG-471	Silicone Agent

a/ Procedure used for making a cast insulator:
(1) Combine constituents A, B, C, D, and E; blend thoroughly.
(2) Add the fillers in several increments and blend thoroughly.
(3) De-gas; fill the evacuated (and preheated) mold.
(4) Cure for 16 hours at 150°F.
(5) Turn off water cooling (to the reservoir) after 8 hours.
(6) Remove from the mold at the end of the cure cycle.
(7) Postcure, properly supported, for 8 hours (min.) at 280°F.

b/ Constituent Suppliers:
A, B (Union Carbide); C (Archem); D (Eastman Organic Chem.); E (Kenrich Petrochemical); F (Alcoa Chem. Div.); G (Monsanto Chem. Co.)

Table 3-1. Calculated Radial and Tangential Stresses (psi) vs. Radius (for a Differential Pressure of 60 psi across the Insulator).

Radial Location	Inner Radius (4.8 in)	Skirt Radius (6.6 in)	Outer Radius (12.6 in)
1. Fixed-Support Outer Edge			
1.1 Radial Stress a/	0	-80	1,500
1.2 Tangential Stress a/	-700	-600	400
2. Simply Supported Outer Edge			
2.1 Radial Stress	0	-800	0
2.2 Tangential Stress	-4,200	-3,300	-1,500

a/ Stresses given are on pressure-load side of insulator. Positive/negative signs denote tensile/compressive stresses.

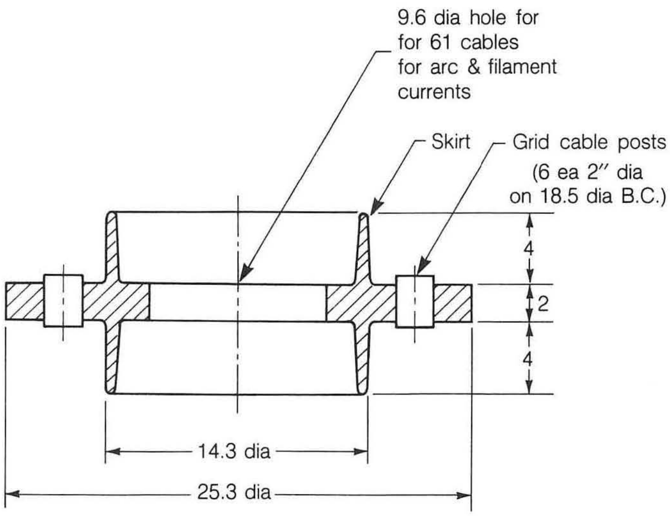


Fig. 3-1 Cross-Section Sketch of Insulator
XBL 869-1204

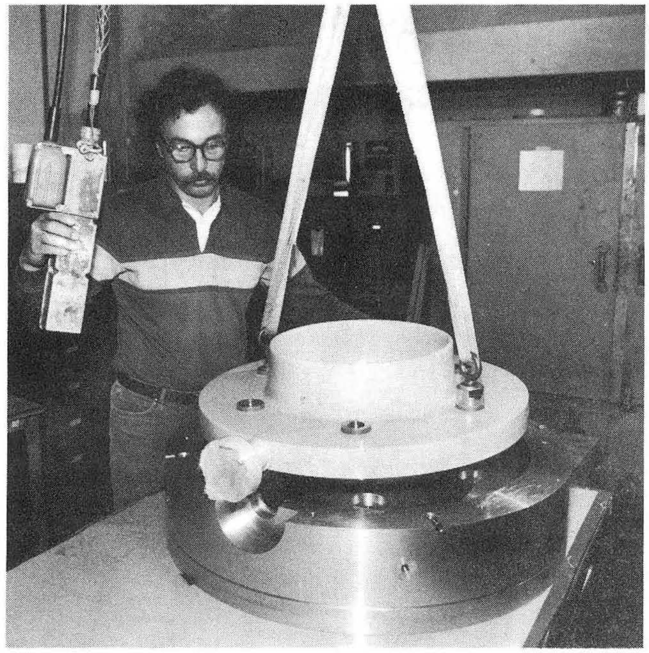


Fig. 3-3 Finished Insulator Being Removed from Casting Mold CBB 855-3943

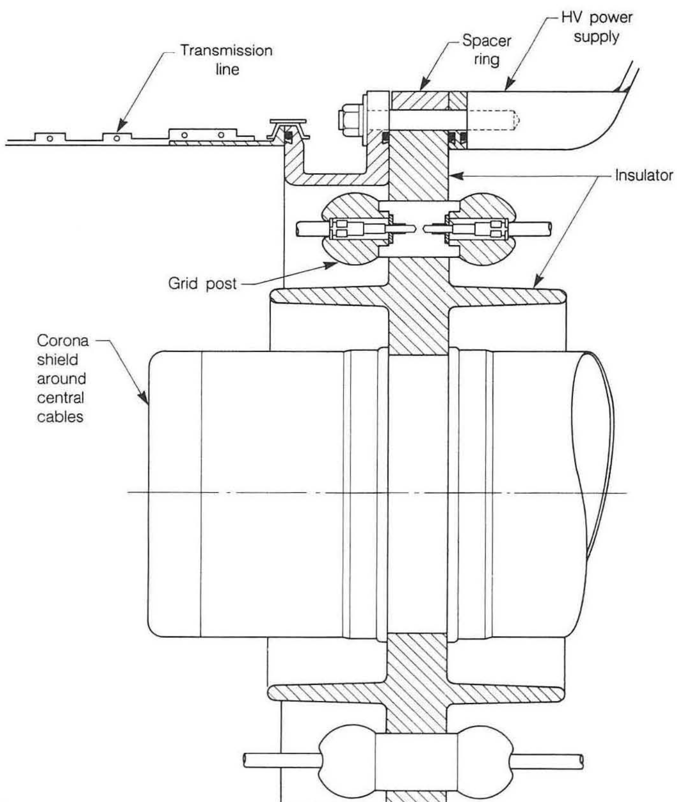
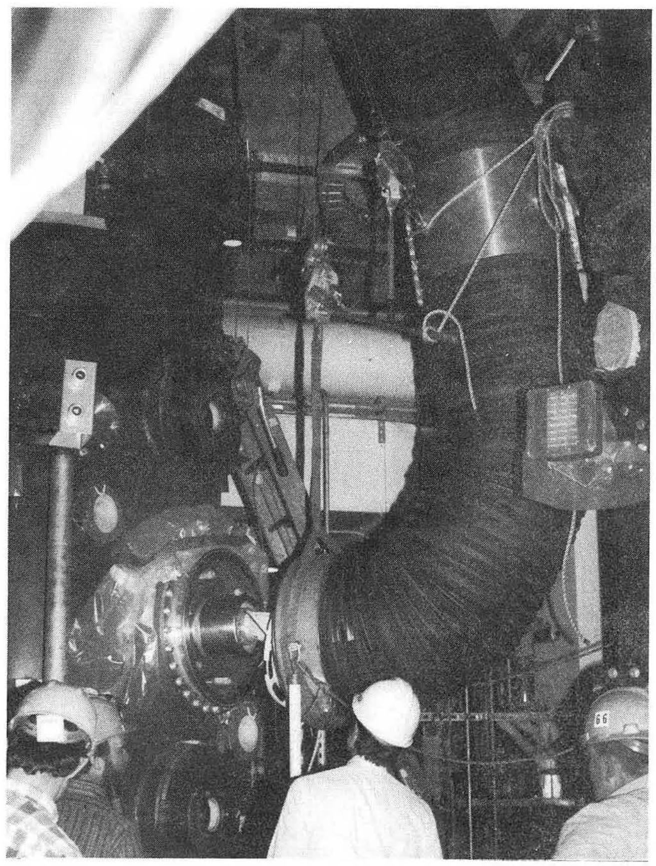


Fig. 3-2 Installation Sketch of Insulator at HV Power Supply



XBC 845-3667

Fig. 3-4 View of X-Line Below Main Floor

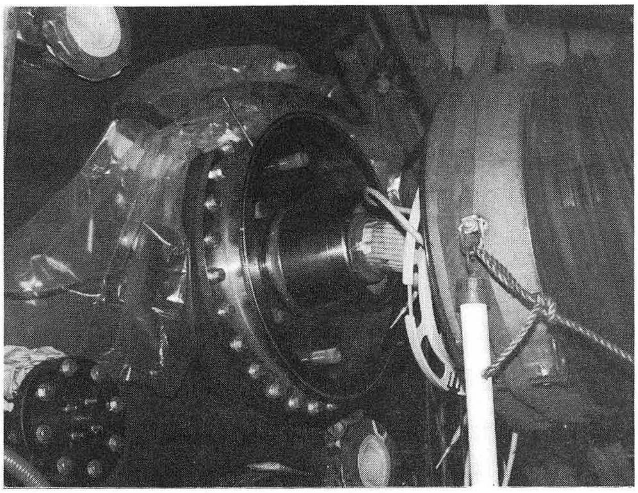
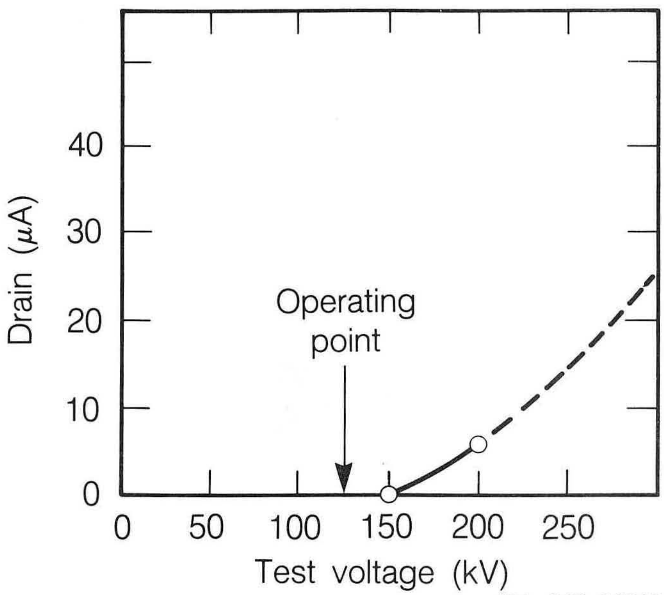


Fig. 3-5 Close-Up of Insulator (original G-10 Design) at HV Power Supply and X-Line Below Main Floor XBC 845-3668



XBL 869-12038

Fig. 4-1 Typical Acceptance HV Test Results

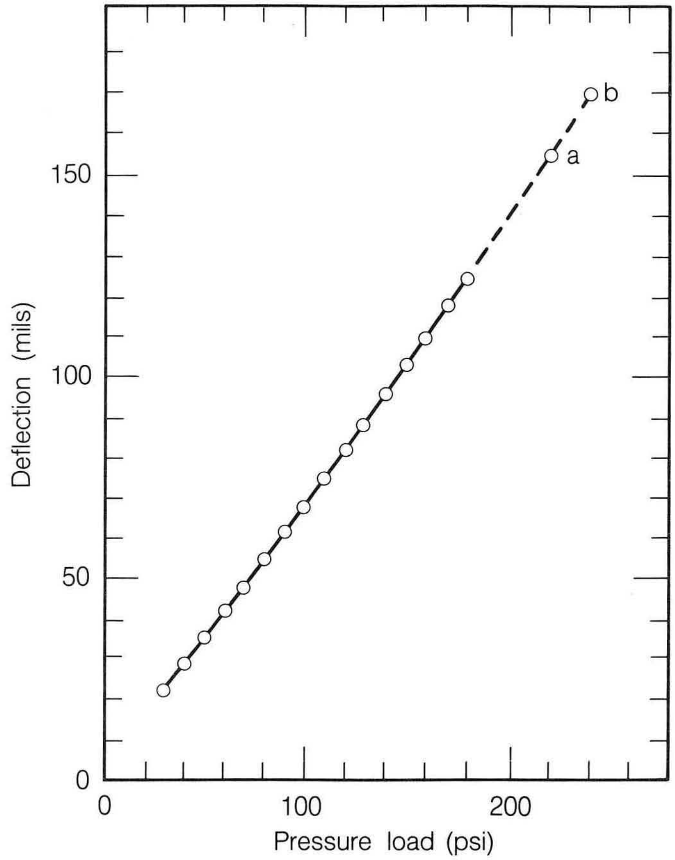


Fig. 4-2 Pressure Load vs. Deflection for Destructive Test of Prototype Insulator. At 220 psi (point a/) a loud crack was heard and the pressure dropped to 205 psi; pumping brought the pressure back up to 240 psi (point b/) when a second crack was heard and the test was stopped. XBL 869-12039

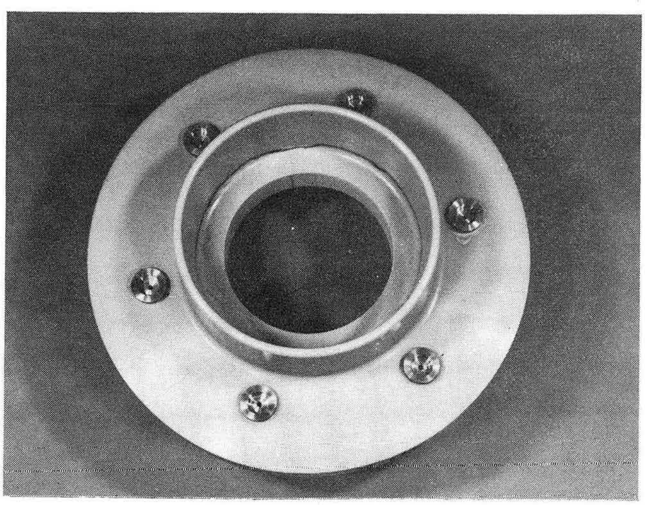


Fig. 4-3 Pressure-Load Side of Insulator After Destructive Test CBB 855-3606

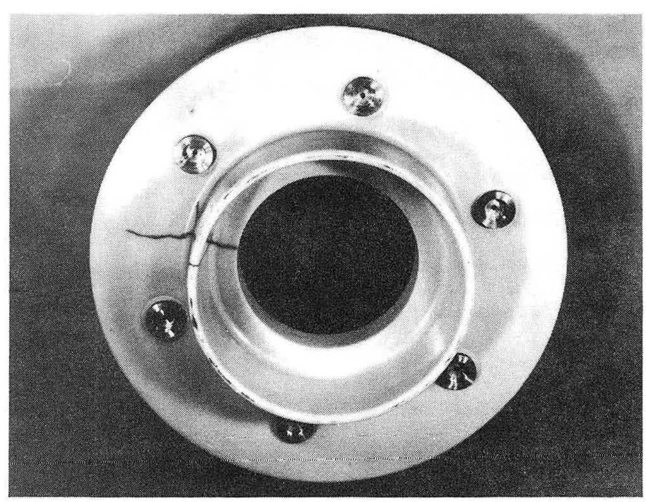


Fig. 4-4 Air Side of Prototype Insulator After Destruct Test CBB 855-3608

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