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Final Report

CESIUM FEED SYSTEMS ELECTRICAL ISOLATION

Prepared for
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NASA Resident Office - JPL
4800 Oak Grove Drive
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Volume II

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ABSTRACT

Work performed on an experimental program to determine the high temperature breakdown characteristics of cesium vapor through cracks in an insulating material is reported.

SUMMARY

This report describes work performed during the period 1 June 1967 to 28 February 1968 under Contract NAS7-502. The objective of this experimental program was to determine the breakdown potential of cesium vapor at elevated temperatures through cracks in an insulating material. The breakdown voltage of cesium vapor through cracks in a Lucalox insulator was determined at 450°C, 700°C and 900°C. Data was obtained over the cesium vapor pressure range of 10^{-2} to 10 torr using a flat parallel electrode geometry for tests at 450°C and a cylindrical electrode geometry for tests at 700°C and 900°C. The resistance of the breakdown path was determined to be 0.3 to 0.5 ohm at 1 to 10 torr cesium vapor pressure with an electrode temperature of 900°C.

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ILLUSTRATIONS

SECTION 1

INTRODUCTION

This is Volume II of the summary report on Contract NAS7-502, Cesium Feed Systems Electrical Isolation. This volume contains a summary of the program to determine the breakdown potential of cesium vapor through cracks in an insulating material. Volume I contains a summary of the program to analyze the effects of electrically isolating an ion engine from its propellant source, to determine the breakdown potential of cesium vapor, and to develop a cesium high voltage electrical isolator.

1.1 CONTRIBUTORS

Principal participants in the program and their respective areas of effort were:

G. E. Trump	Program Management
G. D. Seele	Breakdown Studies

1.2 DESCRIPTION OF PROGRAM

The program was an experimental task to determine the breakdown potential of cesium vapor at elevated temperatures through cracks in an insulating material. This task was accomplished during the period 1 June 1967 to 28 February 1968.

SECTION 2

INSULATOR BREAKDOWN STUDIES

The program to determine the breakdown potential of cesium vapor through cracks in an insulating material is reported in this volume. It was divided into two tasks, the first was the determination of breakdown potential at 450°C and the second the determination of breakdown potential at 700°C and 900°C.

2.1 BREAKDOWN STUDIES AT 450°C

The test chamber and electrodes used for determining the breakdown potentials at 450°C are shown in Figs. 1 and 2. All data were obtained using stainless steel electrodes. A liquid nitrogen baffled oil diffusion pump was used to evacuate the test chamber with typical pressures within the test chamber before the start of tests being in the 10^{-7} torr range.

The insulating material used for these tests was Lucalox which is a high density polycrystalline alumina of high purity. Test specimens were fabricated in the shape of 0.010 and 0.030 in. thick discs, two of which are shown in Fig. 3. The bottom disc has been sliced into two parts and the mating edges ground flat, allowing a variety of crack widths to be tested.

Figure 4 shows the inside of the test chamber with the solid disc in place between the electrodes. Initial studies were made with air and argon both with and without a 0.030 in. thick Lucalox insulator between the electrodes. Breakdown potentials were measured as a function

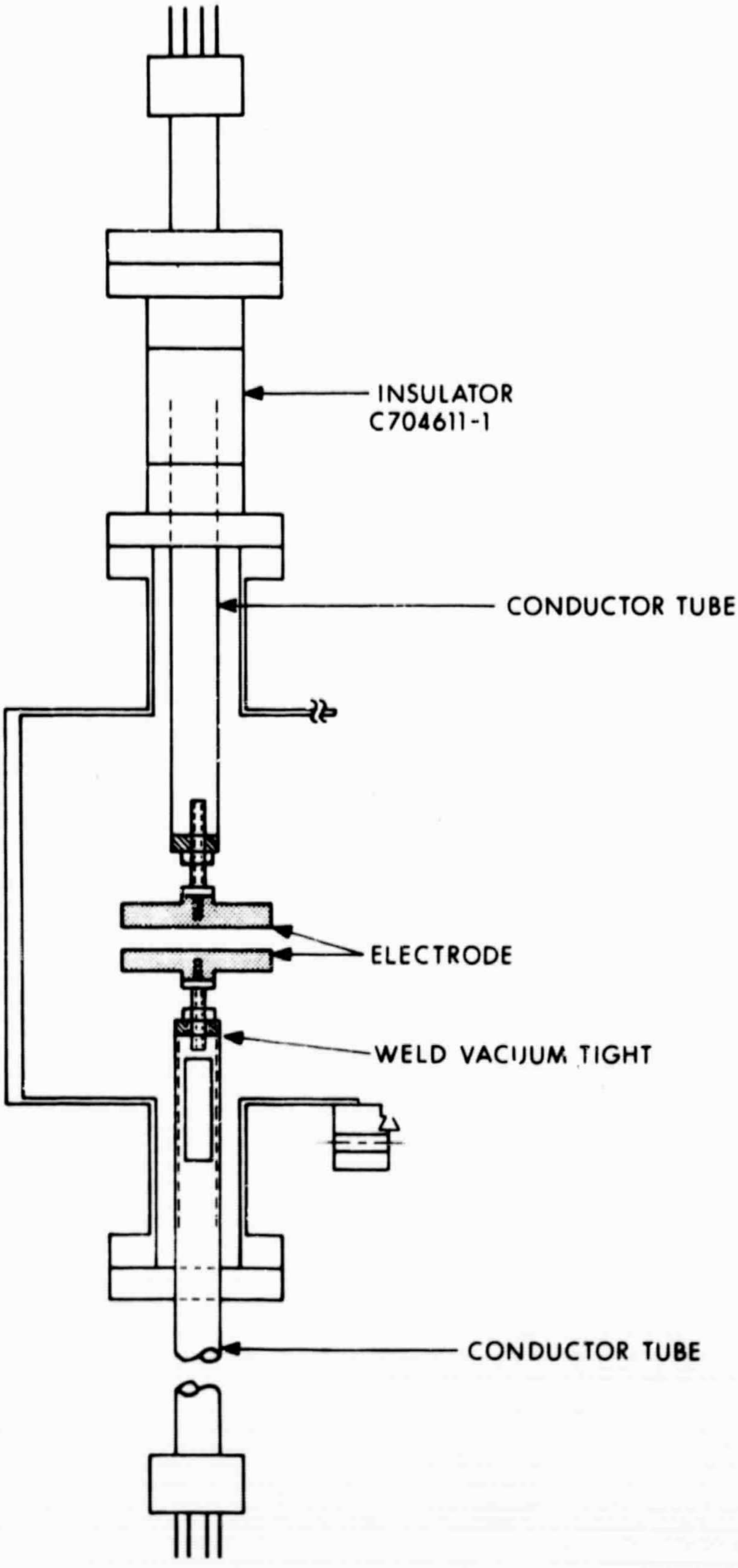

Figure 1. Test Chamber

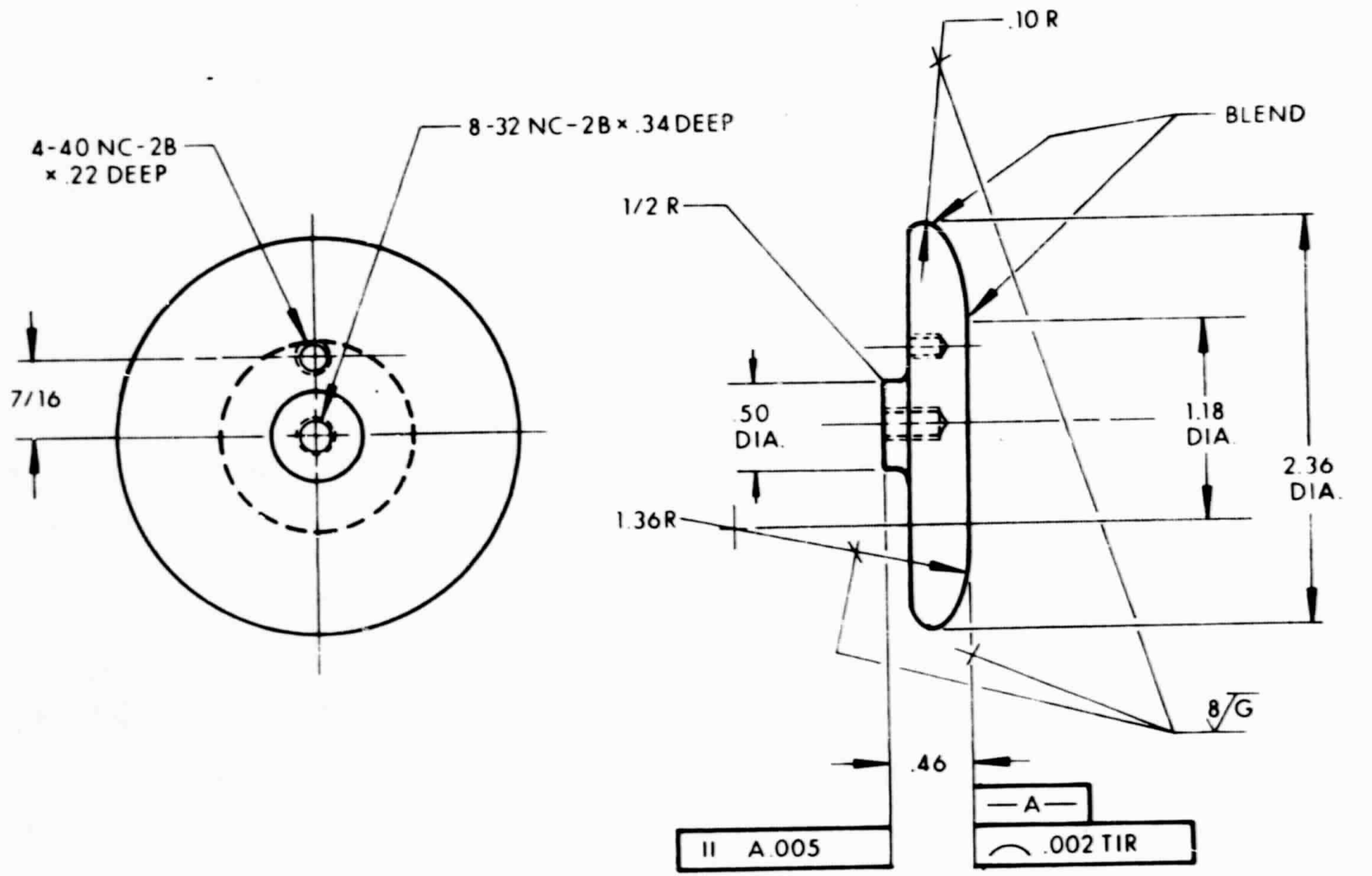

Figure 2. Electrode Design

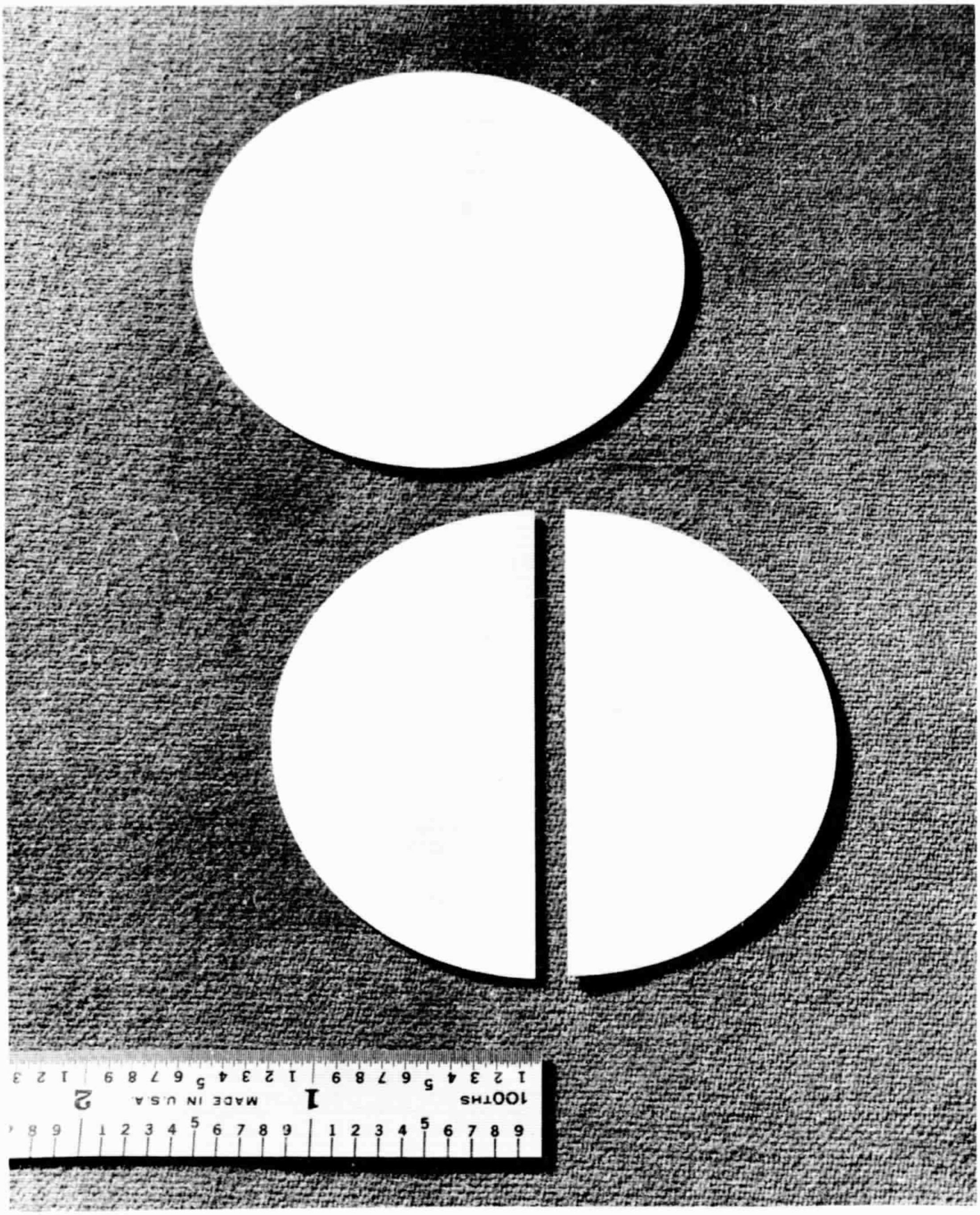

Figure 3. Lucalox Insulators: 0.030 Inch Thick, 2.50 Inch Diameter

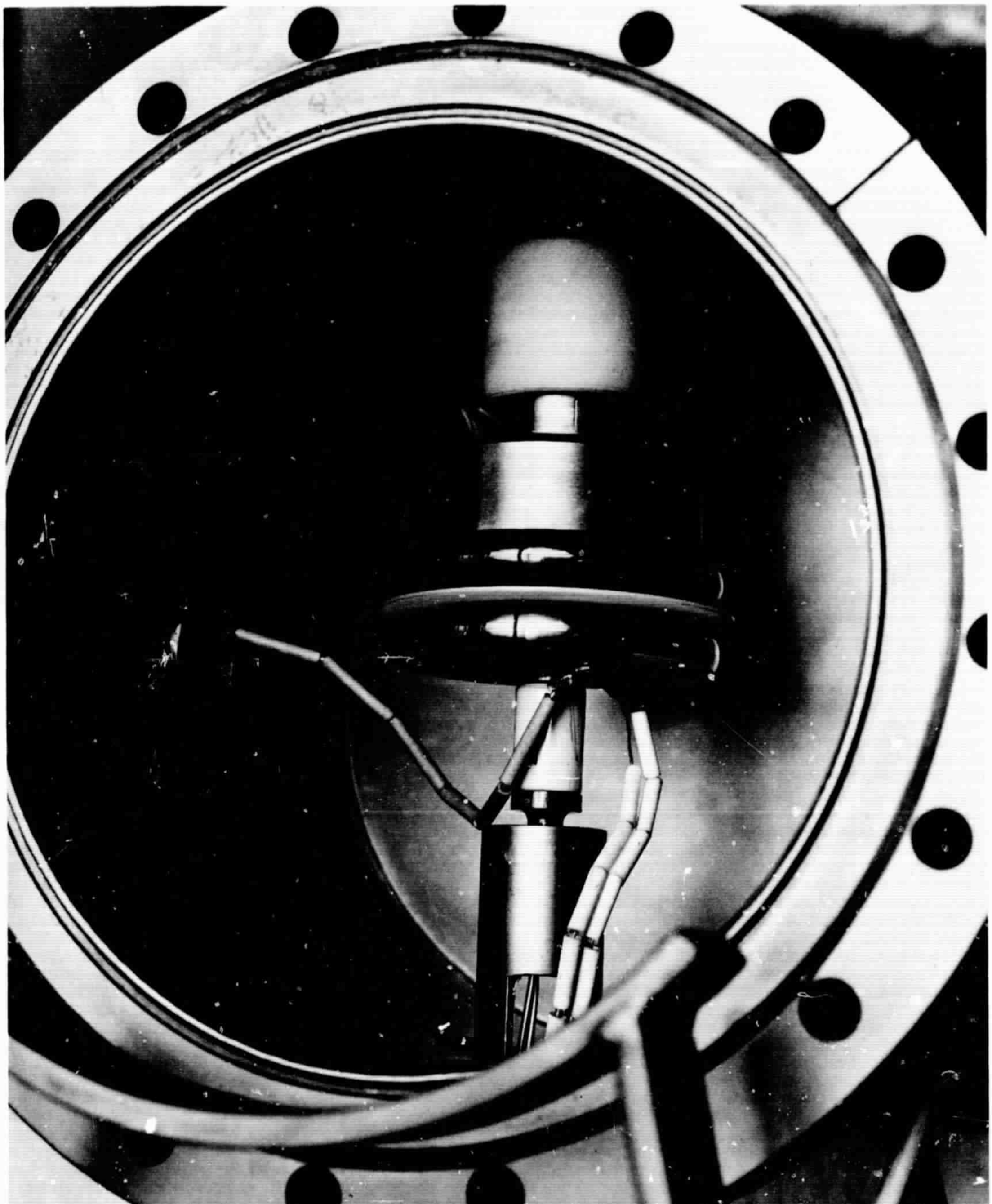

Figure 4. 450°C Breakdown Chamber

of gas pressure. The pressure was measured by a commercial Pirani gage previously calibrated with a McCleod mercury manometer pressure gage.

The test procedure followed was to adjust the gas pressure to a stable value either by introducing air or argon into the chamber or by heating a cesium reservoir attached to the test chamber. The potential across the electrode was then increased until breakdown occurred. At no time was current allowed to flow across the breakdown path for any appreciable time. This prevented damage to the electrodes and insulator by ohmic heating. In all cases maximum current was limited by the power supply to 200 mA.

2.1.1 AIR BREAKDOWN TESTS

Shown in Fig. 5 are breakdown curves for air at room temperature for a 0.030 inch electrode spacing with and without a 0.030 inch thick solid Lucalox insulator inserted between the electrodes. In both cases the minimum breakdown potential is about 390 volts. Without the Lucalox insulator the minimum occurs at about 3 to 5 torr and with the insulator it occurs at about 100 to 150 microns reflecting the difference in breakdown paths in the two tests.

2.1.2 ARGON BREAKDOWN TESTS

Shown in Figure 6 are breakdown curves for argon at room temperature and at 450°C. These data were obtained with a 0.030 inch electrode spacing under the following conditions: (1) no insulator, (2) solid insulator, and (3) sliced insulators with the two segments in direct contact. The general shape of the resulting curves is similar to the breakdown data for air. The minimum breakdown potential is about 200 volts at 6 to 9 torr for argon without the insulator. With the solid

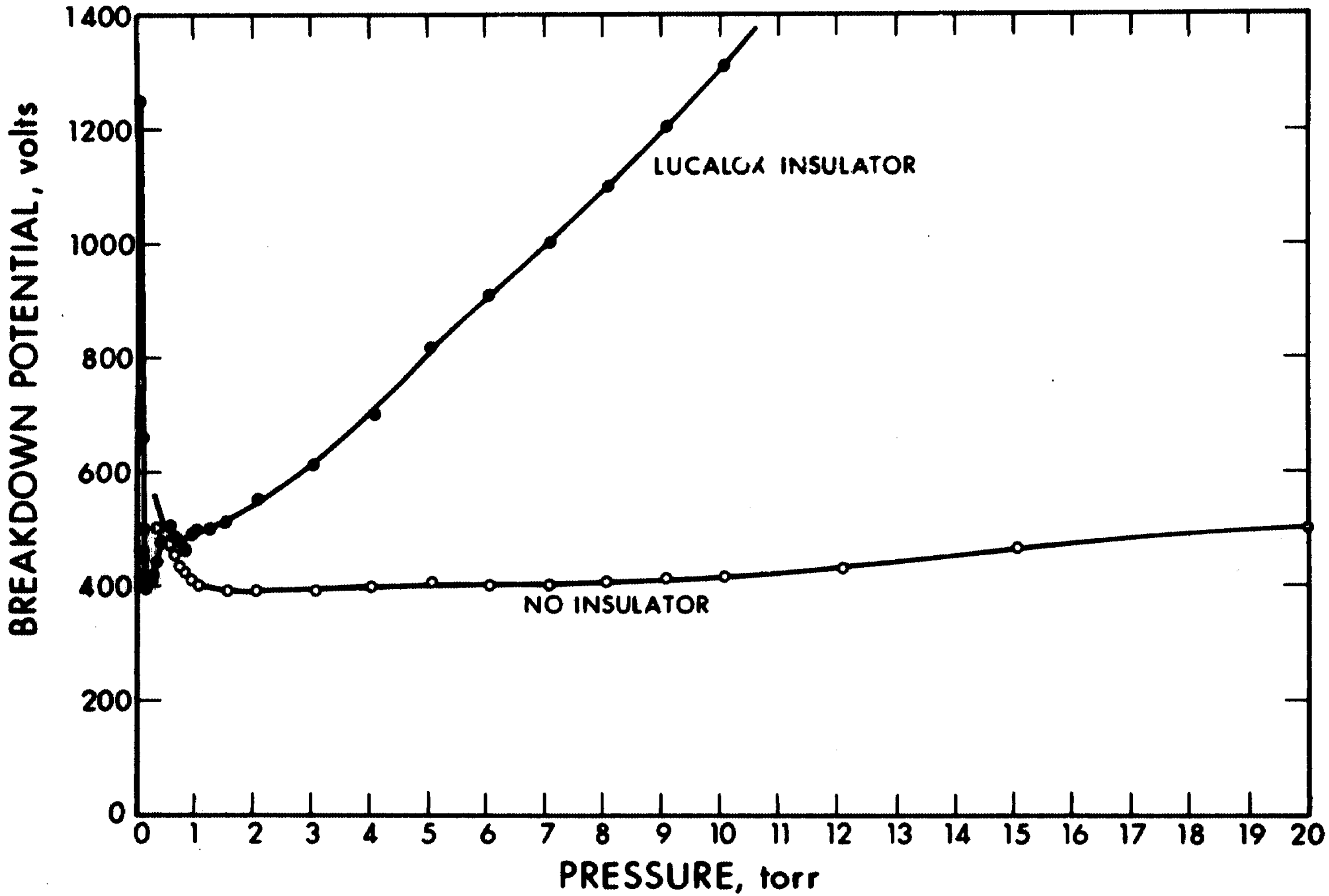

Figure 5. Air Breakdown at Room Temperature, 304 Stainless Steel Electrodes, Spacing 0.030 Inch

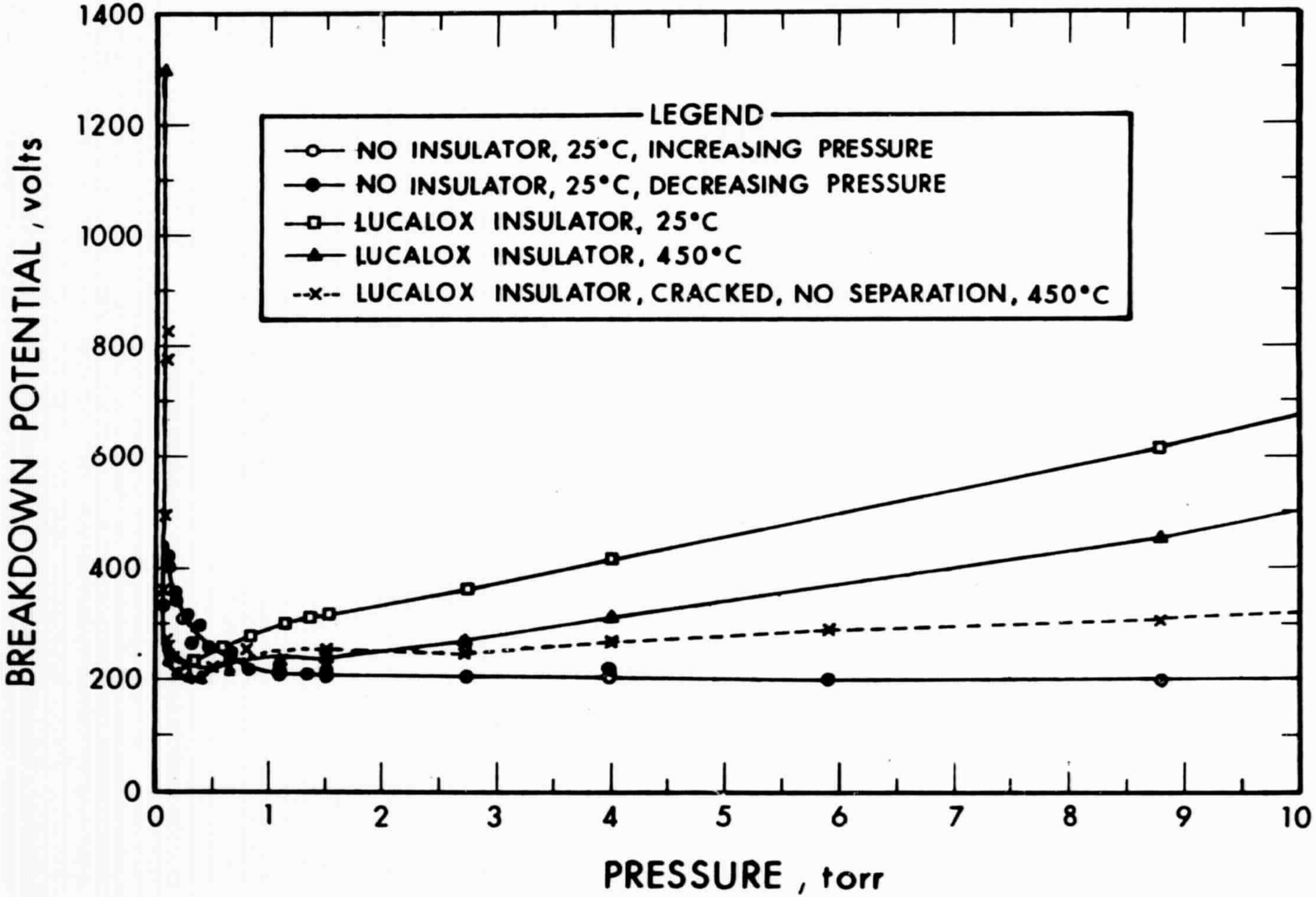

Figure 6. Argon Breakdown at Room Temperature and at 450°C With Various Lucalox Insulator Configurations

insulator at room temperature, the minimum value is 210 volts at 200 to 250 microns; at 450°C the minimum breakdown potential is 200 volts at 200 to 250 microns. As for air, the minimum breakdown pressure has been decreased by a factor of about 30 to 35 representing the ratio of the length of the breakdown path around the edge of the Lucalox to that across the 0.030 inch gap. At pressures above the breakdown minimum, the Lucalox insulator allows a greater potential to be placed between the electrodes at room temperature than at 450°C. Likewise the cracked insulator, created by placing two semicircular segments of Lucalox, such as shown in Fig. 7, in direct contact is able to insulate to a degree intermediate between the whole insulator and no insulator.

2.1.3 CESIUM BREAKDOWN TESTS

Shown in Fig. 8 are breakdown curves of cesium vapor at 450°C. These data were obtained with a 0.030 inch electrode spacing under the following conditions: (1) no insulator, (2) whole insulator, (3) sliced insulator with the two segments in direct contact, (4) sliced insulator with the two segments separated by 0.010 inch, (5) sliced insulator with the two segments separated by 0.030 inch, and (6) with the thermally cracked insulator shown in Fig. 7. Thermal cracks were obtained by heating the Lucalox insulator with a fine oxy-acetylene flame. If started at one edge a crack can be produced and "grown" across the diameter of the insulator. All cracked insulators show insulating properties intermediate between the whole insulator and no insulator. Likewise the cracked insulator with greatest separation is a poorer insulator than the cracked insulator with least separation.

Examination of the surfaces of the electrodes after using the sliced Lucalox configuration showed that breakdown had indeed taken place through the simulated crack. The breakdown pattern is shown in Fig. 9. A photograph of the cracked Lucalox insulator after the 0.010 inch spaced study is shown in Fig. 10.

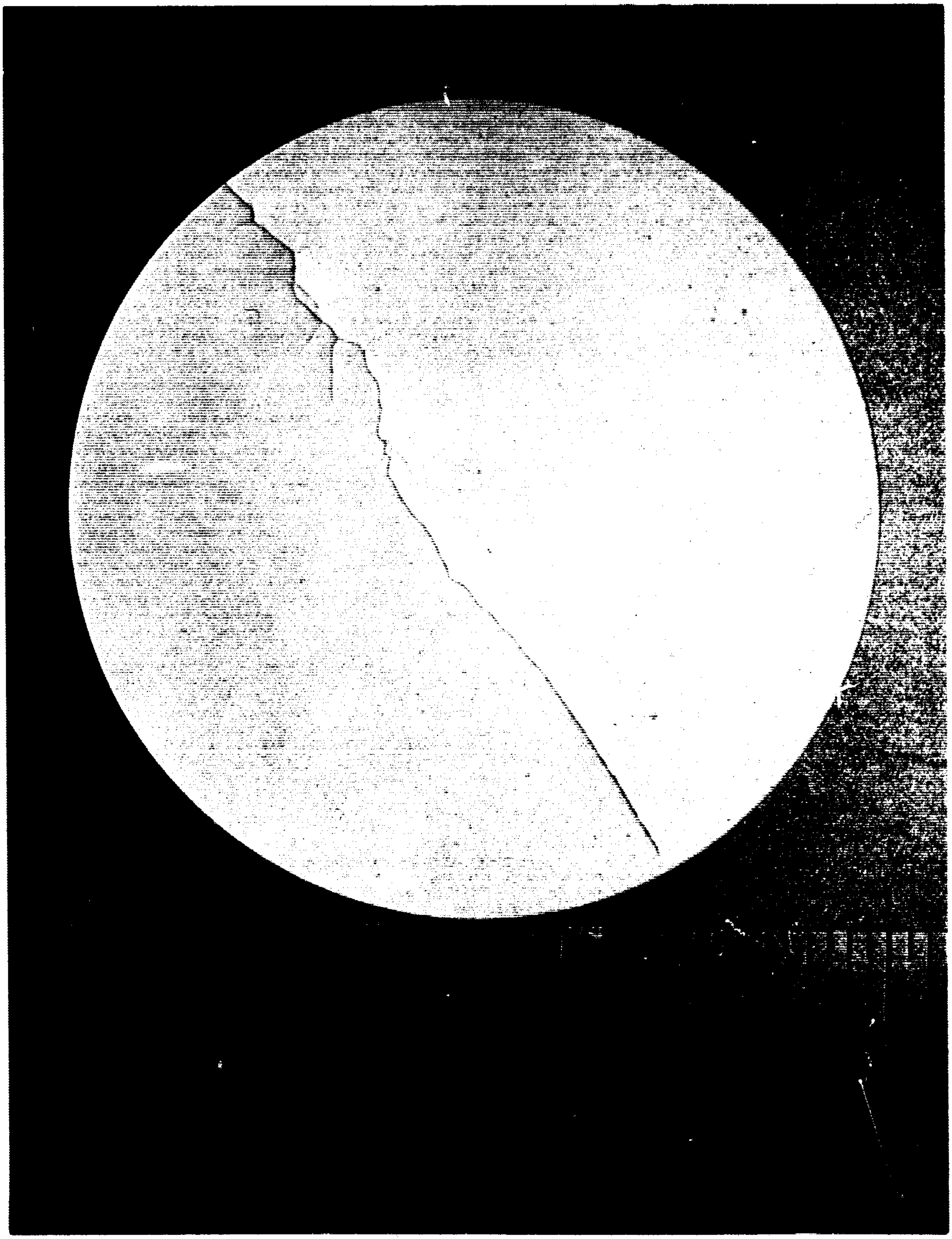

Figure 7. Thermally Cracked Lucalox Insulator, 2.50 Inch Diameter, 0.030 Inch Thick

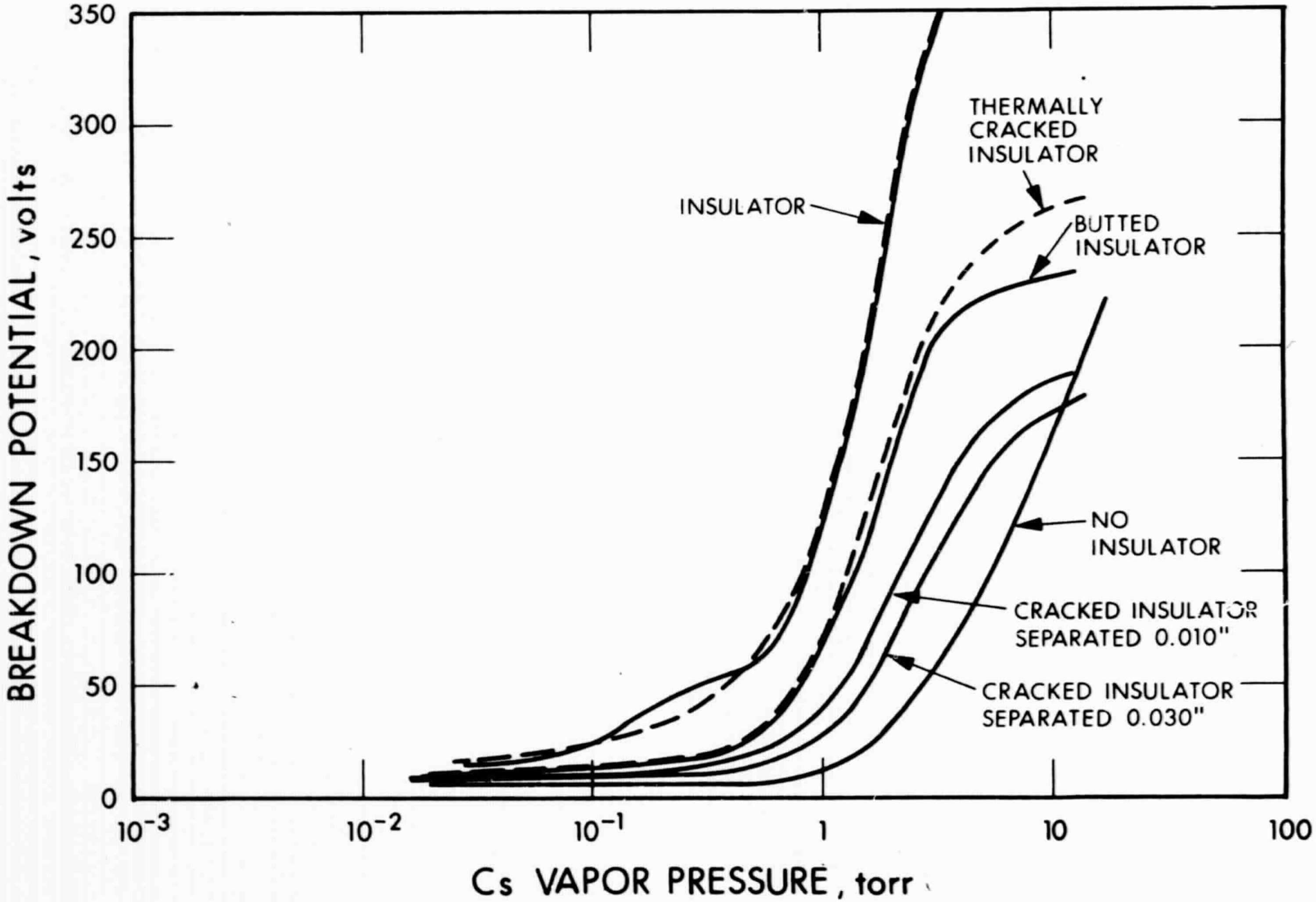

Figure 8. Cesium Vapor Breakdown at 450°C (304 Stainless Steel Electrodes, Spacing 0.030 Inch)

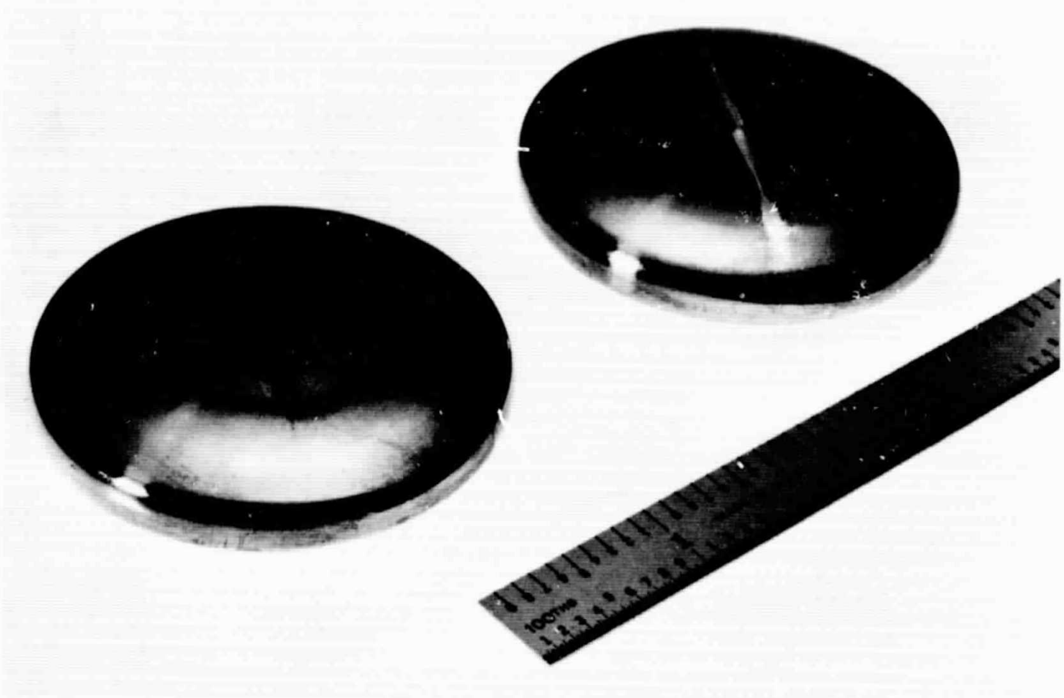

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Figure 9. 304 Stainless Steel Electrodes After Spaced Insulator Test With Cesium at 450°C

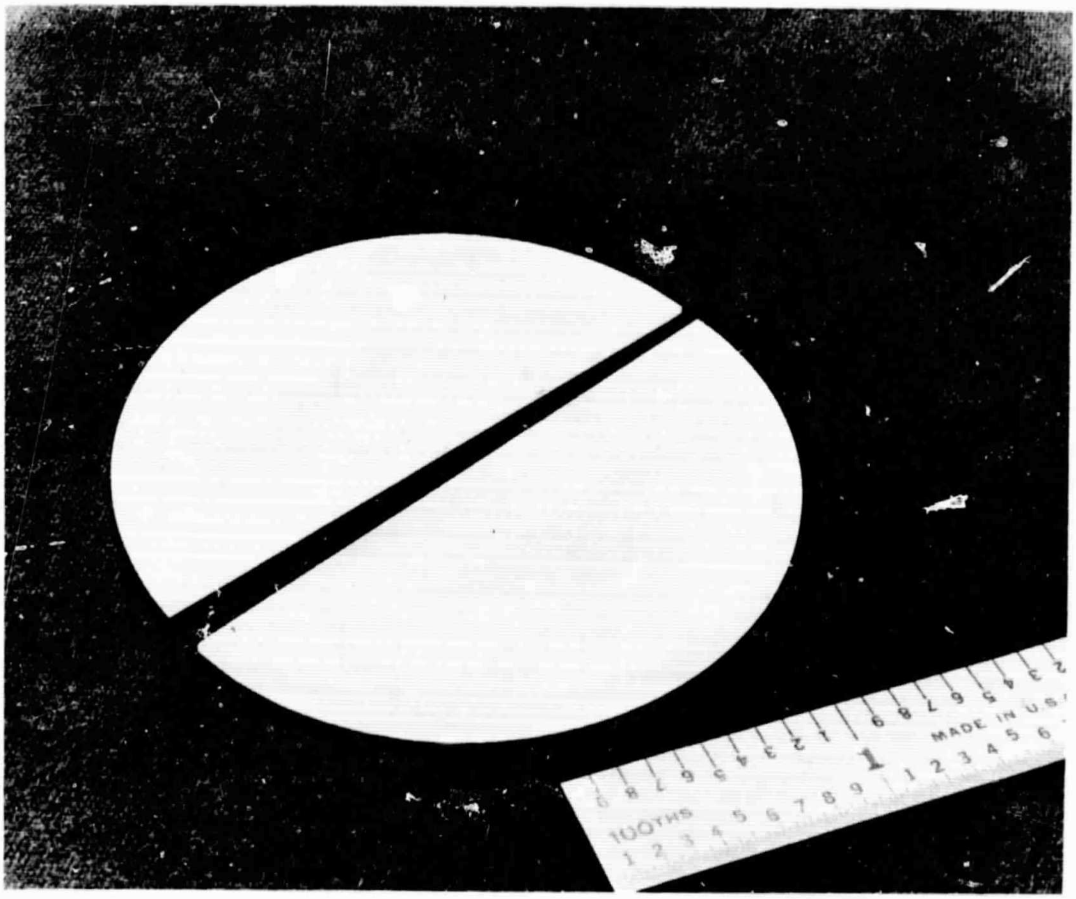

Figure 10. Lucalox Insulator After Spaced Insulator Test With Cesium at 450^{o}C

2.2 BREAKDOWN STUDIES AT 700 AND 900°C

Because of the temperature limitations of the apparatus used for the 450°C studies it was necessary to develop a different test apparatus for the high temperature tests. This assembly, shown in Fig. 11, uses the Lucalox isolator body Fig. 12 developed for the isolator task described in Volume I of this summary report.

The test assembly consists of cylindrical columbium electrodes separated by the insulating material. The center electrode is 3/8 inch diameter x 1/2 inch long. An alumina insulating tube covers the electrode stem from the electrode to the supporting flange. The outside electrode is 1/2 inch outside diameter. Lucalox insulator tubes were fabricated with dimensions of 3/8 inch inside diameter x 0.030 and 0.010 inch wall x 2 inches long. Figure 13 shows a picture of the Lucalox tube, electrodes and insulator after the high temperature tests. Note that there are no electrical or thermocouple leads exposed to the cesium vapor during operation with this system. The device is heated by the outside cylindrical heating shroud shown in Fig. 12. Figures 14 and 15 are pictures of the assembled test apparatus with and without the heating shroud.

The cesium reservoir, cesium valve, and venting valve are also seen in the photographs.

The procedure followed during testing was as follows:

a. The test assembly was placed in a 3 ft x 4 ft vacuum chamber evacuated by an oil diffusion pump attached to the chamber by a liquid nitrogen cooled elbow. Operating pressures were in the low 10^{-6} torr pressure range.

b. The vent and cesium valves were opened and the heating shroud heated. After the test assembly reached proper operating temperature the vent valve was closed.

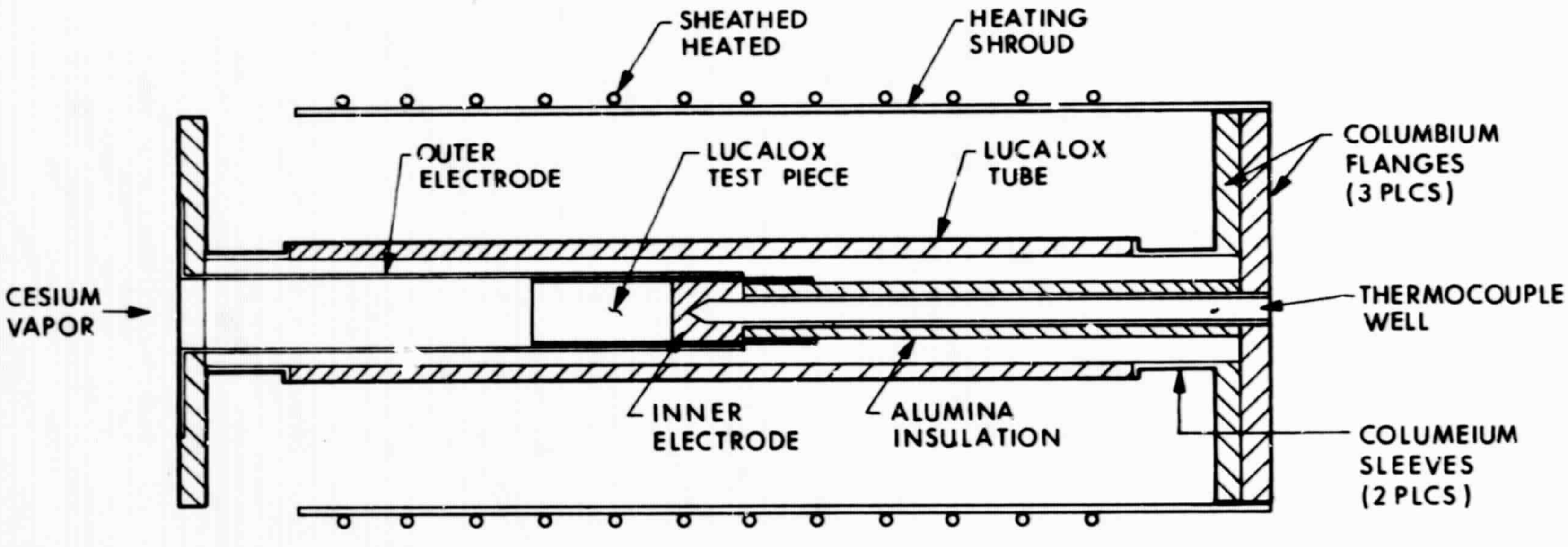

Figure 11. 700-900°C Insulator Breakdown Test Device

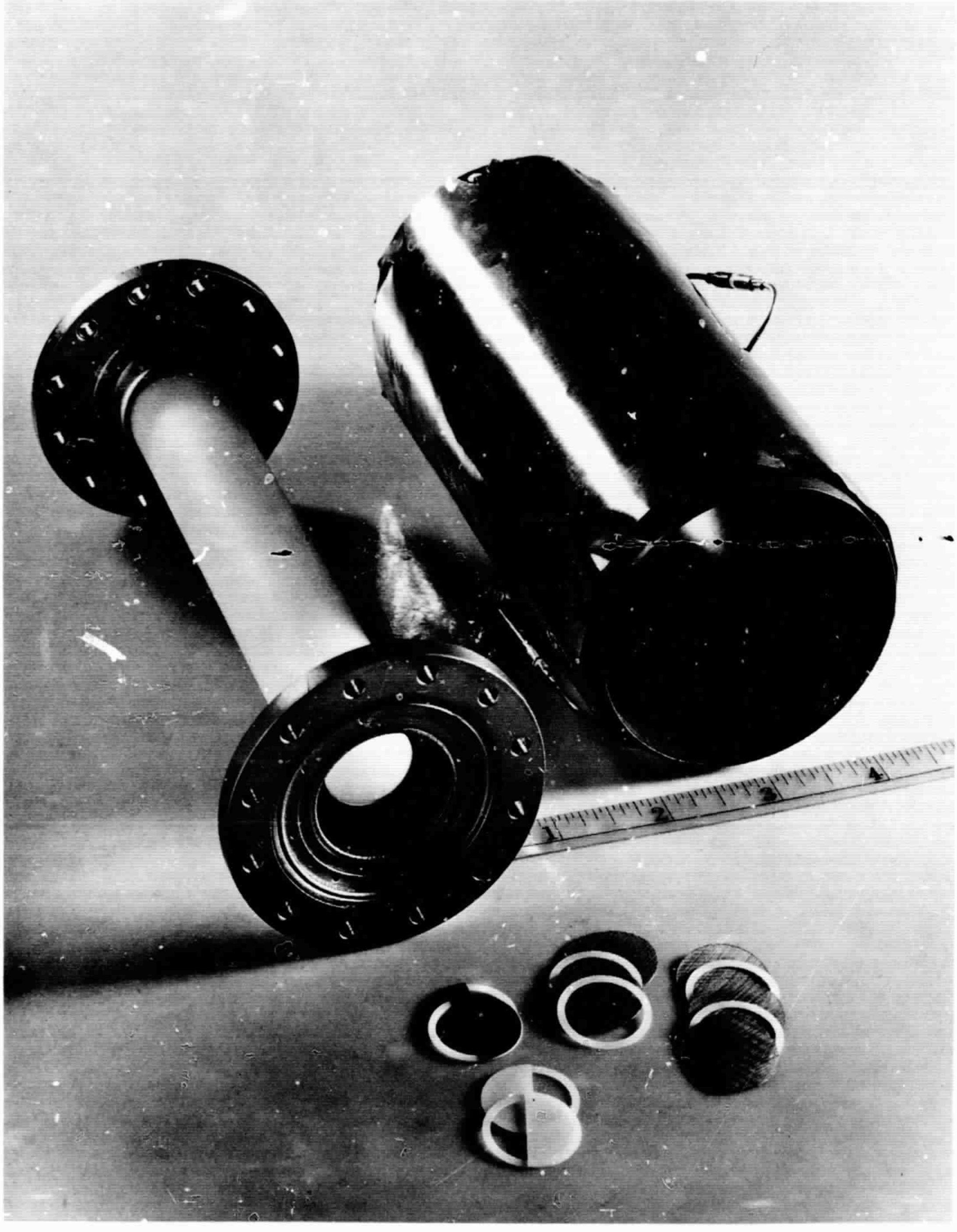

Figure 12. Lucalox Isolator, Heating Shroud, Electrodes and Spacers

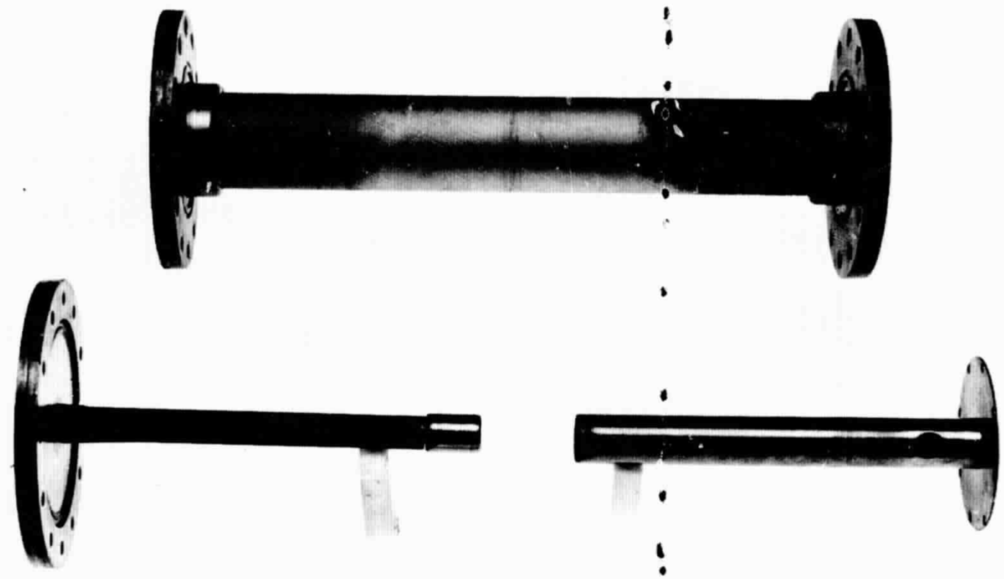

Figure 13. High Temperature Breakdown Test Apparatus Showing Isolator Body, Electrodes, and Lucalox Test Specimen

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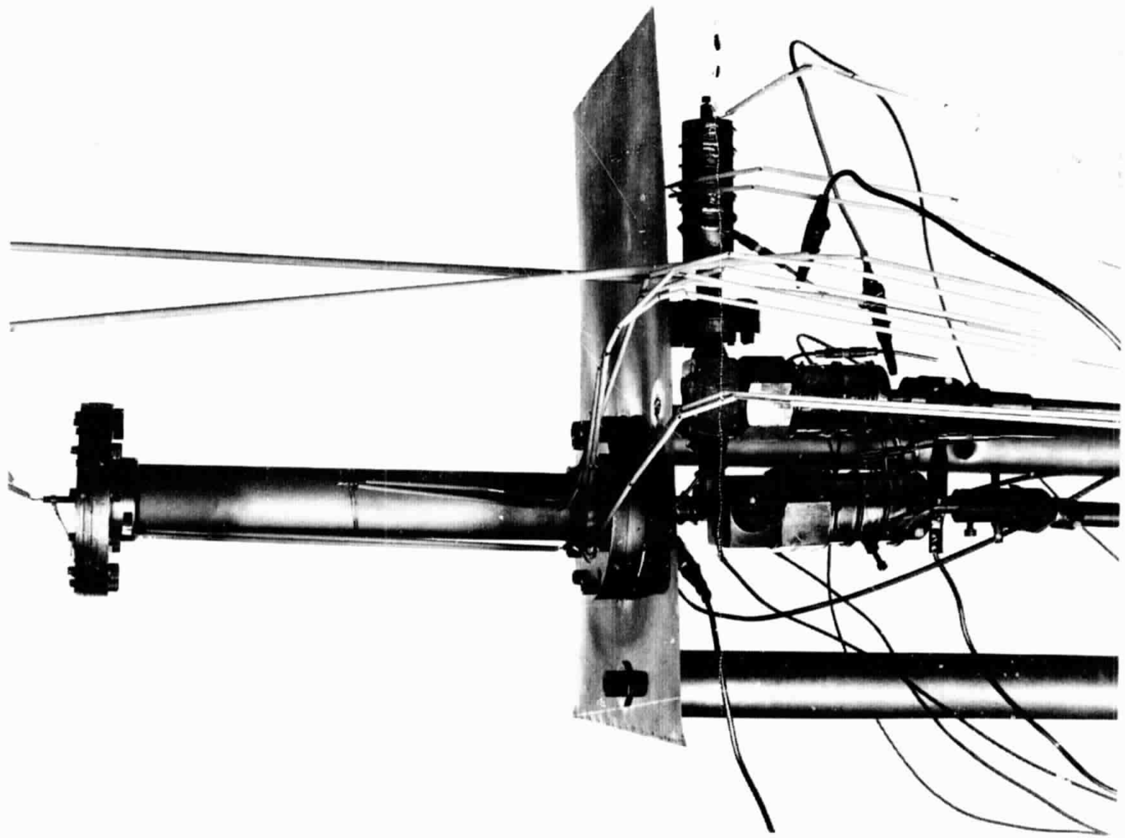

Figure 14. High Temperature Test Apparatus Showing Test Body, Cesium Valve, Cesium Reservoir, and Vent Valve

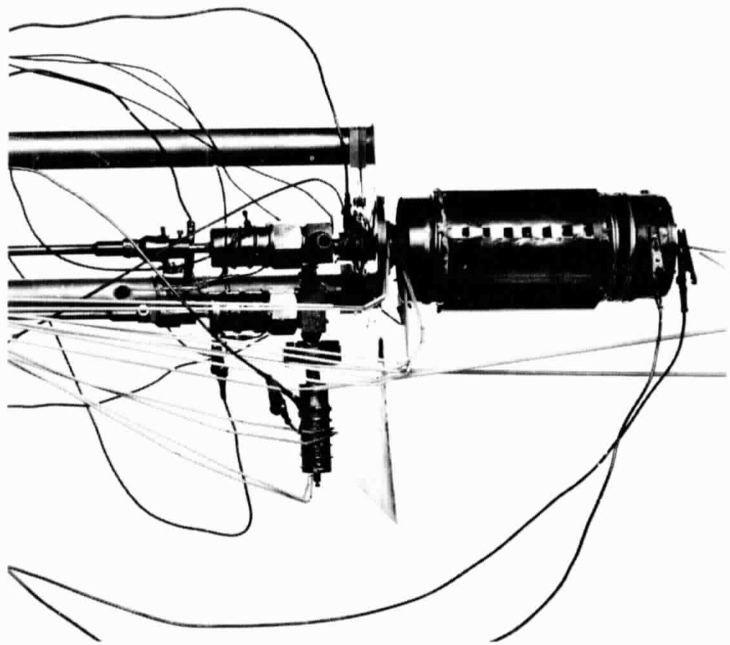

Figure 15. High Temperature Test Apparatus With Heating Shroud

c. Cesium was introduced into the test assembly by heating the reservoir. At various cesium vapor pressures the potential across the electrode was increased until breakdown occurred. At no time was current allowed to flow across the breakdown path for any appreciable time. Again this was a precaution to prevent damage to the electrodes and test specimen.

Breakdown studies were conducted using the following insulator configurations:

1. Hairline crack through 0.030 wall Lucalox at 900°C. (Fig. 16)
2. 0.030 gap at 900°C.
3. Hairline crack through 0.010 wall Lucalox at 900°C.
4. 0.010 gap at 900°C.
5. Hairline crack through 0.010 wall Lucalox at 700°C.
6. 0.010 gap at 700°C.

In tests 1, 3, and 5 the hairline cracks were thermally created as described previously. Curves of the data for tests 1 and 2 are shown plotted in Fig. 17, for tests 3 and 4 Fig. 18 and for tests 5 an 6 in Fig. 19. The gap in tests 2, 4, and 6 was created by using a Lucalox spacer for alignment, with breakdown occurring between the exposed electrode surfaces.

Table I shows the important temperatures recorded for each test. T_1 is the temperature of the surface of the Lucalox test body determined by an optical pyrometer. T_2 is the same temperature determined with a chromel-alumel thermocouple. T_3 is the temperature of the inner electrode also determined by a chromel-alumel thermocouple. The center electrode (T_3) was at the positive potential for all tests. All thermocouple temperatures were obtained using an ice bath cold junction reference.

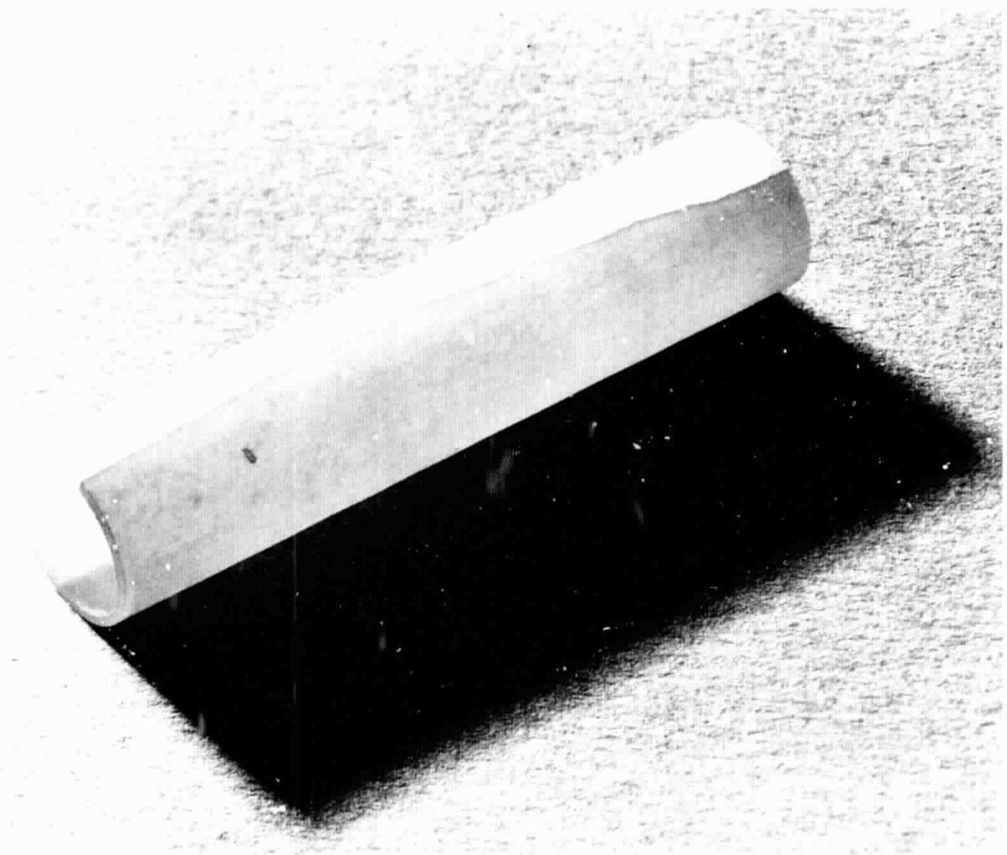

Figure 16. 0.030 Inch Wall Lucalox Test Specimen Showing Thermal Crack

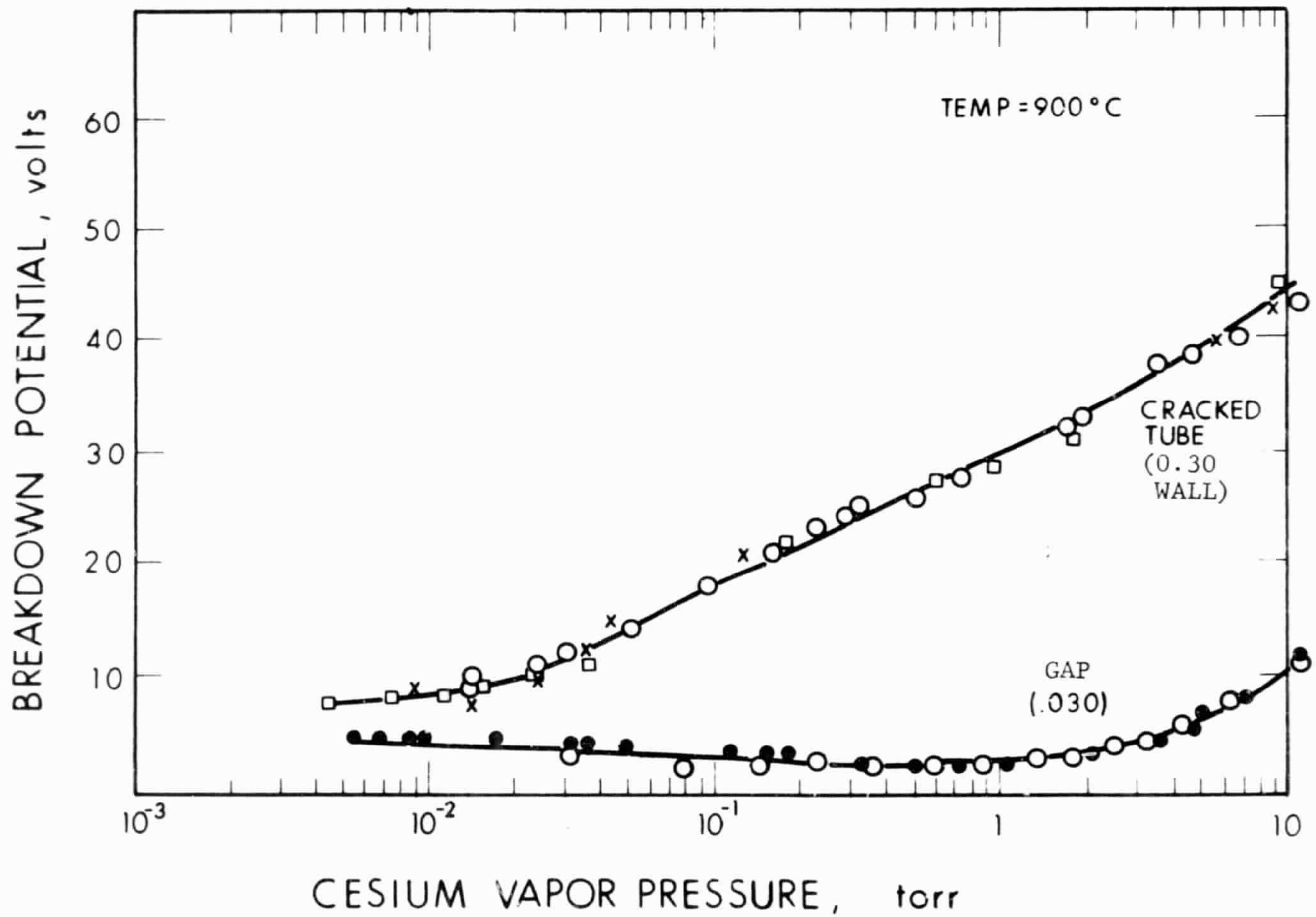

Figure 17. Breakdown Potential versus Cesium Vapor Pressure for 0.030 Inch Wall Lucalox Tube at 900°C

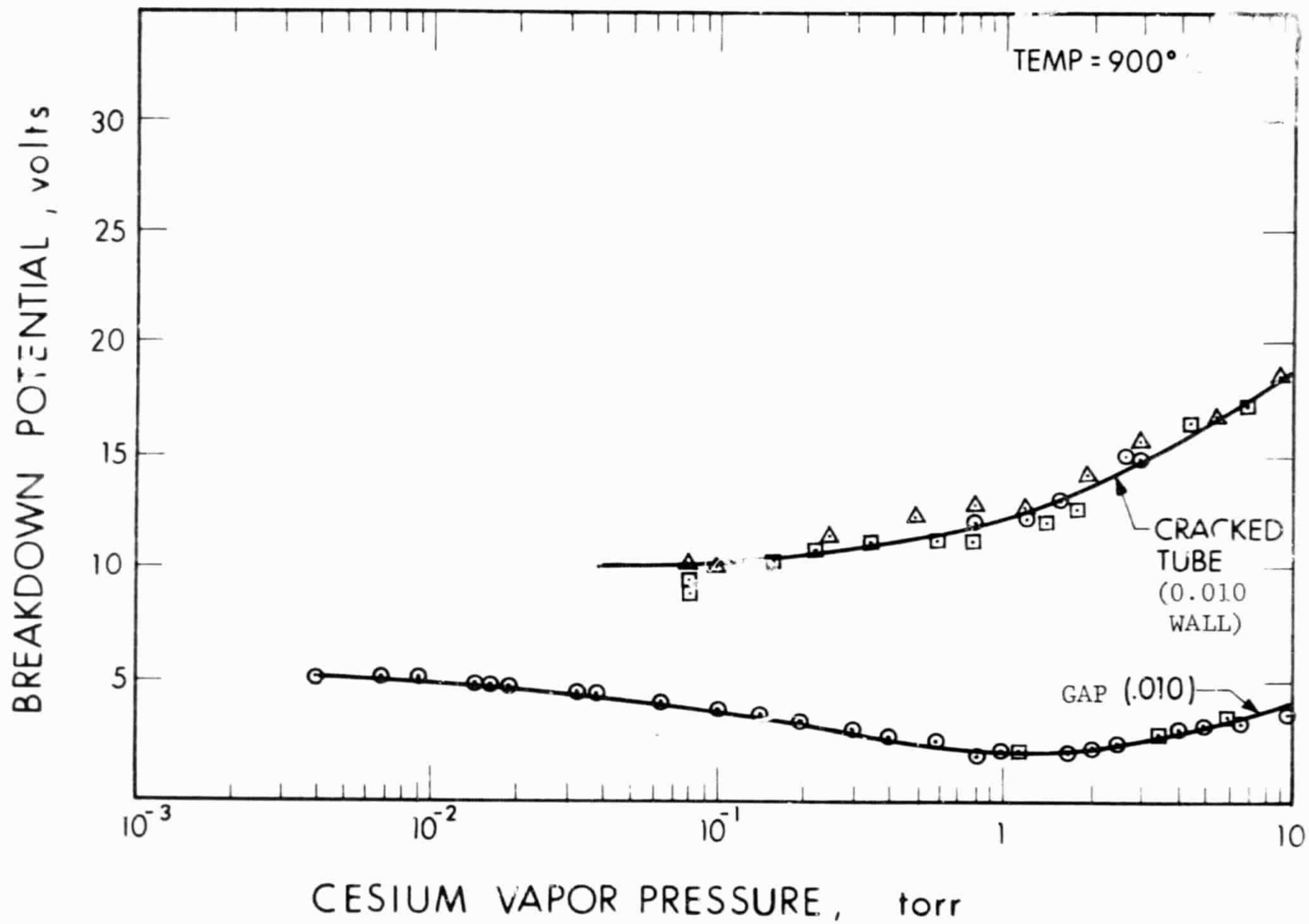

Figure 18. Breakdown Potential versus Cesium Vapor Pressure for 0.01 Inch Wall Lucalox Tube at 900°C

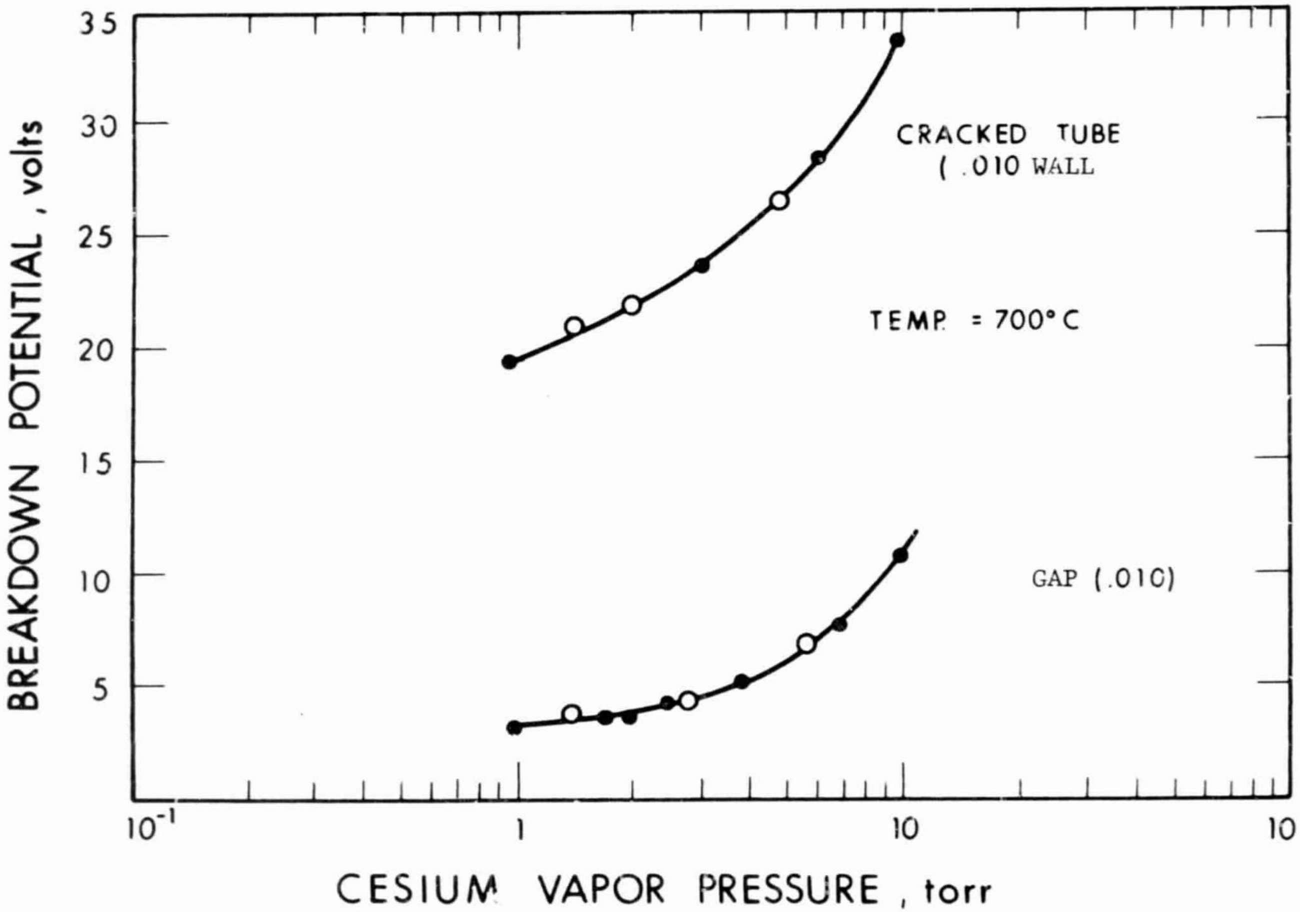

Figure 19. Breakdown Potential versus Cesium Vapor Pressure for 0.01 Inch Wall

TABLE I

TEST TEMPERATURES

Test	T_1(°C)	T_2(°C)	T_3(°C)
1	905	899	866
2	900	901	859
3	909	904	852
4	903	904	861
5	735	725	676
6	735	-	679

Test 3 was repeated to determine the resistance of the breakdown path. It was necessary in this test to use a high current power supply because of the low breakdown path resistance. The voltage was determined at the electrodes and measured by means of a precision resistor voltage divider and chart recorder. The current was measured by recording the voltage across a precision current shunt. Figure 20 shows the voltage versus current relationship at 1, 6, and 10 torr cesium vapor pressure. These values were taken as rapidly as possible because of the rapid heating of the center electrode caused by ohmic heating in the arc. At higher current values (> 5A) there were indications of the start of a a runaway current condition. This condition was not allowed to continue.

After the test the apparatus was completely disassembled. The insulating material was found to have cracked and melted in the area of the breakdown arc. Figure 21 shows a picture of the center electrode and the 0.010 wall Lucalox test specimen. The area of arcing on the electrode is evident by the discolored and pitted area. The insulator is melted and pulled into drops by surface tension forces.

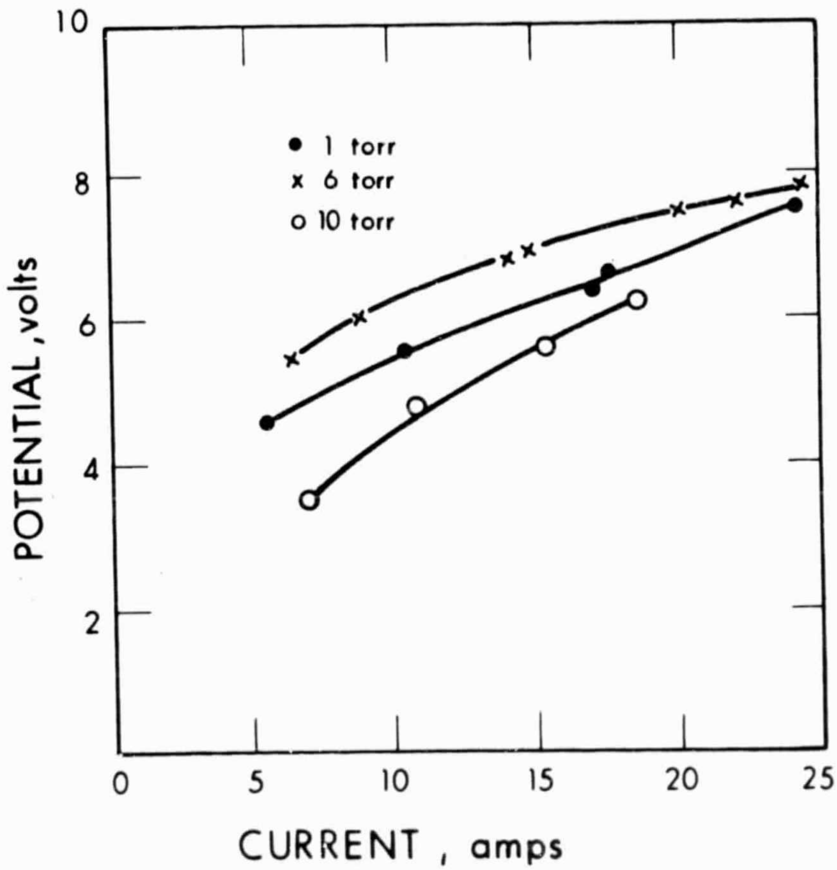

Figure 20. Voltage-Current Relationship After Breakdown With 0.010 Inch Wall Lucalox Tube at 900°C

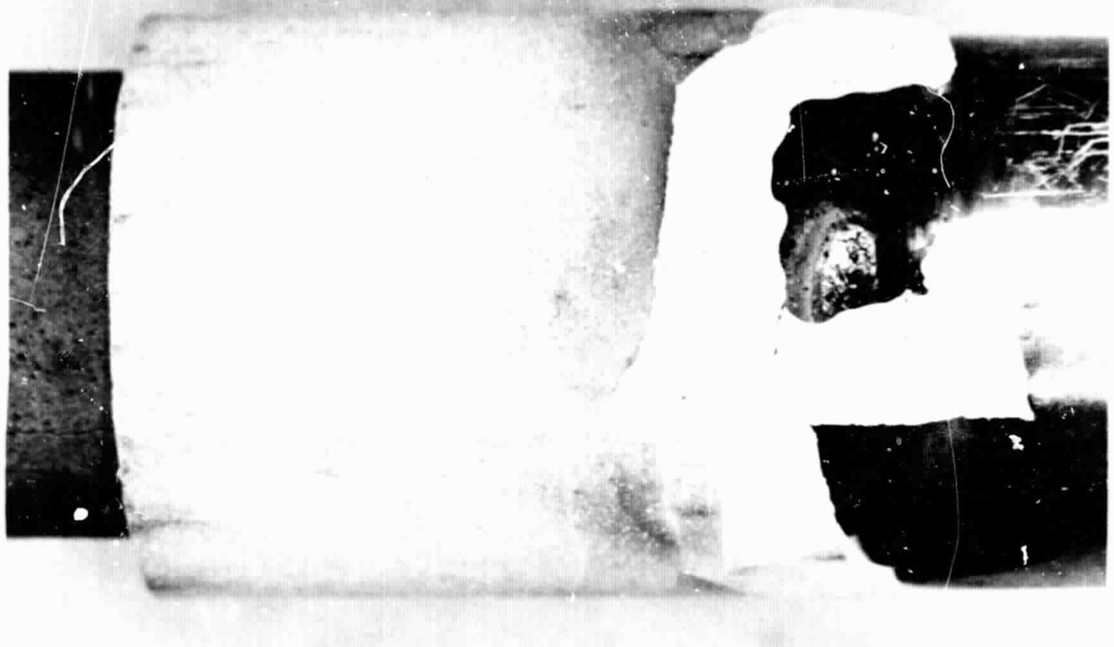

Figure 21. Center Electrode and Lucalox Test Specimen After High Current Arc Test

SECTION 3

CONCLUSIONS

The main conclusions that can be drawn from the breakdown tests are:

a. The potential that can be supported across an insulator is decreased if cracks through the material are present.

b. The potential that can be supported across a crack is proportional to the material thickness and inversely proportional to the crack width and insulator temperature. Tables II and III summarize this trend.

c. The resistance of the breakdown path is less than one ohm after breakdown.

d. After breakdown severe heating can occur at the point of breakdown causing melting of the insulating material and increase in crack width.

TABLE II

BREAKDOWN VOLTAGE AT 5 TORR CESIUM VAPOR PRESSURE

	700°C	900°C
Hairline crack (0.010 wall)	27 volts	16 volts
0.010 gap	6 volts	3 volts
Hairline crack (0.030 wall)	---	38 volts
0.030 gap	---	5 volts

TABLE III

MINIMUM BREAKDOWN VOLTAGE AT CORRESPONDING CESIUM VAPOR PRESSURE

	700°C	900°C
Hairline crack (0.010 wall)	16 volts ($\sim 10^{-1}$ torr)	10 volts (6×10^{-2} torr)
0.010 gap	3 volts (1 torr)	2 volts (1 torr)
Hairline crack (0.030 wall)	---	8 volts (6×10^{-2} torr)
0.030 gap	---	3 volts (5×10^{-1} torr)