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**SOME CHARACTERISTICS OF THE 1B41,
1B45, AND 1B49 SERIES SPARK GAPS**

REPORT

682-4

RADIATION LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE MASSACHUSETTS

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NDRC
Div. 14
OEMsr-262

Radiation Laboratory

Report 652-4 March 19, 1946

SOME CHARACTERISTICS OF THE 1B41,
1B45, AND 1B49 SERIES SPARK GAPS

Abstract

Operation of concentric, cylindrical electrode, aluminum cathode type series spark gaps at SCL and AEW conditions is discussed. These gaps are shown to be satisfactory for operation under several combinations of high power, high repetition rate, and high pressure; but that in general the voltage range which can be relied on over 500 hours is quite small for operation at high values of these quantities taken simultaneously. In all cases, attempts to reduce the time jitter to the order of 1% of the pulse width have been unsuccessful. Jitter of 1 to 3 μ sec is to be expected.

The impulse ratio of these gaps when now for a 20 kv/ μ sec rate of rise of voltage increases from 1.62 to 1.93 in raising the pressure from 90 to 250 cm. During operation at 1155 pps, 1 μ sec, and 21 kv in a 50 ohm circuit, the pressure of gaps filled initially to 150 cm has been observed to decrease by as much as 8.5%. This decrease is found to be due largely to the loss of hydrogen and not argon. However, changes in pressure due to loss of gas during operation have a relatively small effect on the range as determined by re-filling and retesting gaps after 500 hours operation.

Joseph R. Dillinger

Approved by:

W. V. Roberts
Leader, Group 51

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19 Numbered Pages
2 Plates

A. J. Hill
Head, Division 5

V-22527

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SOME CHARACTERISTICS OF THE 1B41, 1B45, AND 1B49 SERIES SPARK GAPS

I. Introduction

The development work on cylindrical electrode, aluminum cathode type series spark gaps reported here has been carried out in cooperation with the Westinghouse Electric Company under the terms of OSRD contract OEMsr-709. Their work is summarized elsewhere*.

The development of gaps to operate in a line type modulator capable of supplying 0.5 megawatt to a magnetron load was first undertaken. As the power requirements of radar sets increased, the power level at which work was done on this type gap was also increased. It was found that these gaps would operate over a very wide range of conditions with certain limitations on operating voltage range. Although operation of these gaps is satisfactory for many combinations of high power, high repetition rate, and high pressure, in general, the voltage range which can be relied on is quite small for operation at high values of these quantities taken simultaneously. In all cases, attempts to reduce the time jitter to the order of 1% of the pulse width have been unsuccessful. Jitter of the order of 1 to 3 μ sec is to be expected.

II. Operation at SCI Conditions

The SCI radar sets are the Radiation Laboratory preproduction models of the SX production units built by the General Electric Company. Each set requires two modulators. One is for search purposes and is required to operate at 1 μ sec pulse duration and a repetition rate of 390 pps. The other is for height finding and is required to operate at 1 μ sec and 1170 pps with a provision for switching to 390 pps for searching if and when desired. The search and height finding sets use an HK7 and HI5 magnetron respectively. Initial plans were to operate the search and H.F. sets at 3 and 2 megawatts respectively into the magnetrons requiring operating modulator switch or network voltages of 29 and 24 kv respectively. These powers were later lowered to 2 and 1 megawatt respectively which lowered the required switch voltages to 24 and 17 kv. This decrease in power was necessitated by unsatisfactory operation of the magnetrons at the higher powers.

A. Preproduction WX3240

Photograph 1 of Plate I is a print of an X-ray of a preproduction WX3240 series gap. The outer electrode is an aluminum cylinder which serves as the cathode, and the inner electrode is an iron rod serving as the anode. The inside diameter of the cathode is 1.0" and the outside diameter of the anode is .340". A drop of RnBr solution is placed at the bottom of the cathode to provide background ionization to aid in starting these gaps which was found necessary for good starting of similar gaps operated at lower voltages--about 12 kv across 3 gaps in series. At these higher voltages required for SCI, it

*E.G.F. Arnott, "Development of Series Spark Gaps", January 1, 1943 to June 30, 1944, Division 14, NDRC Report No. 327.

E.G.F. Arnott, "Final Report on Contract OEMsr-709", July 12, 1945, Division 14, NDRC Report No. 494.

is believed that there is sufficient corona present in the tube to produce ionization for starting without the RaBr.

Figure 1 shows range vs. operating time for three of these gaps operated in series in a line modulator with a 50 ohm network and 50 ohm resistance load at 390 pps and 1 μ sec. Each gap was filled to 175 cm actual pressure with 80% hydrogen and 20% argon. Negative switch voltage was used with a positive trigger voltage pulse coupled to the lower intermediate point. Six megohm dividing resistors and a 60 μ mf trigger coupling condenser were used. It was later found that coupling the trigger to both intermediate points would lower V_{min} and V_{start} but have negligible effect on V_{max} after 50 to 100 hours operation. Two-point triggering is to be preferred and is being used in these modulators. Operation of the gaps was still satisfactory at 700 hours. V_{max} is the maximum voltage at which the switch would operate without prefiring, and V_{min} the minimum voltage at which it would operate without missing, as determined by observing the resonance charging switch voltage on an oscilloscope. 25 kv trigger voltage was required to obtain maximum range with these gaps. Trigger voltage is measured by a substitution method. Figure 2 shows three methods of coupling the trigger to three of these gaps in series. It is necessary to use three gaps in series since the range obtained with two is not sufficient at high powers where there is considerable change in the range during operation. The input capacitance from point P to ground was measured to be 15 μ mf. A capacity voltage divider, also having 15 μ mf input capacitance to ground, was substituted for the gaps at point P and the trigger voltage measured. Thus, the trigger transformer was loaded the same during the measurement as during operation of the gaps. This gives one approximately the actual voltage presented to the gaps. This substitution method is made necessary by the fact that this and other similar high voltage, low energy trigger circuits are sensitive to loading. The trigger circuit used is as shown. Satisfactory design procedure has been found to be to make $C_1 = 3C_2$ where $C_2 = n^2 C_0$. n is the turns ratio of the pulse transformer, T, and C_0 is the capacity load on the secondary of T, about 15 μ mf. Three transformers satisfactory for use as T are in production. The K2740 and K2730B are the SX and AEW transformers respectively manufactured by the General Electric Company. They are rated for 35 and 30 kv respectively. The 234B $\frac{1}{2}$ is a transformer designed for general laboratory testing to give 35 kv on 15 μ mf up to 2000 pps and 25 kv up to 4000 pps. Westinghouse manufactures this unit. C_1 can be charged through a resistance from the main or auxiliary power supply, or it can be choke, or choke-diode charged from an auxiliary supply. The trigger pulse shape is not critical. The rate of rise with the above transformers varies from 38 to 55 kv/ μ sec. with no added inductance in the plate circuit of the 4C35 hydrogen thyratron. 60 μ h added in this circuit reduces the rate of rise to about $\frac{1}{2}$ of these values. Matters pertaining to rate of rise and also design data for these and other transformers with higher rates of rise are discussed in connection with work on the iron sponge-mercury cathode series gap where rate of rise is important from the standpoint of obtaining minimum time jitter.*

*J. R. Dillinger, "Operation of Sintered Iron Sponge-Mercury Cathode Type Series Gaps at SCI, AEW, and 5 μ sec Conditions", November 28, 1945.

Figure 2

652-4-2

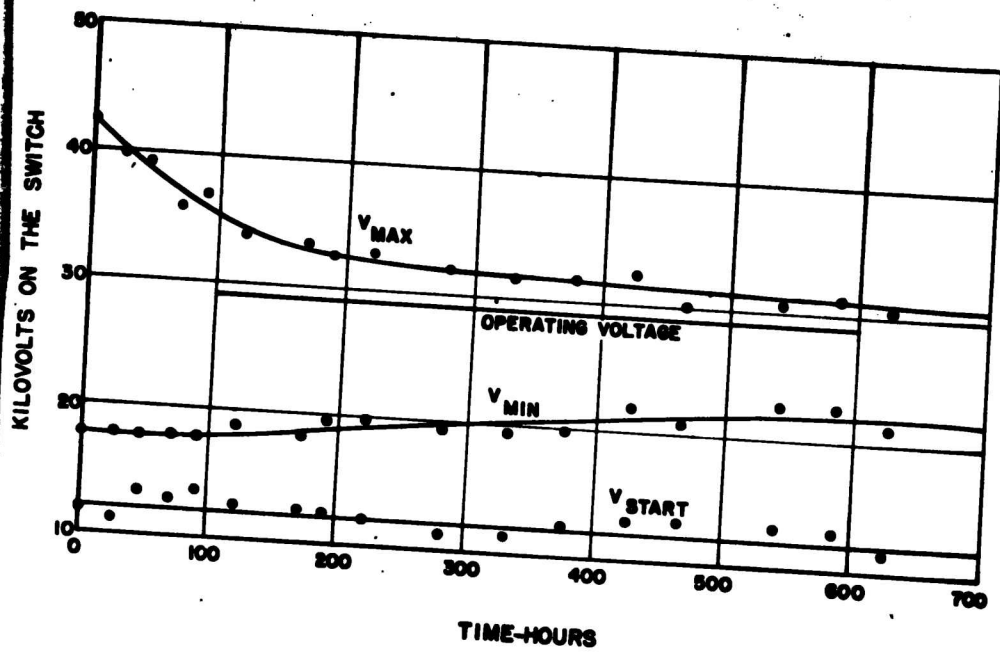


FIGURE I

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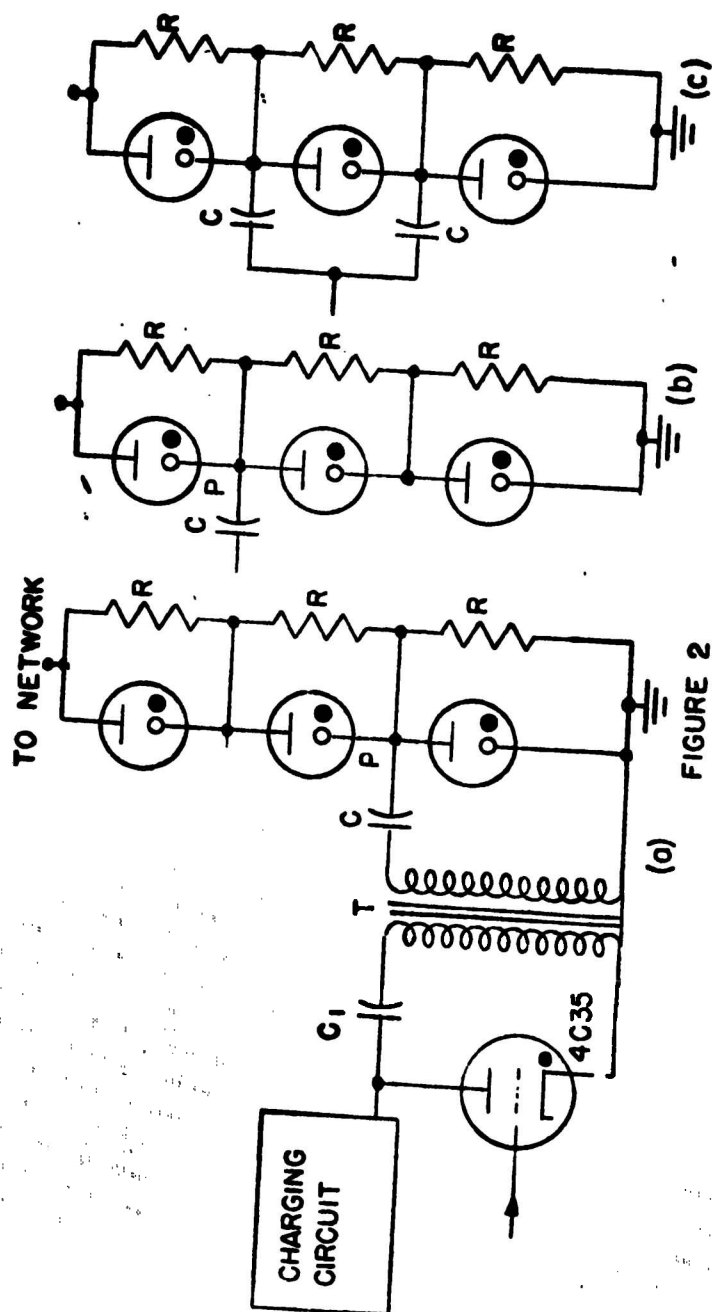


FIGURE 2

Figure 3 shows changes in range with time for a set of three of these gaps filled to 175 cm and operated at 1170 pps and 1 μ sec in a 50 ohm circuit. At 105 hours, it was necessary to lower the switch voltage in order to stop the kick outs. Operation within 1.5 kv of V_{max} at these conditions is not satisfactory due to kick outs. The trigger was coupled to the lower intermediate point. Table I shows the range of three new tubes at 1010 pps with $R = 1.5$ megohms and $C = 60$ μ mf. A and B are for the triggers coupled as in a and b of Figure 2 respectively, and C_1 is for c with the trigger polarity opposite to that of the switch voltage and C_2 with the trigger polarity the same as the switch voltage. The variations in V_{max} with trigger coupling can be accounted for from the standpoint of voltage division for given values of R , f , and C .

TABLE I				
	A	B	C_1	C_2
V_{max}	37.0	34.0	32.0	32.0
V_{min}	17.8	17.6	14.5	14.0
V_{start}	11.0	11.7	9.0	9.5

Lower values of V_{min} and V_{start} with two-point triggering show that this method is advantageous from this standpoint. Two point triggering at high power is decidedly better than single-point triggering although this is not apparent from comparisons made on new tubes, for after the anodes get rough and V_{max} has come down, V_{max} is essentially the same regardless of how the trigger is coupled, but V_{min} and V_{start} remain lower for two-point triggering. Division of voltage and trigger coupling is discussed in some detail elsewhere.*

Photograph 1 of Plate II shows the anode of one of the three tubes on which the data of Figure 3 were taken. During operation of these gaps, aluminum is eroded from the cathode, transferred to, and deposited on the anode. Under many sets of operating conditions this anode build-up remains sufficiently smooth so as not to seriously affect range over at least 500 hours. However, the combination of high power, high pressure, and high repetition rate accounts for this rough anode build-up which in turn accounts for the large drop in V_{max} . The more fundamental aspects of cathode erosion and anode build-up in these tubes are discussed elsewhere †

One set of gaps filled to 150 cm pressure had a V_{max} of 35 kv at 500 pps and 28 kv at 1300 pps. Measurement of the rate of energy dissipation in each gap filled to 175 cm pressure and operated at 1000 pps and 1 μ sec, with a measured peak current of 250 amps gave 90 watts. Further consideration to diss

*J. R. Dillinger, F. E. Bothwell, "Division of Voltage Across Series Spark Gaps in a Line Type Modulator", R.L. Report 682-2, October 31, 1945.

†J. R. Dillinger, "General Characteristics of Enclosed Spark Gaps with Emphasis on Aluminum Cathode Type Series Gaps", R.L. Report 682-3, November 21, 1945.

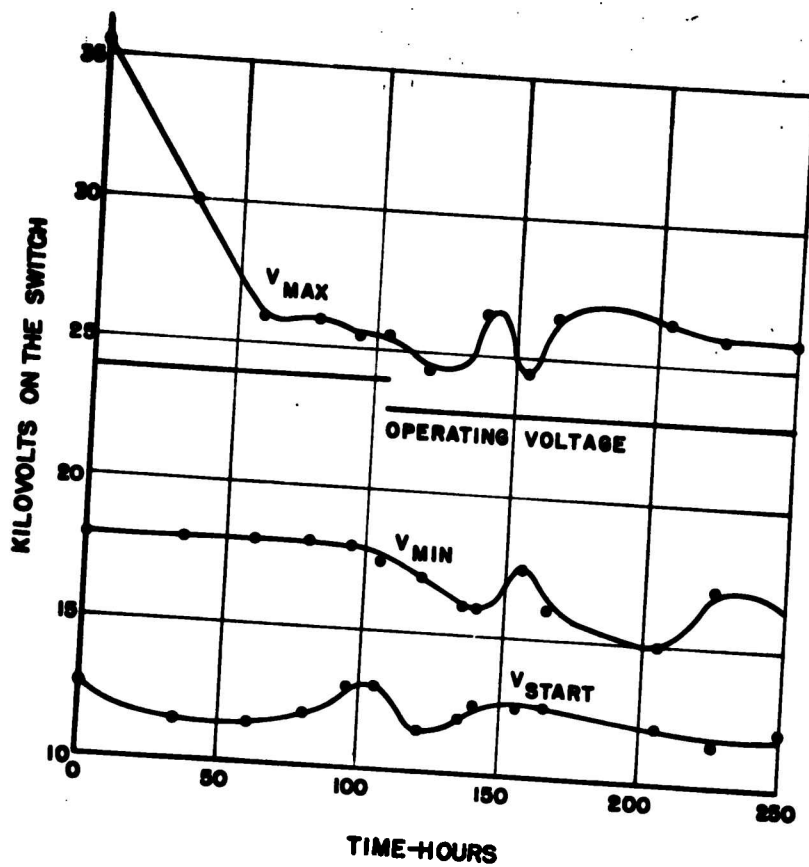


FIGURE 3

pation, etc. is given elsewhere."

B. .440" Spacing Tube

Three tubes, similar to the preproduction WX3240 except with 1.317" I.D. cathodes and .437" O.D. anodes (making the spacing .440") were filled to 150 cm pressure with 80% H₂ and 20% A and operated at 1170 pps and 1 μ sec in a 50 ohm circuit with the trigger coupled to the lower intermediate point. Two megohm dividing resistors and a 60 μ mf coupling condenser were used. Figure 4 shows changes in range with time, and photograph 2 of Plate II is a print of an X-ray of one of these tubes after 500 hours operation. At 500 hours the tubes were repumped, baked, and refilled. The encircled data shown at 500 hours were taken after the tubes had been refilled, showing that pressure changes had been insignificant from the standpoint of affecting range.

C. The 1B45

Photograph 2 of Plate I is a print of an X-ray of a production model WX3240 gap manufactured by the Westinghouse Electric Company. This gap filled to 175 cm pressure with 80% H₂ and 20% A is a 1B45. It has a drop of NaBr solution at the bottom of the cathode. Figure 5 shows range vs. time for operation of three of these gaps in series at 1170 pps and 1 μ sec in a 50 ohm circuit. There were 20 kick outs during this 280-hour test. Range at each time was taken in each of the three ways referred to in Figure 2 as indicated, "a" referring to coupling at the lower, "b" to the upper, and "c" to both intermediate points. Values of R and C used were 2 megohms and 60 μ mf respectively. Photographs 3 and 4 show the anodes of two of these tubes after 280 hours of operation. Figure 5 shows that two-point triggering is definitely better for operation of these gaps under conditions at which there is considerable anode roughening. V_{min} and V_{start} (the dashed lines are V_{start}) are considerably lower. However, V_{max} is generally higher with the trigger coupled to the lower point, particularly so when the gaps are new. These gaps were operated with the trigger coupled to the lower point for the first 200 hours and with it coupled to both points thereafter.

Figure 6 shows range vs. time for 3 of these gaps operated at 1170 pps and 1 μ sec in a 50 ohm circuit with an HI5 magnetron load. At 20.5 kv switch voltage the measured input to the magnetron was 1.6 megawatts and 1.1 megawatt at 17.5 kv. At 1.6 megawatts the magnetron sparked very badly, and its life was about 50 hours. At 18 hours the trigger was changed from being coupled to the lower point to being coupled to both points which accounts for the shift in range. Operation of these gaps at 17.5 kv appears to be quite reliable for at least 500 hours with a sufficiently wide range for most purposes with double-point triggering. 17.5 kv is the present SX level.

D. Grooved Anode Tubes

Figure 7 shows range vs. time for three of these gaps filled to 175 cm pressure and operated at 1170 pps and 1 μ sec in a 50 ohm circuit. These gaps were of the same geometry as that shown in photograph 1 of Plate I except the

*E. G. Fluharty, J. R. Dillinger, "Dissipation in Series Spark Gaps and Voltage-Current Relationships During the Discharge", R.L. Report 682-1, August 31, 1945.

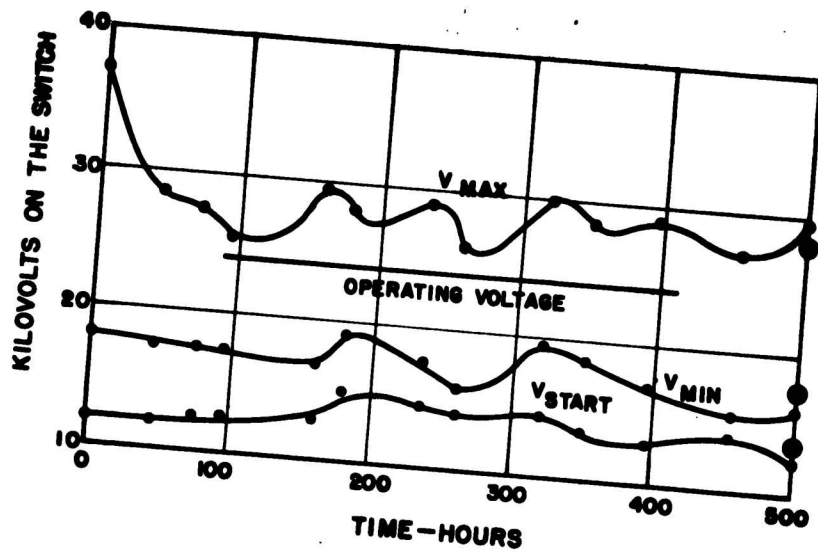


FIGURE 4

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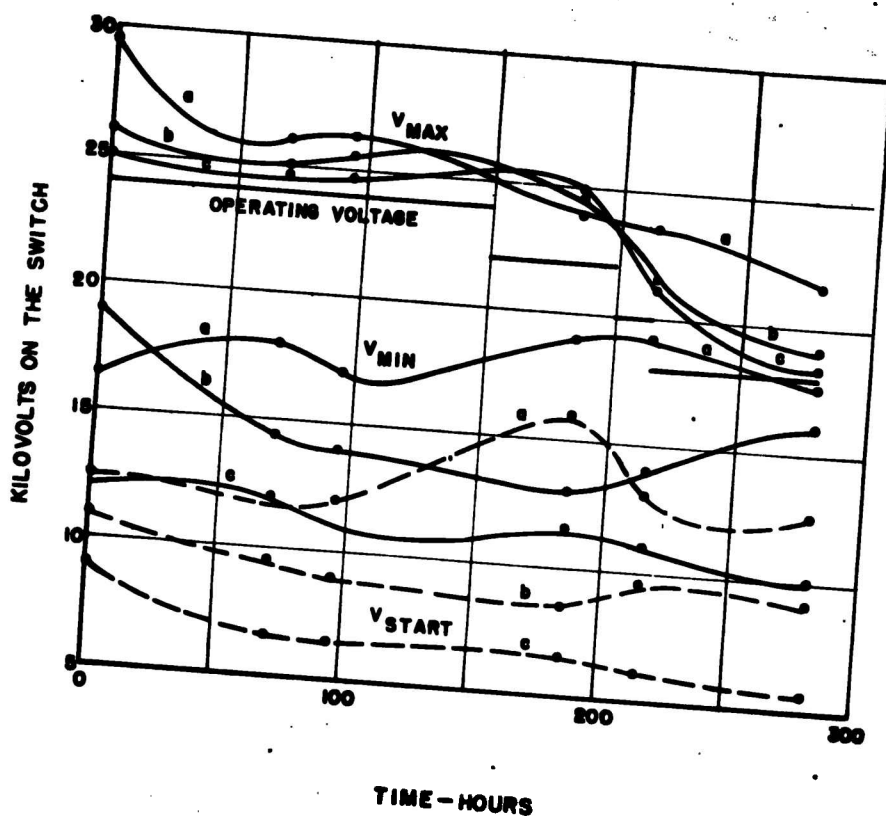


FIGURE 5

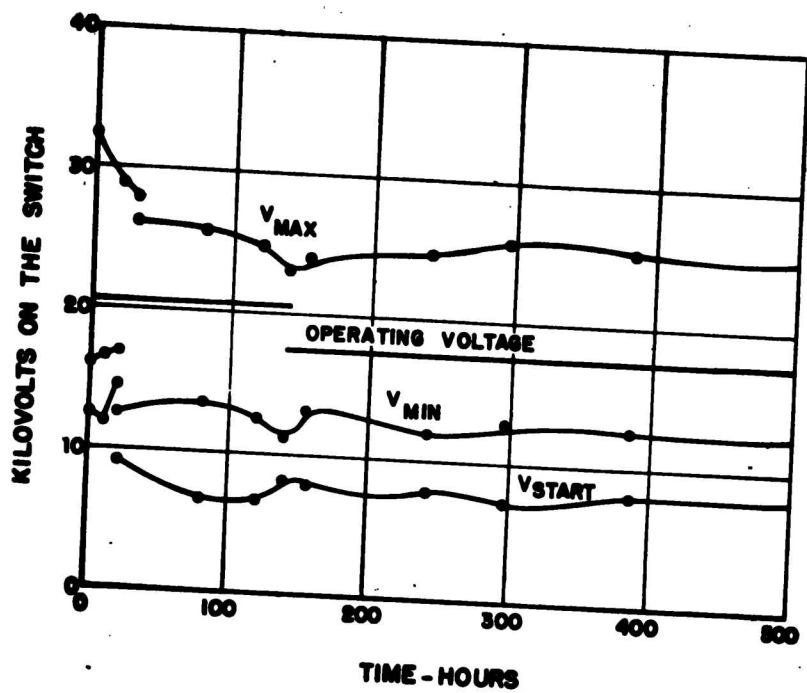


FIGURE 6

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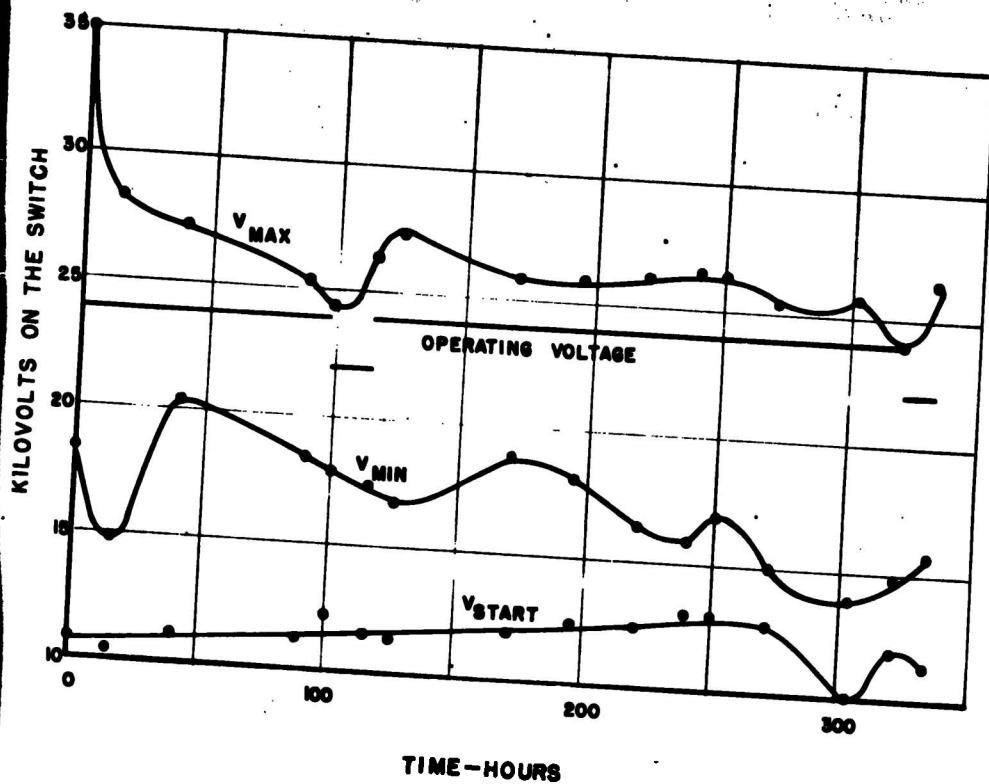


FIGURE 7

anodes of these gaps were as these shown in photograph 3 of Plate I. The trigger was coupled to the lower point. Photograph 5 of Plate II shows the anode of one of these gaps after 333 hours of operation. The build-up is quite rough, and the distribution of sparking was not very good as is the case in most of these gaps. It was believed that the center grooves would reduce the amount of sparking at the end and so reduce the end build-up.

E. Grooved Anode and Cutaway Cathode Tubes

Figure 8 shows range vs. time of three gaps filled to 155 cm and operated for 300 hours at 1170 pps and 1 μ sec in a 50 ohm circuit. The geometry of these gaps was as shown in photograph 3 of Plate I. The geometry is the same as that of the production WX3240 except that the anode is grooved and the cathode is cutaway opposite the end of the anode. Cutting away the cathode opposite the end of the anode increases the breakdown voltage for a given pressure such that a set of these gaps filled to 140 cm pressure was observed to have the same range as a set of production WX3240 gaps filled to 175 cm. Photographs 6 and 7 of Plate II show anodes of two of these tubes after 300 hours operation. There were 25 kick outs. Range was taken each time with all three ways of trigger coupling with a, b, and c of Figure 8 corresponding to those of Figure 2. These data again show that two-point triggering gives the widest operating range.

F. WNaO End-Sparking Tubes

Figure 9 shows range vs. time for three gaps as shown in photograph 4 of Plate I operated with the trigger coupled to both points at 1170 pps and 1 μ sec in a 50 ohm circuit. There were 60 kick outs distributed over the whole 500 hours. The cathode of each of these gaps was a pellet of a sintered mixture of tungsten and barium oxide with nickel for a binder. The low work function of this sinter reduces the cathode erosion rate by a large factor. These gaps were hard to start after being left inoperative for some time, indicating the presence of some sort of surface activation process.

III. Operation at AEW Conditions

The modulators for the AEW radar set require a switch to operate from 13.5 to 15.5 kv at 300 pps and 2 μ sec in a 25 ohm circuit making the peak current about 300 amps. This is a self-synchronous system, so small time jitter is not required.

A. 1B41

Three production WX3240 gaps filled to 90 cm pressure (the 1B41) operate quite satisfactorily at these conditions. The jitter is of the order of 2 to 3 μ sec. Trigger voltage of 20 kv, as measured on a 15 μ mf load, is sufficient to obtain maximum range. One set of these gaps were operated for 1000 hours

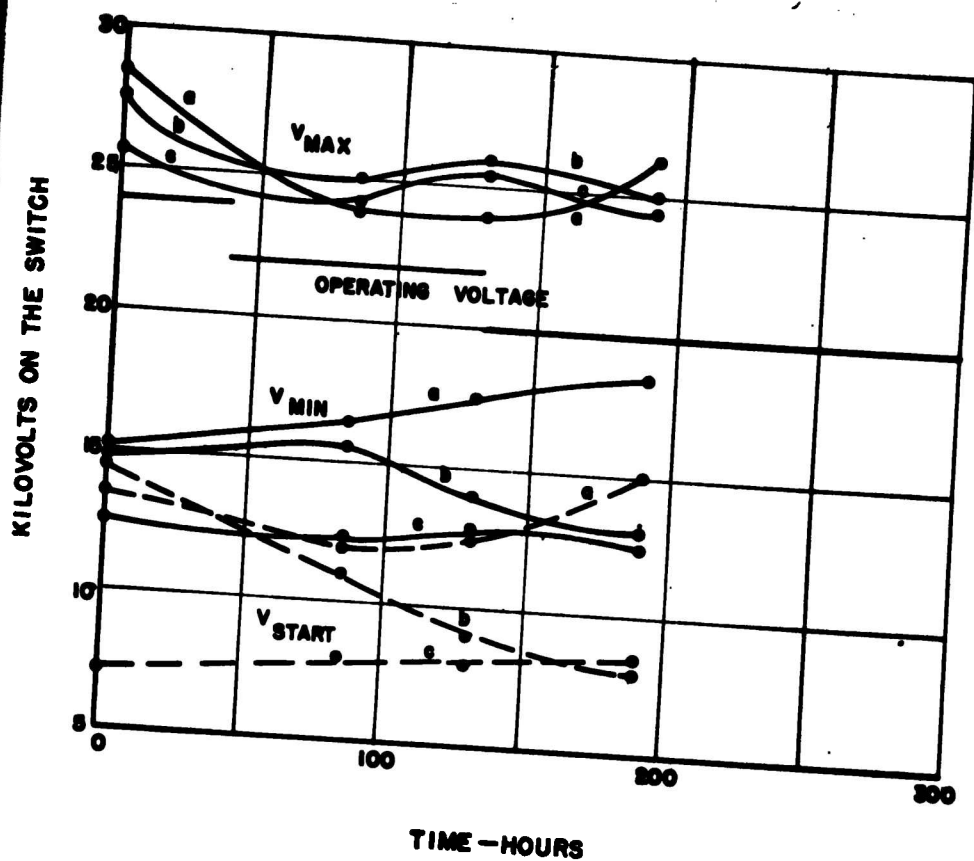


FIGURE 8

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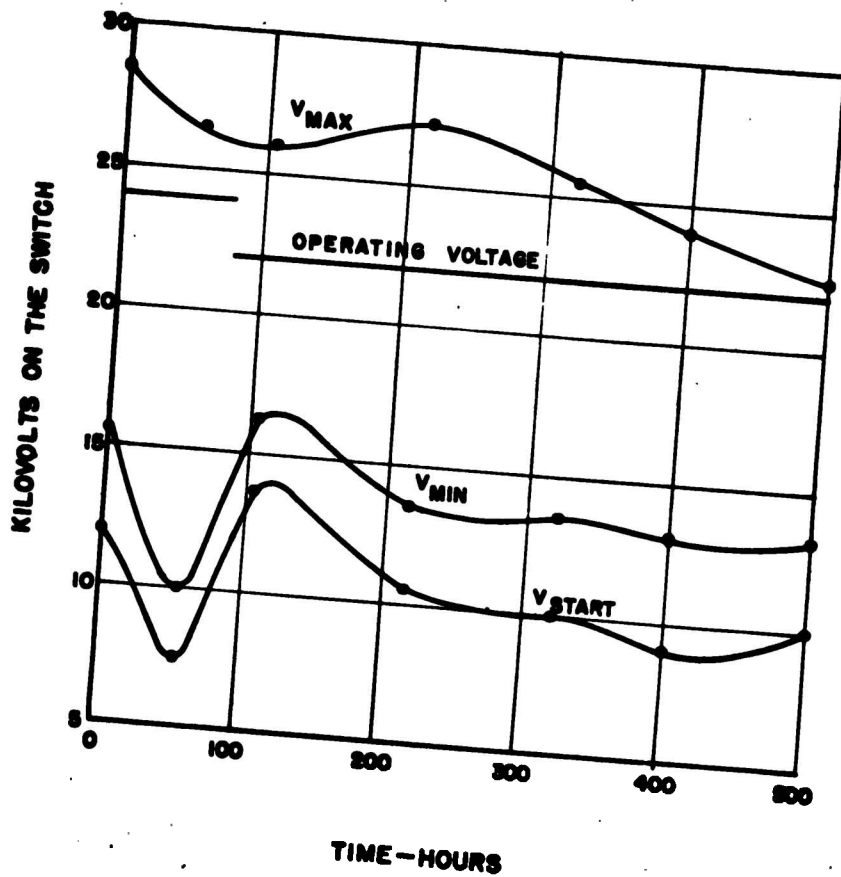


FIGURE 9

68 2-4-14

under these conditions with a resistance load. The range remained as good as or better than 12 to 16 kv during this test with the trigger coupled to the lower point. Two other sets of gaps were operated at 15.5 kv giving 2 mw into an HK7 magnetron load for 500 and 660 hours respectively. Figure 10 shows range vs. time for one of these sets with the trigger coupled in each of the three ways. It is seen that two-point triggering is to be preferred. Photograph 8 of Plate II shows the anode of one tube after 660 hours operation. The anode build-up under these conditions is very smooth. When the WX3240 gaps are operated at conditions under which the anode build-up is smooth as shown here, the range and operation of these gaps are quite satisfactory, and the life very long indeed--in excess of 1000 hours.

IV. The 1B49

The 1B49 is a production model WX3240 as shown in photograph 2 of Plate I filled to 110 cm. This gap is used in some equipment developed by the National Research Council of Canada. Three of these gaps in series should maintain a range at least as good as 15 to 20 kv for over 500 hours at 700 pps and 1 msec in a 50 ohm circuit.

V. Impulse Ratio vs. Pressure

Table II gives d-c breakdown voltages, impulse breakdown voltages with a rate of rise of voltage = 20 kv/ μ sec, and impulse ratio for production WX3240 gaps filled to three different pressures with 80% H_2 and 20% A with RaBr added.

TABLE II

Pressure cm	Impulse Breakdown kv	d-c Breakdown kv	Impulse Ratio
90	13.8	8.5	1.62
175	29.0	15.5	1.87
250	32.0	16.6	1.93
260	25.6	16.8	1.52

An attempt was made to operate a 90 cm gap in series with a 250 cm gap. Since the d-c breakdown of two 90 cm gaps in series = that of one 250, it was believed that a 90 and 250 cm gap in series should give the same range as three 90 cm gaps. It is possible that the range vs. life might remain slightly better.

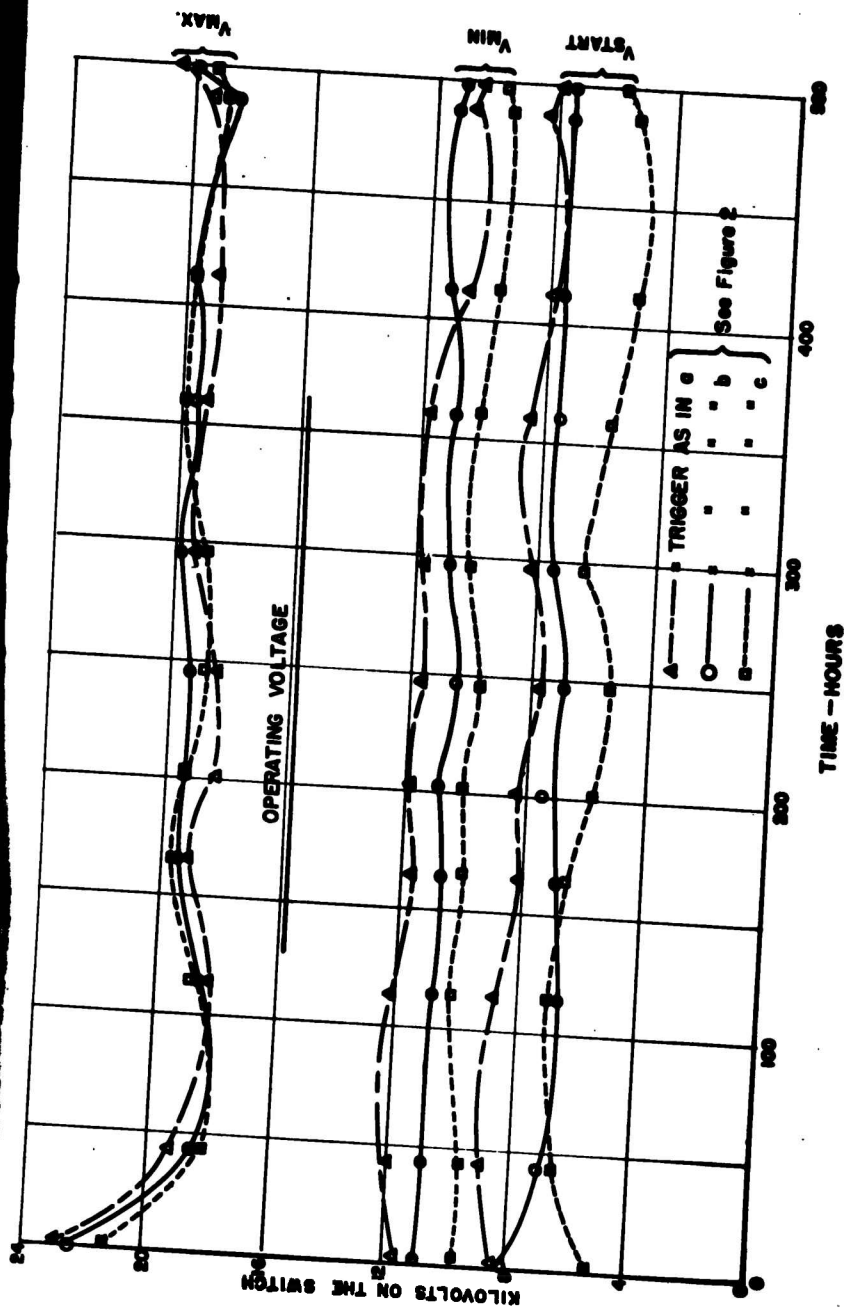


FIGURE 10

002-4-16

for it is believed that V_{max} comes down due to random corona conditions in one or more gaps. These cause partial collapse of the gap accompanied by an overvoltage of the other gaps, which can cause a prefire. Reducing the number of gaps would reduce the number of variables. However, the higher pressure would make the anode build-up rougher in that tube.

It was found that the range of three 90 cm gaps was 21.0 to 11.0 and 20.5 to 12.5 for a 90 and 250 cm in series with the voltage divided in the ratio of 1 to 2. The fact that V_{min} is higher with the 90-250 combination can be explained on the basis of the impulse ratio being higher for one 250 cm tube than for two 90 cm tubes, even though the d-c breakdowns are the same. In supplying the higher trigger voltage to the 250 cm gap required to break it down, a higher voltage than normal is impressed on the 90 cm gap in the reverse direction which breaks it down at higher switch voltage (V_{min}) than is the case when operating three 90 cm gaps with the lower impulse breakdown.

VI. Pressure Change with Life

Since the kovar end cups of these tubes operate at a high temperature, it was suspected that a possible loss of hydrogen through the kovar might account for some of the decrease in V_{max} . At 1000 pps, 1 μ sec, 250 amps and at 400 pps, 1 μ sec, 300 amps, the kovar temperature in a 28°C ambient was measured to be 225°C and 175°C respectively.

To check this, the pressure was measured in six tubes at various times during operation and the gas also analyzed. The pressure was measured by sealing the tube onto a vacuum system and breaking the seal-off tip with a magnetic hammer. By letting the gas expand into a known volume and knowing the volume of the tube, the pressure could be calculated. The gas was analyzed by weighing a standard flask empty and then full of the gas at a known pressure. Results obtained by this method agreed with those obtained by absorbing the H_2 over a PdCl solution. Satisfactory results were not obtained by passing the gas over hot copper oxide and weighing the H_2O formed, nor by heating lithium in the presence of a sample of the gas and measuring the pressure change as the H_2 combines with the Li.

Six electrodeless glass bulbs and six preproduction WX3240 tubes were filled at the same time from the same tank of nominally 80% hydrogen and 20% argon gas to the same pressure (148.8 cm) at the same temperature. Measurement of pressure in the six electrodeless bulbs showed each value to vary by less than $\pm 0.2\%$ from the average value. The average gas composition was 80.8% hydrogen and 19.2% argon with maximum variation of any tube from this of $\pm 0.1\%$.

The six tubes were then operated for various times at 1155 pps, 1 μ sec, and 21 kv in a circuit with a 50 ohm network and 50 ohm load. Pictures of anodes taken at 100, 400, and 500 hours are to be seen in Radiation Laboratory Report 682-3. The data of Table III show the results. Negative and positive values represent a loss and a gain respectively. Pressures were corrected to the filling temperatures.

TABLE III

Hours Run	Change in Pressure From The Average
0	- 0.2%
5	+ 0.9%
100	- 3.2%
265	- 2.5%
400	- 1.7%
500	- 8.8%

The increase at 5 hours is large compared to the fluctuations in the measurements on the standard bulbs. It represents an increase of 14 mm from the average value, and since the maximum variation from this value was ± 3 mm, there is an increase of at least 8 mm which cannot be disregarded. This could be due to gases having been driven out of the metal parts. The losses in pressure shown are not serious from the standpoint of affecting range. Impurities driven out of the electrodes might be expected to affect range; however, one set of gaps was refilled, and the range was not affected as shown in Figure 4.

The tube which was run 500 hours ran the last 290 hours with a hole in the cathode. Operation with such a hole in the cathode has been observed to increase the erosion rate by a factor of 3. (See Radiation Laboratory Report 682-3). If the loss of gas is associated with the erosion of aluminum, this could account for that value being disproportionately high. This increase in the loss of gas after a hole appears in the cathode had been observed previously on tubes with less accurately controlled fillings.

Measurements of gas composition agreed fairly well with calculated percentages of H_2 and A assuming only H_2 was lost and in sufficient quantity to account for the measured pressure loss. The results certainly showed that the number of molecules of H_2 lost was large compared to the number of A molecules lost and/or the number of molecules of foreign gas gained. This is true even after taking into consideration the 4 to 1 ratio of H_2 to A molecules present initially.

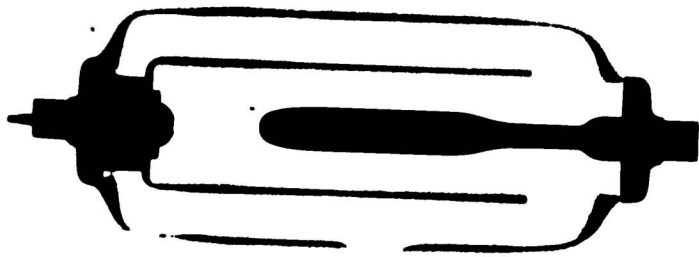
Calculation of the ratio of H_2 molecules lost to A molecules lost gave negative results in some cases which could be accounted for by the number of foreign molecules of gas gained being greater than the number of A molecules

lost. This work was not carried further since neither gas losses nor driving impurities out of the electrodes appeared to account for an appreciable amount of the change in range observed during operation.

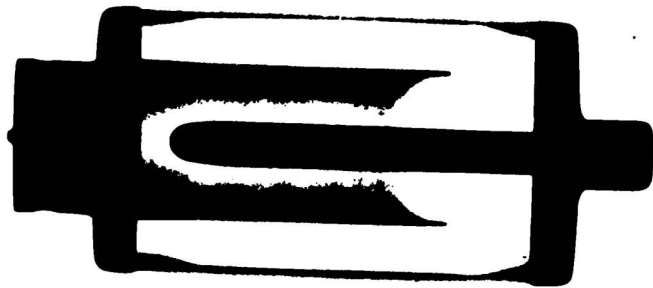
Acknowledgement: I wish to acknowledge the assistance of Edmund Secatore and Howard R. Zeller in obtaining the experimental data of this report.

J. R. Dillinger
November 26, 1945

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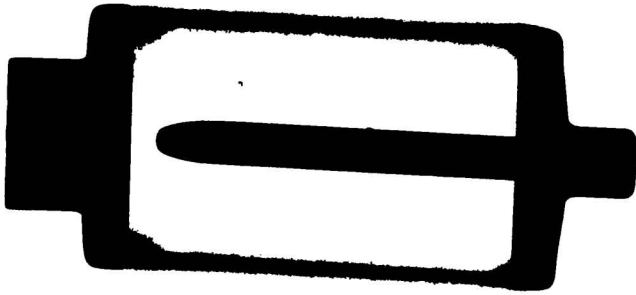
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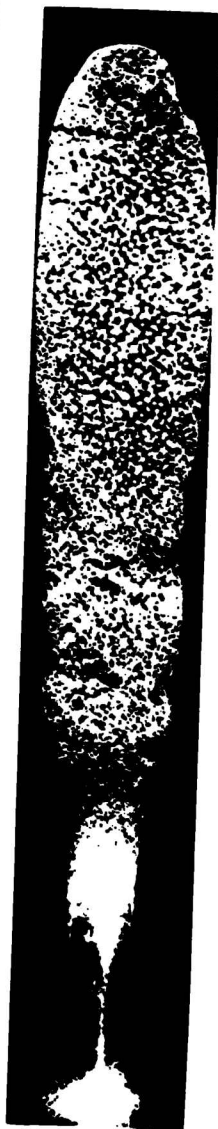
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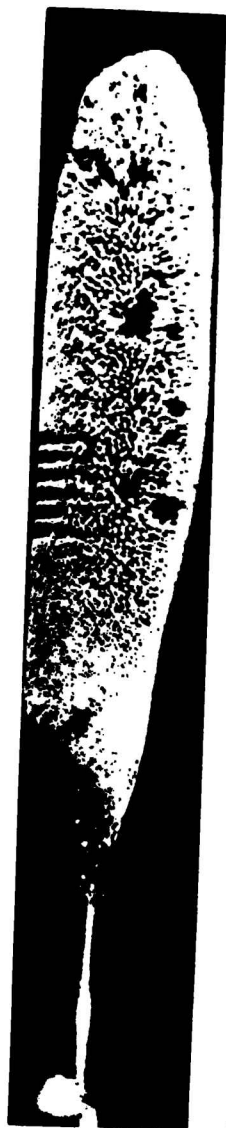
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PLATE I

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XI.5
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XI.5
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PLATE II

REPORT 682-4

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