RPN83

RADIATION PROJECT PROGRESS REPORT NUMBER 17

INTERIM PROGRESS REPORT ON THE G2A DIODE

by

David C. dePackh
Electron Beams Branch
Plasma Physics Division

12 December 1969

This work is funded by the Defense Atomic Support Agency under subtask-work number LA013.

INTERIM PROGRESS REPORT ON THE G2A DIODE

by

David C. dePackh

INTRODUCTION

The G2A is an energy-concentration diode intended for use in systems in which parallel operation of a relatively large number of modules, delivering their energy to a small volume, is proposed. It uses the same insulator structure as the older G2, but the cathode and anode structures are long cones (Fig. 1). This tube is intended to exploit parapotential electron flow, a substantial portion of the emission coming from the shank but not breaking down to the anode because of the magnetic field resulting largely from the tip current. The tip has the form of a 1-inch diameter hollow ring. The ring edge is feathered to enhance emission from this region. Tests were conducted in two runs: 9/10 - 9/12/69 and 11/12 - 11/26/69.

CHARACTERISTICS OF PARAPOTENTIAL-FLOW DIODES:

Figure 2 shows the theoretical characteristic curves of a parapotential diode according to the theory of reference 1. For low values of the tip current a typical load line misses the characteristic altogether, and an upstream short-circuit may be expected. When the tip current is just large enough to prevent this, and for somewhat greater values, the total current tends to be roughly constant (it actually falls slightly with increasing tip current to begin with); when the tip current is very large, the total current again increases, the shank contribution not adding appreciably to the total. Large shank contributions are expected at large tip spacings, just small enough to prevent an upstream short-circuit. Thus the diode is a roughly constant impedance device for a given voltage over a fair range of tip currents. The envelope curve gives the maximum impedance for any load line (it should be pointed out that reference 1 is in error with respect to the numerical value of the conductance by a factor 4, a 2 having gone into the numerator which belonged in the denominator). For G2A the line impedance 60 $\log(r_{anode}/r_{cathode})$ is about 5 ohms, and the following table can be prepared from the envelope in Fig. 2.

$V_{applied}$(MV)	i(MA)	Z(ohms)
0.25	0.12	2.1
0.5	0.20	2.5
0.75	0.28	2.7
1.0	0.35	2.8

It will appear that the observed impedances are lower. This probably means that the tip loading exceeds what corresponds to the minimum total current.

It may be seen from the curves that if the tip current is strongly dependent on the voltage, an increase in voltage may then bring about a drop in shank current which exceeds the increase in tip current so that the tube behaves as a negative resistance element with the possibility of instability. Some anomalous current traces have been observed suggesting such behavior, although noisy circuits cannot be wholly ruled out.

OBSERVED IMPEDANCE

Resistive voltmeter readings appear consistently high compared to $V_o - iZ_o$ (by about 25%-30%). It is not easy to apply an L di/dt correction because of uncertainty in the time zero and noise in the signals. Spectral information from the radiation suggests that the effective electron energy is about 400 kev on most of the shots. The current for those shots where good information is available runs to about 500 kA. The value of $V_o - iZ_o$ gives an average of about 800kV(Z = 1.6 ohms), while the resistive voltmeter gives an average of about 1 Mv (Z = 2 ohms). The spectral data is time-integrated and thus gives no information about the instantaneous peak electron energy. It is probably reasonable to conclude that the impedance is about 1.5 ohms. To optimize the production of radiation which follows the law iV^k for a constant generator voltage and impedance, the ratio of load to internal impedance should be k. From information obtained from the G3 diode and also rather closely from theory it is found that $k \sim 2.6$ over the range of voltages of interest here and for tantalum targets of optimum thickness. Assuming constant generator voltage and k = 2.6, one can find the relative bremsstrahlung from the following table.

Z(ohms)	Rel. Bremsstrahlung
3.9 (opt)	1.00
3.0	0.97
1.5	0.69
1.05	0.49

It is therefore desirable to operate this tube at higher generator voltages than G2, with an impedance of about 3 ohms, if large bremsstrahlung yields are needed. Difficulties were experienced throughout the run with insulator flashover (the final pulses being distinctly short without evidence of shorting in the tip region) so that this could not be tried in this series of tests. It was found desirable to maintain tip spacings of about 5-6 mm during the early part of the tests, but it will be necessary to vary this in later runs. It is of course clear that there is a narrow range over which this parameter can be varied since too large gaps produce upstream shorts, while too short ones produce shorts at the tip.

RADIATION SPECTRUM

The radiation spectrum was estimated with four photodiode-scintillators having absorbers as follows: clear, 0.002" tantalum, 1 mm lead, and 1 cm lead. The photodiodes were checked on several shots with all absorbers removed. Agreement among them was within about 10%, which is something like the experimental error. The outputs were time-integrated by leaving the cable terminations open for dc, and the signals were displayed on a four-channel chopped oscilloscope. These filters are one radiation length thick at 40 keV, 200 keV, and 500 keV respectively. It was noted that the response on the 2-mil tantalum channel was 10% to 20% lower than on the clear channel, indicating material radiation below 40 keV. The graph of Fig. 3 shows the relative transmission through 1 mm and 1 cm of lead for various full Kramers spectra. These can of course be refined by using ELECTREX or similar techniques, but since only the ratio of filtered response/clear response is important, this estimate is probably close enough. Characteristically the ratio 1 mm/clear was about 0.2, and 1 cm/clear was about 0.02. From the figure it is seen that these are consistent with an effective electron energy of about 400 keV. The very low response from the 1-cm channel indicates that the electron energy is materially below 1 Mev. The 4-ohm charging voltage on these tests was about 2.6 Mv, corresponding to $V_o \sim 1.6$ Mv.

FLUENCE

Fluence was measured with an unfiltered photodiode calibrated against TLD's. The calibration was 100 joules per μv-second, assuming an isotropic distribution of radiation, into a 50-ohm load and at 97 inches from the source. Integration was carried out with an RC integrator having a time constant of 1 μsec. This was checked against the area under the unintegrated photodiode pulse on a number of shots with satisfactory agreement.

The highest flux measured was ~ 380 joules (#5, 11/20). Current information was lacking on this shot, but it is suspected that the current was rather low, and the voltage correspondingly high, as indicated by a high peak in the time-resolved photodiode output. Typically a flux of about 300 joules was realized. The delivered flux depended largely on the pulse length.

DOSE

The remarks of reference 2 regarding dose measurements are still apposite. Measured fluence levels are high for the indicated pulse length, voltage, and current levels and the known efficiency of bremsstrahlung production. Thus if one accepts an effective voltage of 600 kV as a reasonable average of the various values, an effective current of 500 kA, a pulse length of 30 nsec, and a 4π efficiency of 0.02, the total flux is

$$6 \times 10^5 \times 5 \times 10^5 \times 3 \times 10^{-8} \times 2 \times 10^{-2} = 180 \text{ joules},$$

which is lower by a factor of almost 2 than what the TLD's measure. According to the calculation and the pinhole pictures one can believe a point source assumption at distances $\geqslant$ 1 cm; at 1 cm one should therefore have a fluence of about 3.7 cal/cm^2, and with dose/fluence = 2 cm^2/gm Au one should measure something like 7 cal/gm Au. If one believes the TLD-photodiode fluence measurement, the corresponding dose should be nearly 12 cal/gm Au. Corrections applied to these figures result from (1) the target-calorimeter spacing, which is probably closer to 1.3 cm, and (2) the absorption in the protective screen (substantially 0.25 inches of magnesium).

The first correction is about 0.59 and the second is about 0.80. It would therefore seem appropriate to look for doses of about 3 cal/gm Au.

The experimental results have been conflicting. One shot showed gas leakage around the edges of the screen. It was felt that this might have impinged on the outer ring of calorimeters and accounted for the high levels (~5 cal/gm) which were observed; unfortunately the center calorimeter was destroyed. An additional 1/8-inch thickness of magnesium was used to keep gas off the calorimeters, and the dose dropped to the unreasonably low level of 0.6 cal/gm. When plastic was substituted for the extra magnesium sheet, the dose increased to 2 cal/gm, but the decrement appeared abnormal. On all shots there was violent displacement of the whole calorimeter array due to momentum transfer from the screen. It is conceivable that mechanical energy can be deposited in either the hot or cold junction under these conditions so as to make the readings erroneous in an unpredictable way. The design of the array was not such as to allow the use of a momentum-absorbing slug such as was described in reference 2. It is recommended that such a slug be used in all subsequent measurements with this machine. This slug should be in direct contact with the second magnesium plate and should be massive enough to reduce the displacement of the array to a negligible level. The mechanical coupling of the array to the slug should be minimal. The target-holder should be redesigned so that the second magnesium plate is large enough to keep gas off the foils. It is also recommended that an independent fluence measurement such as the baked-out and calibrated x-ray diode by developed for these applications. These questions will not be completely answered until this problem is satisfactorily resolved.

ENERGY DISTRIBUTION ON THE TARGET

There have been two versions of the G2A diode. The second version involved mostly differences in anode fabrication which were intended to maintain better concentricity and to facilitate assembly. Extensive pinhole pictures were taken with the earlier version of this tube as tip spacings of about 8.5 mm. Diagnostics were unsatisfactory on this run (9/10 - 9/12, 1969), but 4-ohm line voltages were running consistently lower (~ 1.8 Mv). The pinhole pictures at this distance showed reproducible pinching (Fig. 4).

In the later version it was difficult in early shots to obtain enough tip current to suppress breakdown on the shank. Tip spacings were therefore reduced and held to 5-6 mm. These shots (Fig. 5) showed less pinching than was seen in the earlier run with greater spacing. This result is in agreement with similar observations on the G3 diode. In the later life of the second version the tendency to flash on the shank virtually disappeared. Because of other tests to be made with diagnostics close to the target further studies to examine the effect of tip spacing on pinching were not made in this run, although it is probable that the tube would have accepted the greater spacings. This investigation should be made in a subsequent run. However, it is probably correct to say that almost all the bremsstrahlung in all shots was produced within a ring 1 inch in diameter.

TUBE CONDITIONING

Pulses were short and spiky on the later version of this tube at all voltages (down to 1.8 Mv on the 4-ohm line) as compared to the earlier one, and the large amount of use the insulator had had prior to the run suggests that this was a contributor to the difficulty. Early shots even at 4 mm spacing showed consistent shank breakdown. Generally the probability of shank breakdown became greatly reduced with time. This is attributed mainly to improvement in emission from the ring and the nearby cathode surface. It was frequently observed on examination of the cone adjacent to the ring that there was marked brightening in localized areas; in some cases this took a rather striking form (Fig. 6). In these cases there was no evidence of any corresponding spot on the anode, which suggests that parapotential electron flow was originating from these regions. The consistent shape and size of these presumably emissive spots is noticeable and inexplicable.

The force of the target explosion is observable in the bulging of the cathode ring (Fig. 7; the wall thickness is 1/16 inch and the material is stainless steel). This develops after repeated shots. It appears to have no effect on tube performance.

It is not easy to say in what the so-called tube conditioning consists. Attempts have been made to use vacuum-fired surfaces and the like to no avail; yet repeated shots definitely appear to produce an overall improvement in performance as far as the cathode is concerned (of course the insulator degrades steadily). Further studies on this process are indicated.

STRAIN GAGE STUDIES

Observations were made with strain gages on tantalum substrates. These results were reported later.

INDICATED FURTHER TESTING

(1) Dosimetry with improved calorimeter design, particularly with respect to momentum transfer and gas protection.

(2) Effect of tip spacing on pinching and impedance.

(3) Use of a smaller-diameter cathode cone to raise the tube impedance for better radiation output.

(4) Faraday cup and drift chamber studies of the beam.

It is requested that time be made available as soon as possible after 1 January 1970 for these studies. Item 4 may be in part dealt with during the last two weeks of January 1970, when the ARKON representative will be here.

REFERENCES

1. David C. dePackh, "Parapotential Flow", Radiation Project Progress Report Number 5, June 24, 1968.

2. David C. dePackh, Memorandum for File, "Internal Progress Report on Electron Beams Branch Work on the Gamble I Facility", 7710-59:DCdeP:bjz, 29 June 1969.

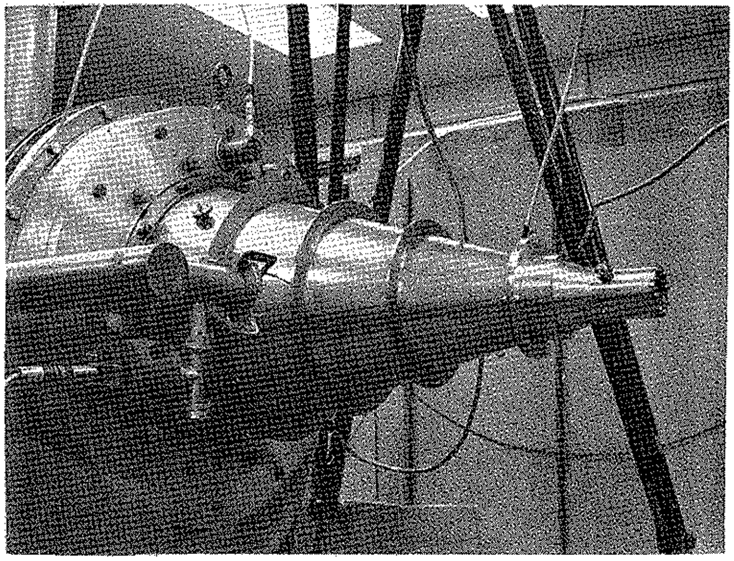


Figure 1. The G2A diode assembled to the Gamble I generator

Figure 2. Characteristic curves of a parapotential diode

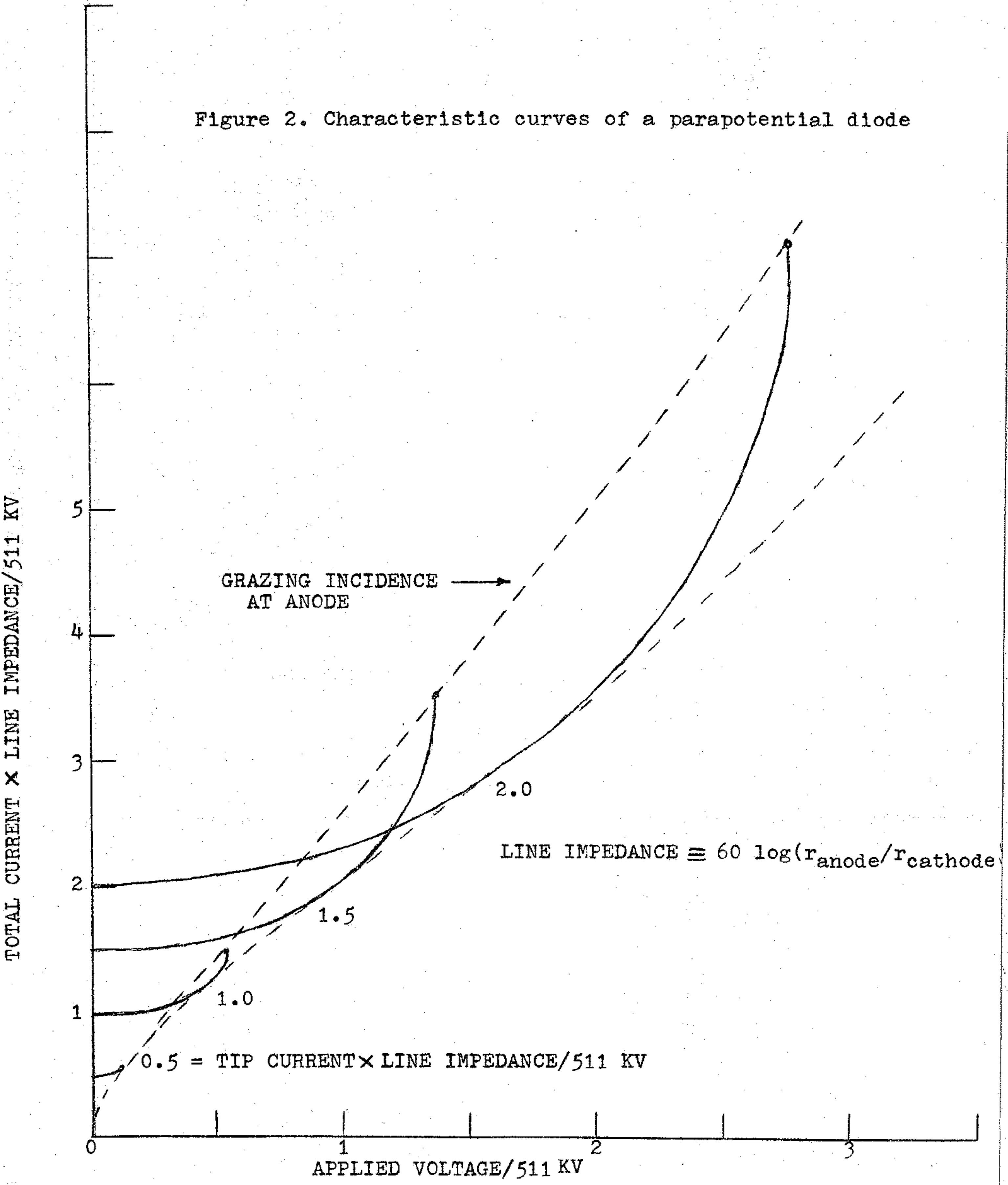
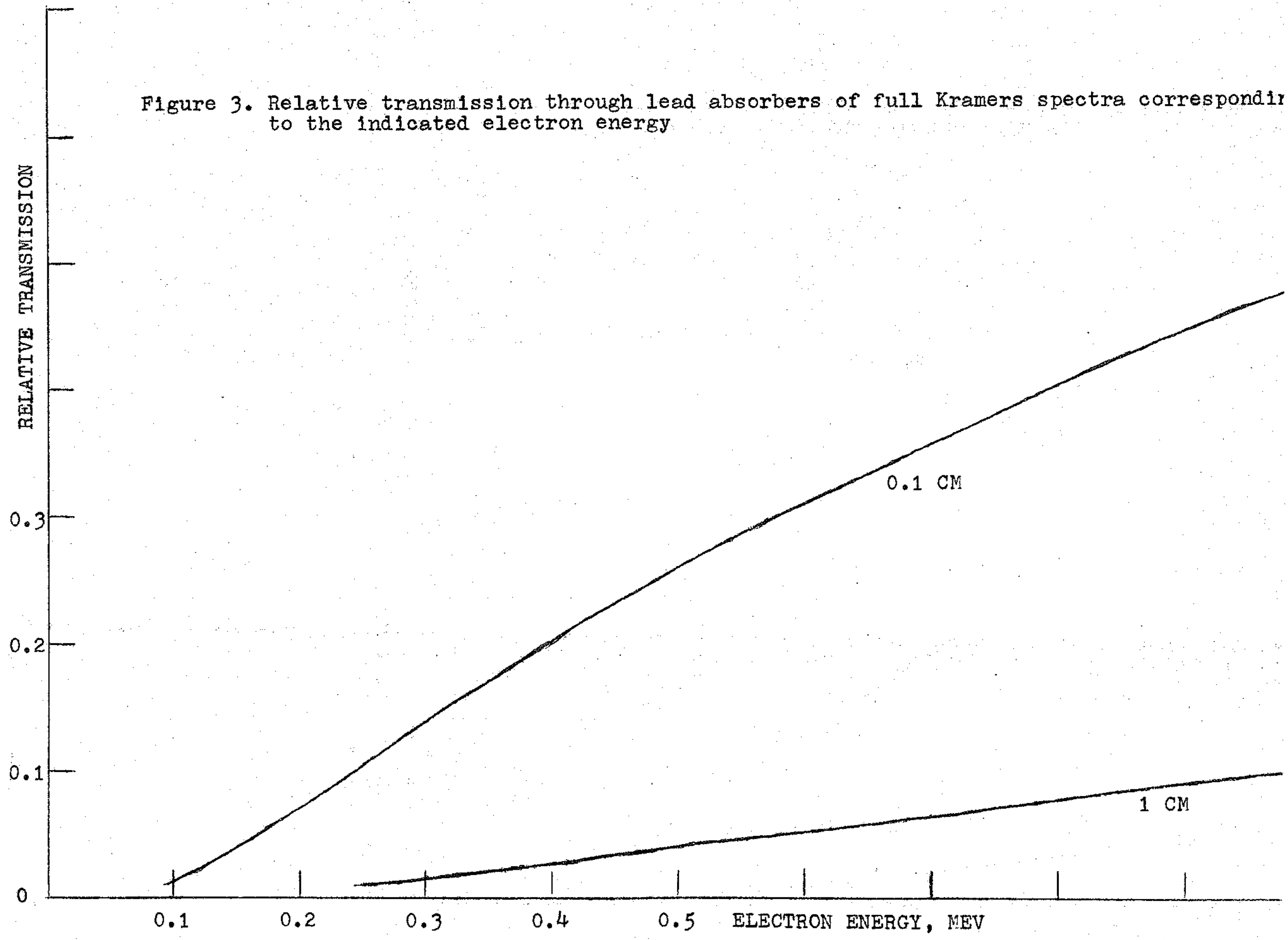


Figure 3. Relative transmission through lead absorbers of full Kramers spectra correspondi to the indicated electron energy



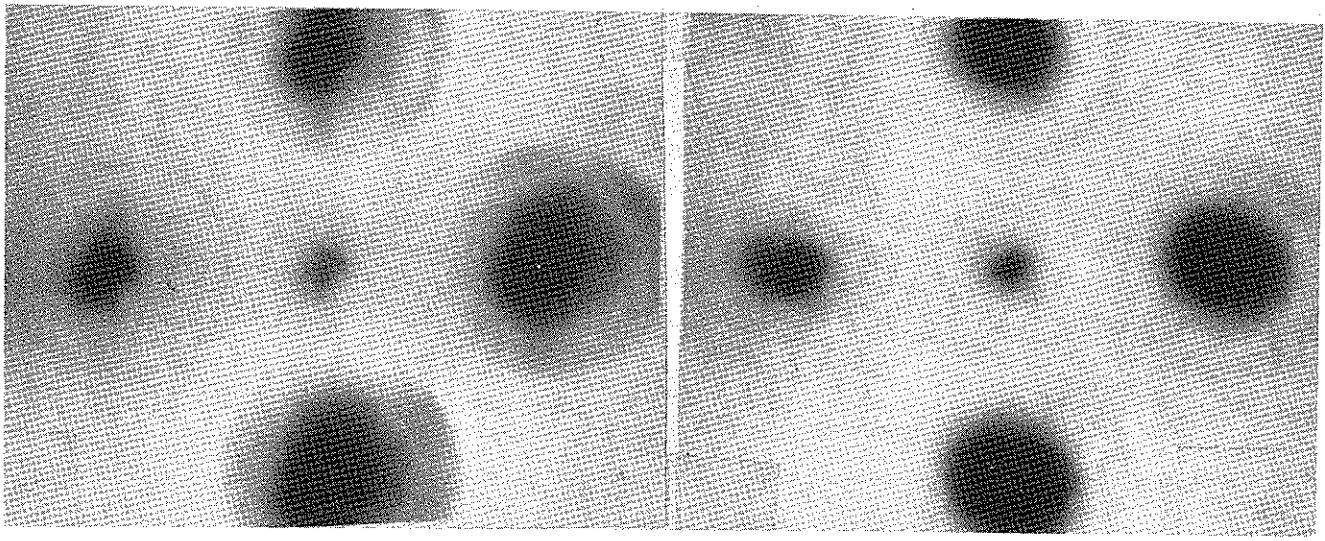


Figure 4. Pinhole pictures through apertures ranging from 40 to 120 mils of shots 14 and 17, 9/12/69 at 8.5 mm tip spacing

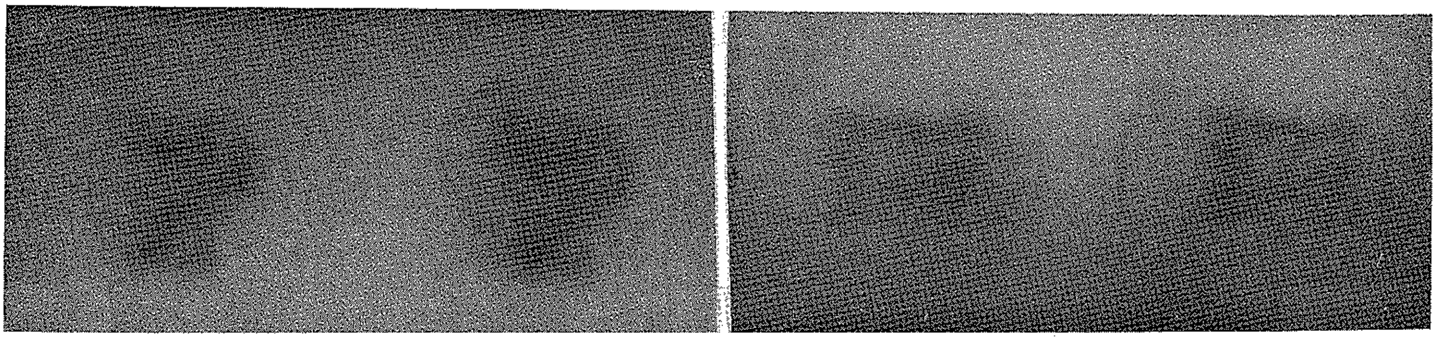


Figure 5. Pinhole pictures through 40 and 60 mil apertures of shots 12 and 14, 11/20/69 at 5 mm tip spacing

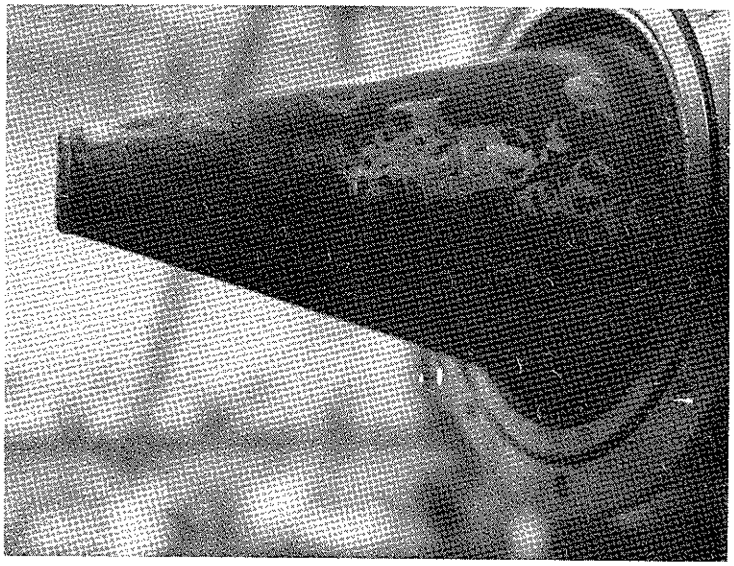


Figure 6. Cathode showing spots believed to be sources of emission

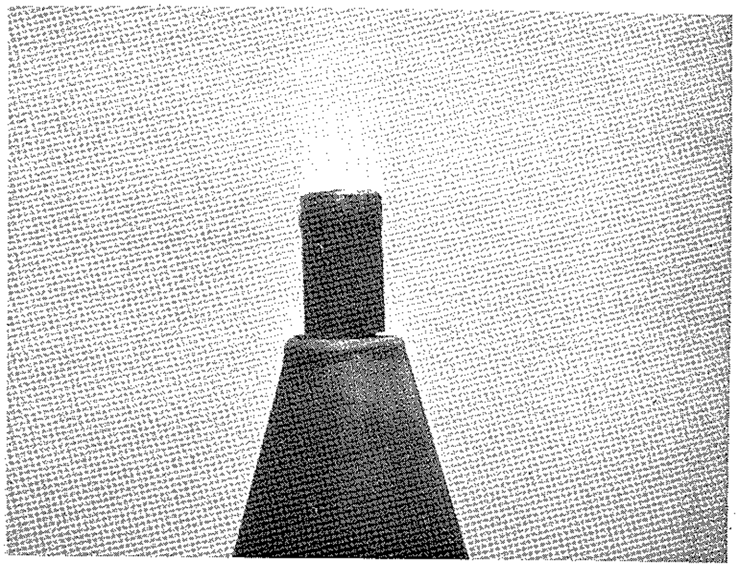


Figure 7. Bulging of cathode ring due to target explosion