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16 February 1961

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US Army Ordnance Technical Intelligence Agency
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Forwarded herewith as Inclosure #1 is Armament Research & Development Establishment Memorandum (P) 87/60 entitled "Development of a Spark Induction Method of Ignition for the 120-mm Tk. Gun X23 - First Progress Report", dated December 1960.

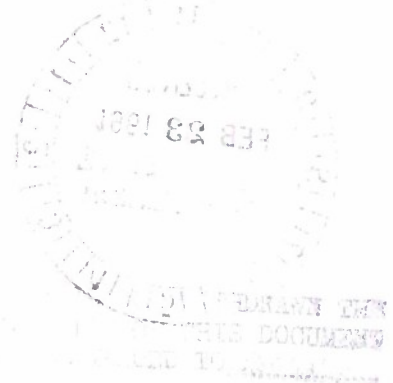
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ARMAMENT RESEARCH AND DEVELOPMENT ESTABLISHMENT

³
A.R.D.E. (MEMORANDUM (P)87/60)

AD-32/595

4 (Development of a spark induction method of ignition
for the 120 mm Tk. Gun X23

^{3a}
(First progress report)

J. R. Price (P2)

Dec 1960

Summary

A novel method of electrical initiation of a gun charge by spark induction is described. Development work on its application to the 120 mm Tk. gun X23 is reported. The main problems have been the mechanical design of the spark plug, and the electrical hazards - static and radio - inherent in the charge design; these have been largely overcome.

Approved for issue:

D. H. Chaddock, Principal Superintendent 'P' Division

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1. INTRODUCTION

The 120 mm Tk gun X23 is a bag charge gun. With such a gun the conventional method of ignition is by means of an electric vent tube, which is loaded into the breech mechanism. In the present case, partly because of the requirement for a high rate of fire, some consideration was given to the possibility of igniting the propellant charge by electromagnetic induction, so as to eliminate the need of a vent tube, or any direct contact with the initiator. Various schemes were proposed and considered, but the present scheme appeared the most practical and likely to be successful.

In addition to its obvious advantages in a much simpler breech, and the elimination of an ammunition component - the vent tube - it may have advantages in leading to less debris, which is of vital importance to the form of obturation in this gun.

2. DESCRIPTION OF THE SCHEME

The scheme appears to be quite novel, and patent action has been taken (Patent Specification No. 37148/58). It may be interesting to know that the Canadian government has applied for the patent.

It is a technique of applying a voltage to an initiator without actual physical contact with it, and is done by means of a spark plug screwed into the gun barrel and connected to a high voltage supply.

The charge consists of a bundle of stick propellant, encircling which are two strips of tin foil, the two strips being connected by means of multi-strand copper leads to the initiator, which is embedded in the igniter. The tin foil is conveniently obtained in the form of a three ply laminate consisting of a layer of tin foil sandwiched between, and cemented to, two layers of fabric. The complete assembly is shown in Fig. 1.

The electrical circuit can be represented as shown in Fig. 2. The high tension unit is essentially an induction coil which works off a 24 volt battery. Included in the secondary circuit is a small auxiliary spark gap which is essential to maintain a good spark should the insulation resistance of the plug drop to a low value (about 10^4 ohms), due to accumulation of dirt or moisture on the insulator surface. When the primary coil is energised, an intermittent high frequency high voltage (about 10 kV) is induced in the secondary, one end of which is connected to the spark plug, and the other to the gun barrel.

In the gun, the point of the spark plug electrode is nearly flush with the surface of the gun chamber, and the minimum distance between the tin foil and the barrel is of the order of 1 to 2 mm. It is essential that the distance of the plug point to the barrel is greater than the critical spark gap for the voltage used, to prevent a flash over to the gun barrel.

In an actual firing of a bag charge, the spark passes through the silk cloth bag and the outside layer of cloth of the first, or "striking" band on to the foil, and returns to the barrel via the same media from the foil of the second, or "earthing" band, thus causing a current to pass through the initiator and fire the round. In practice return sparks occur from both bands so that only part of the available current passes through the initiator.

3. SPARK PLUG DEVELOPMENT

3.1 KLG first designs - Figs. 3 & 4

The essential requirement of a spark plug is that its insulating system must be able to withstand thermal and mechanical shocks, as well as very high pressures. The firm KLG Sparking Plugs Ltd. advertise a product under

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the trade name "Hylumina" which has the properties mentioned, and is the ceramic used for their spark plugs. This firm was approached and asked to design some experimental plugs to specified external dimensions.

Two plugs to the firm's first design - see Fig. 3 - were tried in a 17 pdr. gun which had been modified to accept bag charges specially for this investigation.

The first plug fired only one round, and on testing the insulation it was found to have dropped from infinity to about 4 megohms, and the electrode within the ceramic insulator was loose, the latter having cracked at the point of support.

The second plug fired one round with similar results, but in this case the ceramic insulator had been forced out and was protruding an extra 1/4 of an inch from the end of the plug.

The one plug made to KLG's next design - see Fig. 4 - was more successful. Admittedly it only stood up to a few rounds, but its failure was electrical rather than mechanical. The insulation had dropped due to the ingress of chemical deposits from the gases, which produced an electrical path between the steel body and the central electrode.

3.2 KLG Type Z221 - Fig. 5

At this stage a small contract was placed with the firm to produce a suitable prototype. A family of four designs was considered; Fig. 5 indicates the variations between three of them subsequently manufactured, but one, Z221/2 was not produced. The results obtained with the other designs were as follows:-

Z221/1 - The ceramic nose cap cracked on firing the first round.

Z221/3 - Fired 7 rounds when the insulation broke down due to the ceramic sleeve being broken.

Z221/4 - Fired 63 rounds in all. The insulation deteriorated, and finally reached a stage at which a flash over occurred and the plug ceased to function.

3.3 A.R.D.E. Designs - Figs. 6, 7 & 8

In parallel with this development two plugs - see Fig. 6 - were made in the Establishment using the salvaged ceramic top caps from the first KLG plugs. This was a dismal failure and each plug only lasted for one round; the internal parts being damaged by the ingress of gases in one case, and in the other completely blown out.

An improved design, still utilising the salvaged ceramic caps, is shown in Fig. 7. Here the tufnol insulation is far more robust and 34 rounds were fired with this plug, but the insulation gradually deteriorated, and the plug was taken out for examination. It was found that some gas had been forced between the sealing surfaces of the ceramic cap and the tufnol, shown by small eroded channels on the surface of the tufnol, and these had created leakage paths to the body of the plug.

At this stage it was felt that a simpler design based on more orthodox methods of sealing should be tried, and some plugs were accordingly made to the design shown in Fig. 8. The insulation was of tufnol, which though it might not endure, was at least easier to obtain and machine, and enabled more rapid progress to be made on some of the side issues of plug testing.

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The first plug made to this design fired 74 rounds in the gun, the insulation remaining almost perfect throughout its life. The tufnol however was eroded away where exposed, and the wall of the recess at the top of the plug, into which the electrode fits, was reduced to about half its original thickness, when it cracked, and the spark passed through the crack to the body of the plug.

It was thought that the sealing copper washers were not necessary, and were omitted in some tests of four new tufnol inserts in the same steel body.

The results obtained were as follows:-

Insert No.1 - Survived 17 rounds. Top eroded and cracked.

Insert No.2 - " 3 " " " " "

Insert No.3 - Survived 1 round. The insulation broke down in the long sleeve and sparked through to the body leaving a tiny pin hole.

Insert No.4 - Survived 19 rounds. The top eroded and cracked as in No.1 & No.2.

With all these inserts the insulation remained good up to the point of break down.

These experiments have shown that tufnol is not an ideal material to use, but it has been established that this method of sealing is sound.

3.4 KLG Types Z221/5 & 6 - Figs. 9, 10 & 11

It was now decided to ask KLG to produce two types of plug, the first to A.R.D.E. design incorporating the simpler sealing principle of Fig. 8, and the second a variation of this to their own design.

These designs bear the serial number Z221/5 and Z221/6 and are shown in Figs. 9 and 10. They were tested in the experimental 17 pdr.gun, and the results obtained were as follows:-

Plug Z221/5 - After this plug had fired 10 rounds the tufnol insulator failed and was ejected. The plug was then redesigned with a copper washer underneath the ceramic cap to protect the tufnol from the gases. This work was done in the Establishment and the redesign is shown in Fig. 11. After making this modification the plug fired 34 more rounds in the gun.

As the pressure in the 17 pdr.gun is only of the order of 22 to 23 ton/sq.in. and the plug has eventually to withstand a pressure of 30 ton/sq.in. in the 120 mm gun, it was thought advisable to test the plug at this high pressure.

Up to date no 120 mm guns have been modified to take a spark plug, and to obtain the high pressure required use was made of a primer proof vessel which was adapted to take a spark plug. By suitable choice of propellant charges, one can simulate conditions in the gun in this vessel. About 8 rounds were fired with this plug in the vessel at a pressure of between 30 & 32 ton/sq.in.

Unfortunately the plug was damaged on being inserted in the vessel, though this was not discovered until the plug was removed. The ceramic cap was chipped where it had fouled the sides of the orifice machined in the vessel, owing to incorrect clearances, but it did not appear to have suffered further damage due to the gas pressure.

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Plug Z221/6 - This plug, after firing 40 rounds in the 17 pdr. gun, was broken down for examination, when it was found that the tufnol washer had spread excessively, causing the tip of the electrode to drop considerably below the top, which might eventually cause a misfire. The plug was modified using a copper washer instead of the tufnol one. A further 26 rounds were fired until the plug failed due to the top being cracked. Thus in all this plug fired 66 rounds.

KLG were asked to make two more plugs to the modified design as shown in Fig. 11, and three to the design shown in Fig. 10, with a copper sealing washer instead of tufnol. The plugs were fired in the 17 pdr. gun with the following results:-

Z221/5(MOD)	No.2	-	survived	5	rounds	-	the top cap cracked and splintered)
Z221/5(MOD)	No.3	-	"	14	"	"	"	"
Z221/6	No.1	-	"	2	"	"	"	"
Z221/6	No.2	-	"	14	"	"	"	"
Z221/6	No.3	-	"	14	"	"	"	"

These were very disappointing results, but on examination it was discovered that the copper washers under the electrodes had spread under the gun pressure, subjecting the walls of the recesses in the ceramic tops to radial stresses which presumably caused them to crack. It was considered that a clearance of .01 inch on diameters should be allowed between the washer and the wall. Six more plugs have now been made to this specification, and are in the process of being tested in the gun. So far 1 plug to design Z221/5 has survived 50 rounds.

4. BAG CHARGE DEVELOPMENT

As previously mentioned, the absence of debris is a very important factor, and this will depend on the choice of material used for the bag and igniter container, and on the composition of the igniter itself. In the design of charge used for this ignition system the igniter is put at the forward end of the charge, just behind the shot, so that any igniter debris is more likely to be swept out by the main gas flow. This seems effective in practice, since gun powder has been used as the igniter throughout this investigation.

In the first experimental charges made, the position of the spark plug in the barrel had to be taken into consideration. The particular gun used for the development of this system was a 17 pdr. in which the spark plug was situated at about 9 inches from the breech face, and the charge was made to suit this position. The assembly is shown in Fig. 1.

It consists of two bands of 3 ply fabric placed around a stick charge and connected to the igniter at the front end of the charge by means of thin multi-strand copper leads, which are attached to the foil by means of Wood's metal. Both bands are about 3 inches wide. The first band is so placed that its centre is 9 inches from the breech face thus ensuring that the spark will strike the tin foil in spite of any random positioning of the charge, which could be at most half an inch backward or forward from the central position.

When firing this charge, one or two misfires occurred, and these were explained as due to the fact that the outside surface of the charge was very irregular forming a kind of corrugation, which in some instances could leave too much of an air gap between the tip of the spark plug electrode and the tin foil. To obviate this some sponge rubber was placed underneath the 3 ply fabric to give a smooth surface and so provide a more constant spark gap.

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No more misfires due to the above mentioned cause were experienced, but the rubber was not completely consumed, and was left as debris, though not enough to cause any trouble with the breech mechanism. In all several hundred rounds were fired with this assembly.

The use of sponge rubber has now been abandoned in favour of a band of sheet cordite, which works equally well electrically, and of course is totally consumed.

5. THE HIGH TENSION UNIT

The Plessey Co. Ltd., were given a small contract to develop a suitable ignition unit. The specification required a high frequency low energy unit with an output of 10 kV, and capable of maintaining a spark over a gap of 0.1 inch in air, even when the insulation of the spark plug had dropped to 10^4 ohms due to accumulation of dirt or moisture on its surface.

A "mock-up" unit to this specification was produced, and successfully fired the c.c. cap as initiator.

When a rocket puffer (fuse F53) was considered as an alternative initiator to reduce the electrical hazards, it was obvious that the low energy unit could not be used, as this fuse requires about 100 times more energy to fire it.

Fortunately Plessey had developed a high energy high tension unit for the R.A.F. to be used as a jet-engine starter. This has an output of about 10 kV, and a peak current of about 80 Amperes, and seemed to meet the requirement admirably. One of these units was obtained, and it has now successfully fired hundreds of both c.c. caps and fuses F53.

Modifications to the 120 mm gun and mounting for incorporating the whole system, including spark plug, H.T. unit, etc. are being worked out in detail by the Gun Design Branch.

6. ELECTRICAL HAZARDS

6.1 Electrostatic hazard

This hazard arises from the possible electrification of the propellant charge in handling, and the conditions ensuing when it is earthed, say by contact to the gun on loading. The silk bag and the necessary dry storage conditions are both conducive to electrification, and the tin foil bands of the ignition system constitute capacitance plates capable of storing sufficient energy (as will be shown below) to fire the sensitive conducting cap initiator.

Firstly consider the conditions of normal firing in a gun; the electrical circuit may be represented as shown in Fig. 2. Although the actual mechanism of firing the initiator may be through the direct passage of the intermittent high frequency current from the induction coil, in the present context we are concerned with the energy available in a single spark. Thus we have the initiator linking the two condensers C_1 and C_2 formed by the bands of tin foil with the gun wall as a common earth electrode.

The capacity per unit length of the foil may be estimated from the formula $C = K/2 \log_e b/a$ for coaxial cylinders of radii b and a with dielectric constant K . With representative values of b and a , capacities of the order of 60 pF were calculated for $K = 1$, but this would be on the low side as the dielectric is partly air and partly fabric.

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With the propellant charge in the gun a single spark from the induction coil charges capacitance C_1 to a voltage V and energy $C_1 V^2/2$. This charge is immediately shared with C_2 , and if $C_1 = C_2$ the common voltage will be $V/2$; the energy remaining stored in the two condensers is $\frac{1}{2} C (\frac{V^2}{4} + \frac{V^2}{4}) = CV^2/4$. The loss of $CV^2/4$ has been dissipated in the finite resistance of the connecting leads viz. mainly in the initiator. The induction coil is capable of providing 10 kV, and this single charge-and-share mechanism then yields 1500 μJ , whereas the conducting cap only requires 250 μJ for 100% operation.

A somewhat similar mechanism may be postulated for the hazards arising with an electrified charge, and it is for consideration whether with the voltages developed, the energies are sufficient to fire the initiator. It has been shown experimentally by Sumner at Waltham Abbey⁽¹⁾ that foil voltages up to 2 kV may be obtained by handling the charge, and in extreme cases (using rubber gloves) up to 4 kV. Here it is assumed that the hazard will arise when the electrified charge is loaded into the gun. Thus when the bag of propellant is brought into contact with the gun, local spark over may occur from one foil, or from the bag in its vicinity, and the foils previously at the same potential now acquire different values. We may postulate immediate sharing of the charge on the foils, or a complete and instantaneous discharge of the other foil to the same spot via the initiator. The latter is the more severe, and practically the whole energy residing on the second foil (viz. $CV^2/2$) is available for firing the initiator; when $C = 60$ pF and $V = 2$ kV the energy is 120 μJ , and if $V = 4$ kV it is 480 μJ . Since the threshold energy to fire a conducting cap is 60 μJ the hazard must be regarded as a real one.

Of course we might have said that the mechanism after sparking of one foil was a sharing of charge, as we did for the postulated mechanism in the gun, but the two outlooks are different; in one the initiator is to be fired so the weaker mechanism is taken; and in the other the initiator is not to be fired and we consider the worst possibility.

6.2 Radio hazard

The Ordnance Board was asked to investigate the electrical/explosive hazards to bag charges fired by electro-static ignition. The Board arranged a radio-hazard trial, and called on D.S.R.D.E. for facilities and assistance to carry it out.

Six dummy charges were prepared and the trial was carried out at Christchurch. The following is a quotation from the Board's report⁽²⁾ "Using a transmitter of variable power output, operating on a frequency of 84 Mc/s it proved possible to fire one charge at 5 ft. from the aerial when the transmitter output was (nominally) 500 Watts and another at 4 ft. when the output was (nominally) 325 Watts. Four more charges were fired at distance between 3 and 5 ft. (inclusive) using higher power levels. In all, six charges out of six were fired, including two which had been fitted with by-pass capacitors across the c.c. cap.

These results suggest that this type of charge may quite easily be fired at 3 ft from the aerial of a C42 transmitter, and that an occasional charge may fire at rather greater ranges".

A more comprehensive trial detailed in an appendix to this report was proposed, but was never carried out.

A means of reducing the hazard is to bring the two foil bands near to one another, which will shorten the connecting leads and so considerably shorten the effective aerial, thus greatly reducing the pick-up signal.

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In order to test the relative merits of the charge designs, two models were made, one to the old design, and one to new, more compact design. These are shown diagrammatically in Fig. 12(A) & (B). The bands were placed around cardboard tubes as shown, and the c.c. cap was replaced by a deaf-aid earphone shunted by a small crystal diode rectifier. The earphones were chosen so that their resistance (60 ohms) was somewhere within the range of that of c.c. caps (20-200 ohms).

A modulated signal was transmitted from a small "Walkie-Talkie" transmitter which had an output of 5 Watts at 70 Mc/s. Listening to the sound in a stethoscope attached to the earphones, and moving away from the transmitter until the sound died out, gave a rough qualitative method of assessing the sensitivity of the two designs.

It was found that with the old design one had to move a distance of about 20 ft. from the transmitter before the sound died away, but with the more compact design it was only 2 ft. Thus the ratio in distance was about 10:1, which meant that the ratio in the power induced was 100:1.

At this stage it was decided that if a less sensitive initiator could be used, the hazard would be greatly reduced, if not totally eliminated.

6.3 Use of Fuse F53

As rocket puffers (fuse F53) are cheap, plentiful and readily available, it was decided to try these as initiators instead of the c.c. caps. They require an energy of 6 to 7 mJ to fire.

When using a c.c. cap as initiator it is only necessary for part of the discharge current to pass through it, and it will fire when the thickness of cloth between the two foils and the barrel is the same, in which case return sparks would occur from both bands.

In the case of a rocket puffer however it is essential that most of the current passes through it, and to ensure this, an extra layer of silk cloth is placed on the inside of the bag, over the striking band, to discourage sparking back to earth in this region, and the earthing band is placed on the outside of the bag. The charge design is shown in Fig. 13.

About one hundred rounds have been successfully fired with this fuse as initiator, the firing interval varying between 35 and 50 milliseconds.

As the results looked so promising, the O.B. was again approached to investigate the electrical hazards of the charge using this initiator.

At a meeting held between representatives of the O.B. and A.R.D.E., it was considered that a static electrical hazard was very unlikely, unless voltages of 25 to 30 kV were involved, and to confirm this it was decided that a trial should be carried out in A.R.D.E., Woolwich to confirm this view point.

For this test a dummy igniter assembly on the lines shown in Fig. 12(A) was used, where the earphone was replaced by the puffer. The assembly was placed on an insulating (distrene) sheet and charged from a high voltage test set with an adjustable output of 0 to 30 kV, by touching the end of the output lead to either of the bands, the lead being held by means of a long polythene rod as insulator. The discharging of the assembly was done by bringing an earth lead up to one or other of the foil bands, simulating the sudden earthing to a gun breech of an electric charge produced by handling. No fuses fired at any voltage up to the limit of the apparatus (30 kV).

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The experiment was repeated with a ball terminating the end of the lead to reduce sparking on approach to the foil bands. No fuses fired.

A metal plate was placed on top of the insulating sheet, and attached to one foil band. The assembly was then charged and discharged through the other foil band. An additional capacity calculated from the dimensions of the plate as 60 pF was thereby introduced. Again no fuses fired.

The results obtained have proved that there is no hazard from static electricity with this charge.

It is anticipated that the radio hazard will be greatly reduced by the use of this fuse instead of the c.c. cap, and the introduction of a small spark gap in series with the fuse (not shown in Fig. 13) should greatly reduce, if not completely eliminate, the radio hazard.

A spark gap which gave good and reliable performance in the laboratory was one which flashed over at about 2 kV. The gap was sealed in a glass envelope in an atmosphere of mercury vapour. Small spark gaps of this type could be easily and cheaply manufactured, and appear to be much more reliable than a plain air gap.

The O.B. has approached the Wayne-Kerr Laboratories to investigate the radio hazard of various charge assemblies, for which purpose, dummy charges of the types shown in Fig. 12(A) & (B) have been made up, in which the ear-phone is replaced by fuse F53. Three charges of each type have been made up as follows:-

- (1) With fuse F53 only.
- (2) " " " + an air gap shunted by 10 megohms, in series with the fuse.
- (3) With fuse F53 + a gap in a sealed glass envelope containing mercury vapour, placed in series with the fuse.

These have been sent to The Wayne-Kerr Laboratories, for testing.

7. PRESENT POSITION

The general feasibility of the scheme has been well established.

A completely satisfactory spark plug has not yet been designed, but there seems no fundamental reason why this should not be done. The last designs tested have been almost good enough. They have failed mechanically by cracking or erosion of the insulation after firing many rounds. Electrically they have behaved well, in that the loss of insulation due to deposits of carbon etc. as a result of firing has been stabilised at a level at which proper functioning is maintained.

A charge design has been developed which is free from electro-static hazards, and is also believed to be free from radio hazards, but this remains to be proved by tests which have been put in hand.

A suitable high energy high tension unit is available from trade.

8. REFERENCES

1. J. F. Sumner WAE/5/04
2. A. J. Dawson O.B. Report TTB/216/011

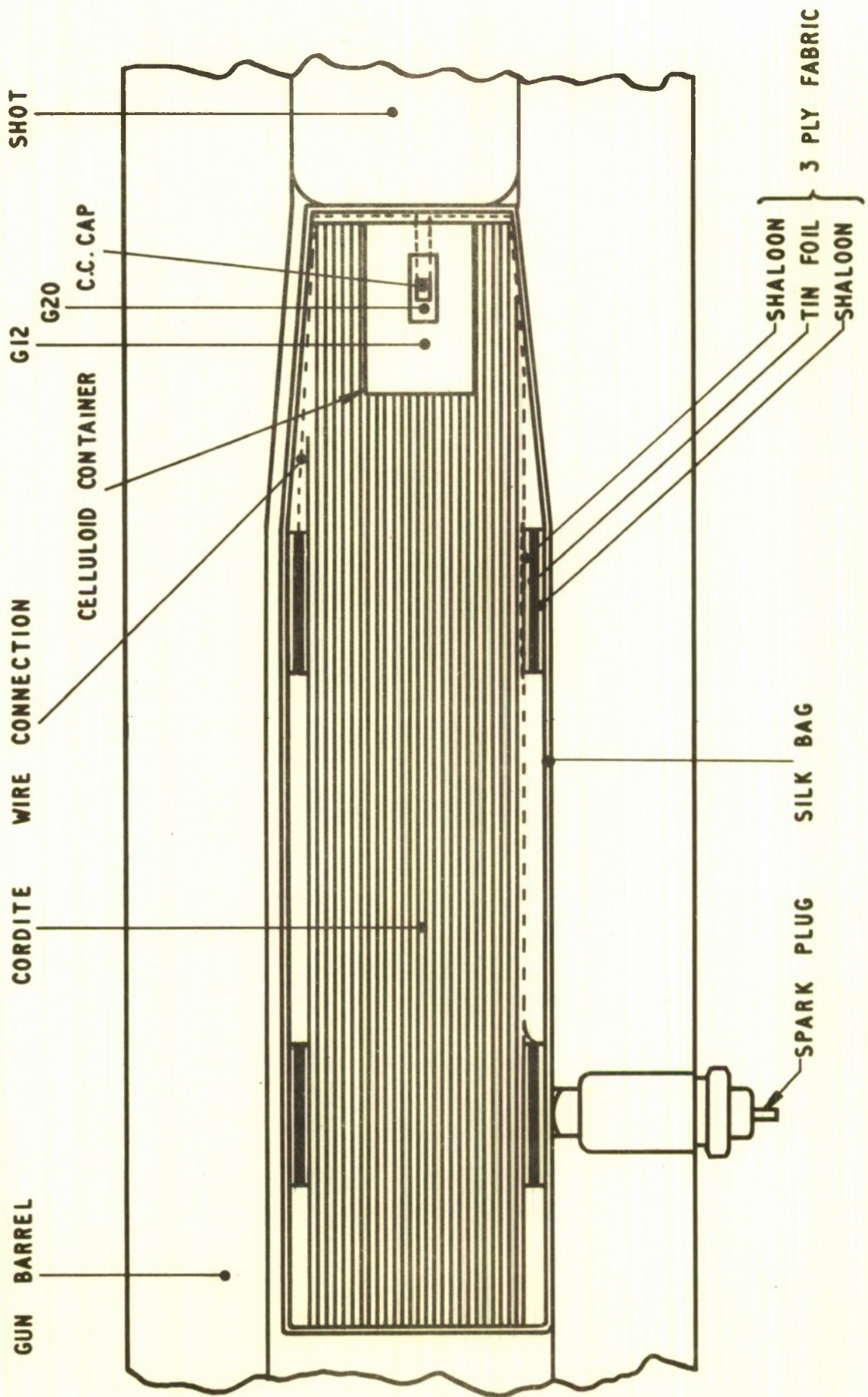


FIG. 1 SPARK INDUCTION BAG CHARGE

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FIG. 2

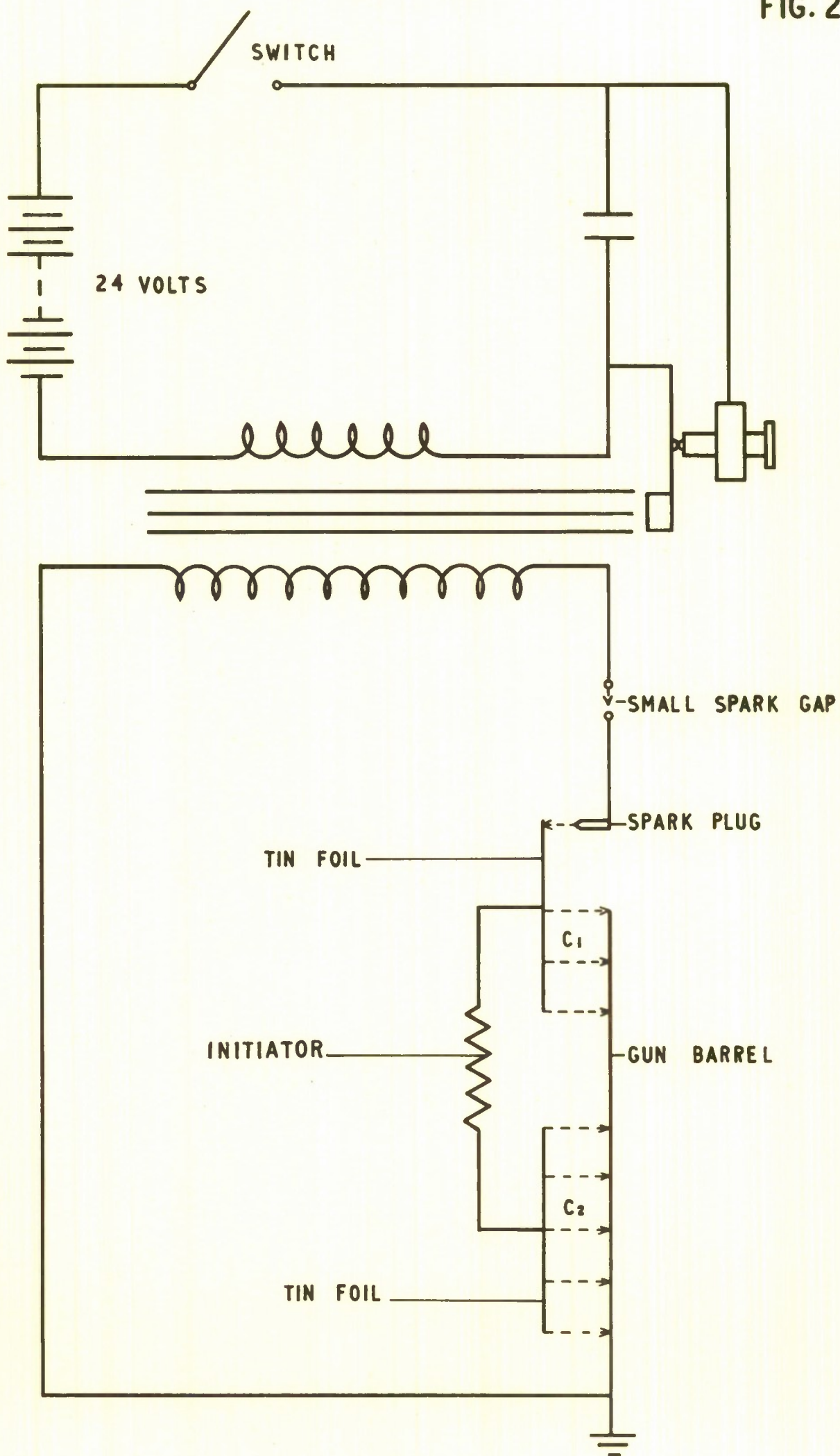


FIG. 2 ELECTRICAL CIRCUIT

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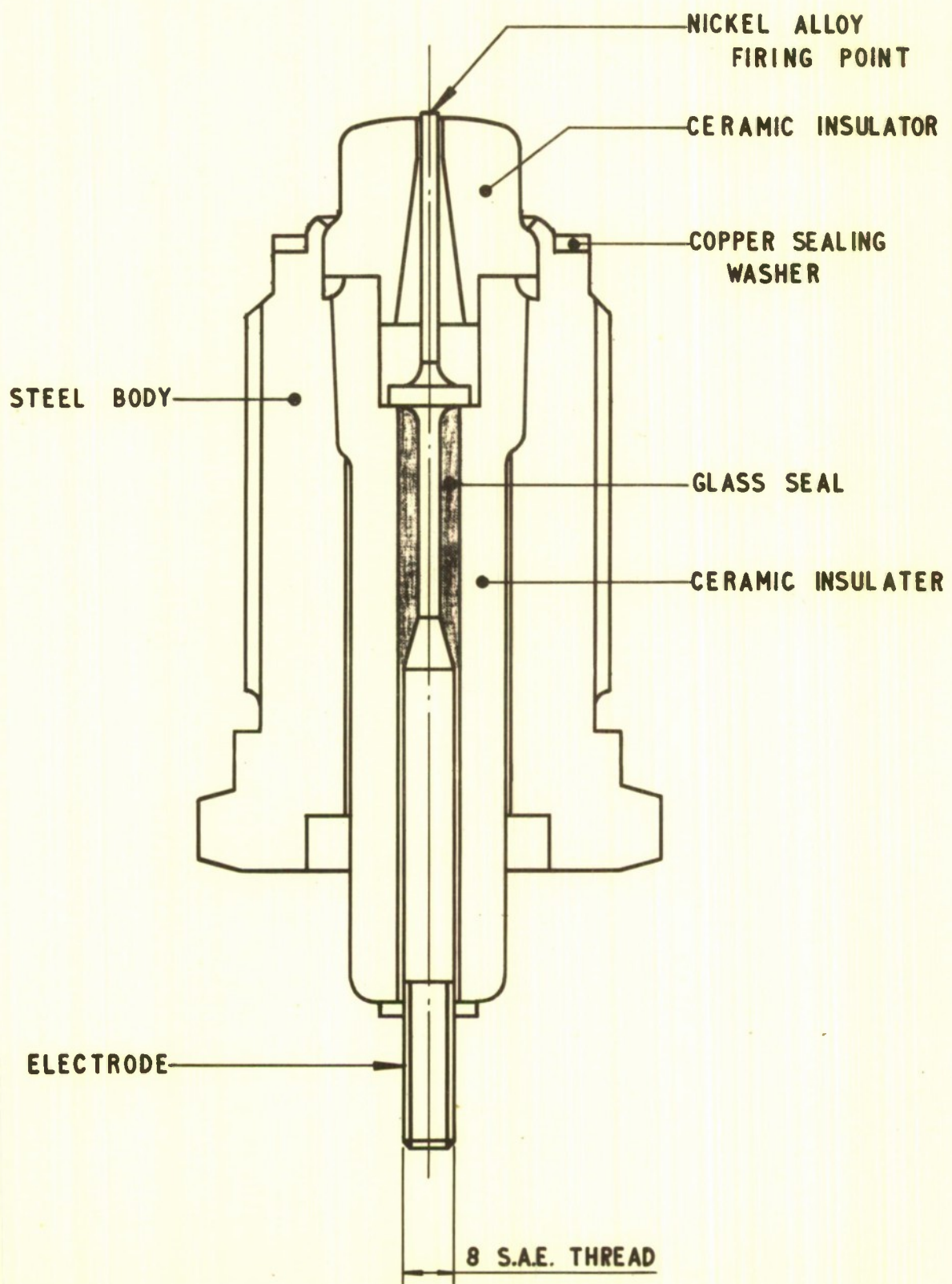


FIG.3 K.L.G. EARLY DESIGN

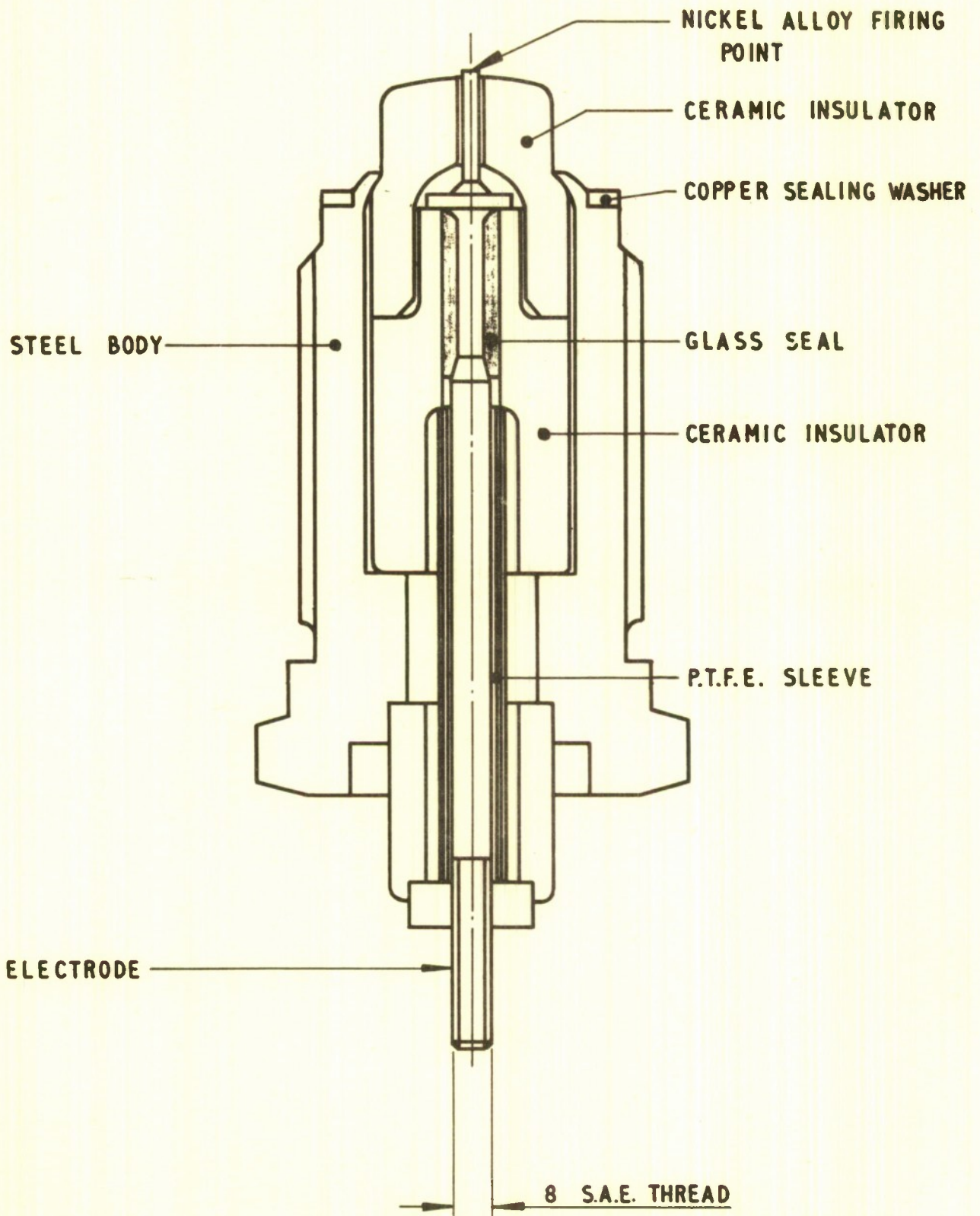


FIG.4 K.L.G. EARLY DESIGN

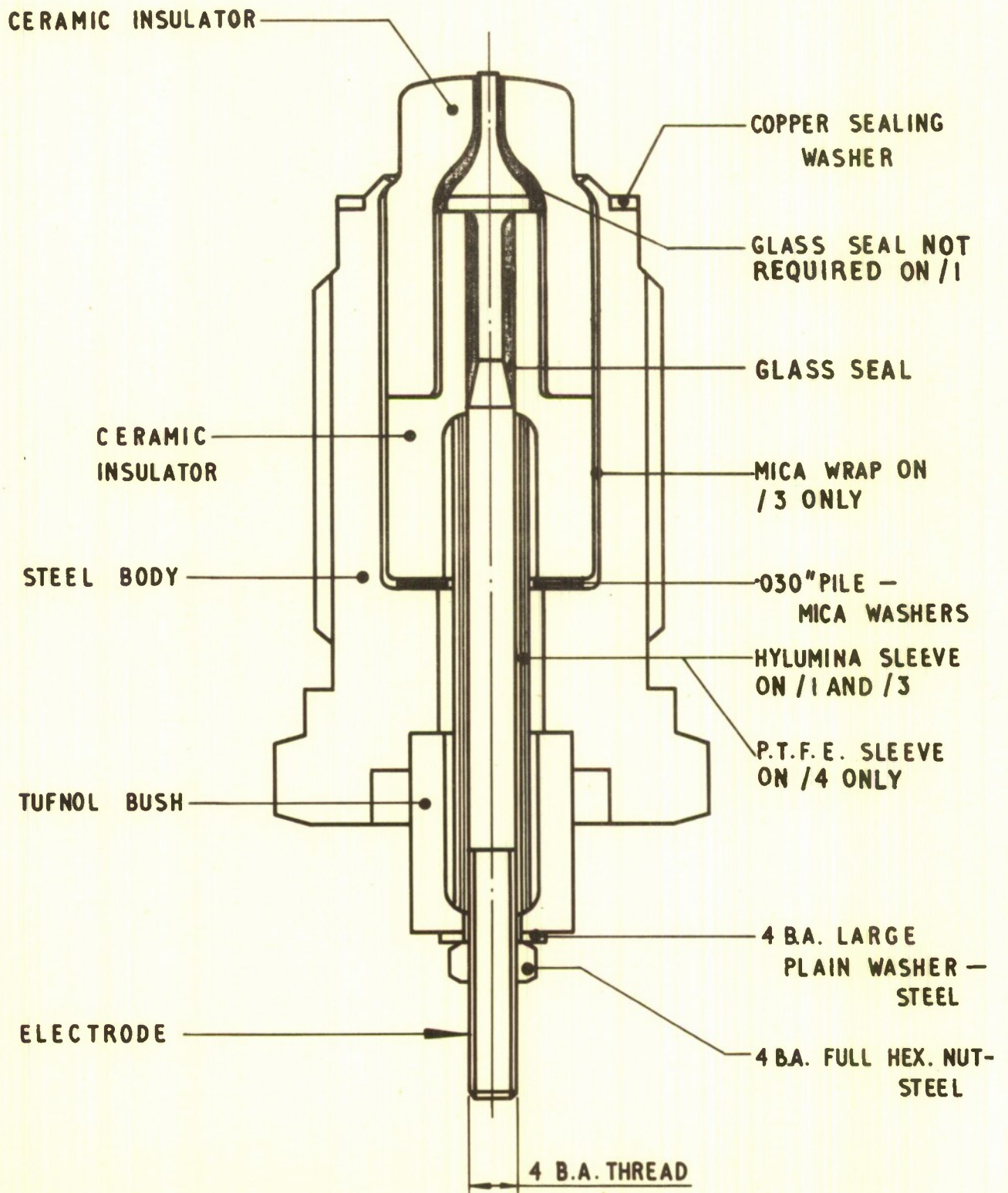


FIG.5 K.L.G. TYPES Z 221 /

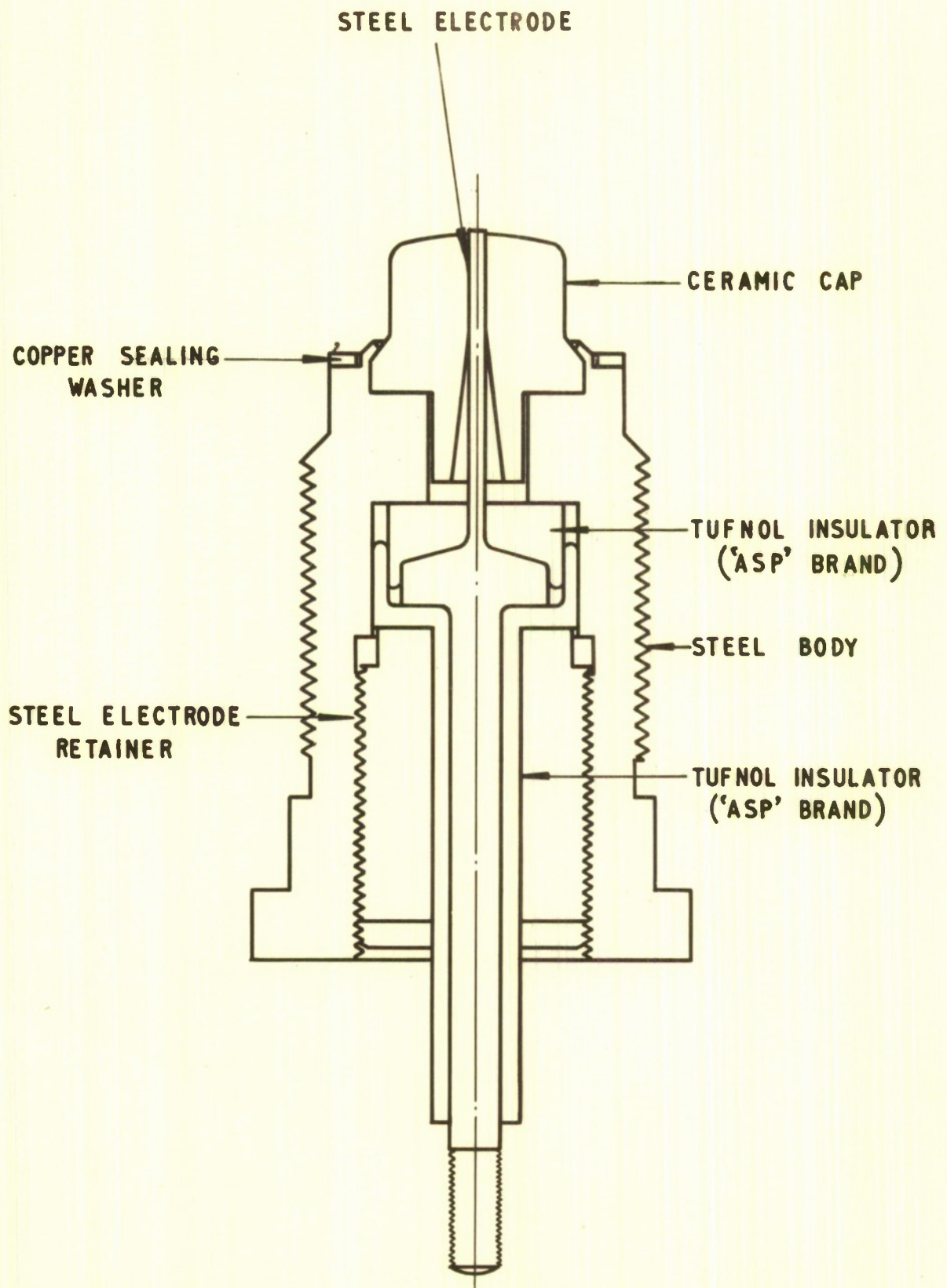


FIG. 6 A.R.D.E. DESIGN (SALVAGED CERAMIC CAP)

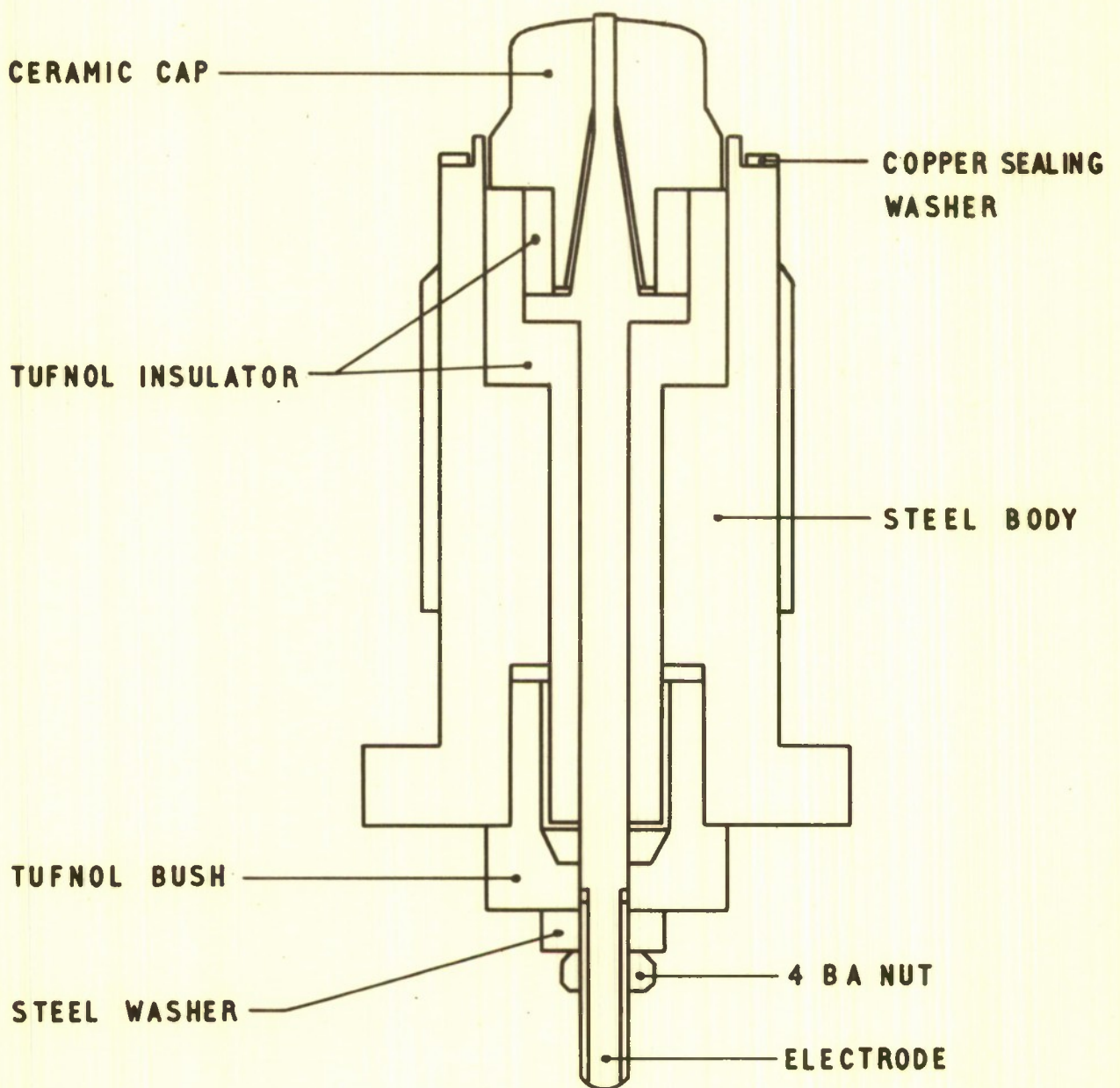


FIG. 7 A.R.D.E. MODIFIED DESIGN (SALVAGED CERAMIC CAP)

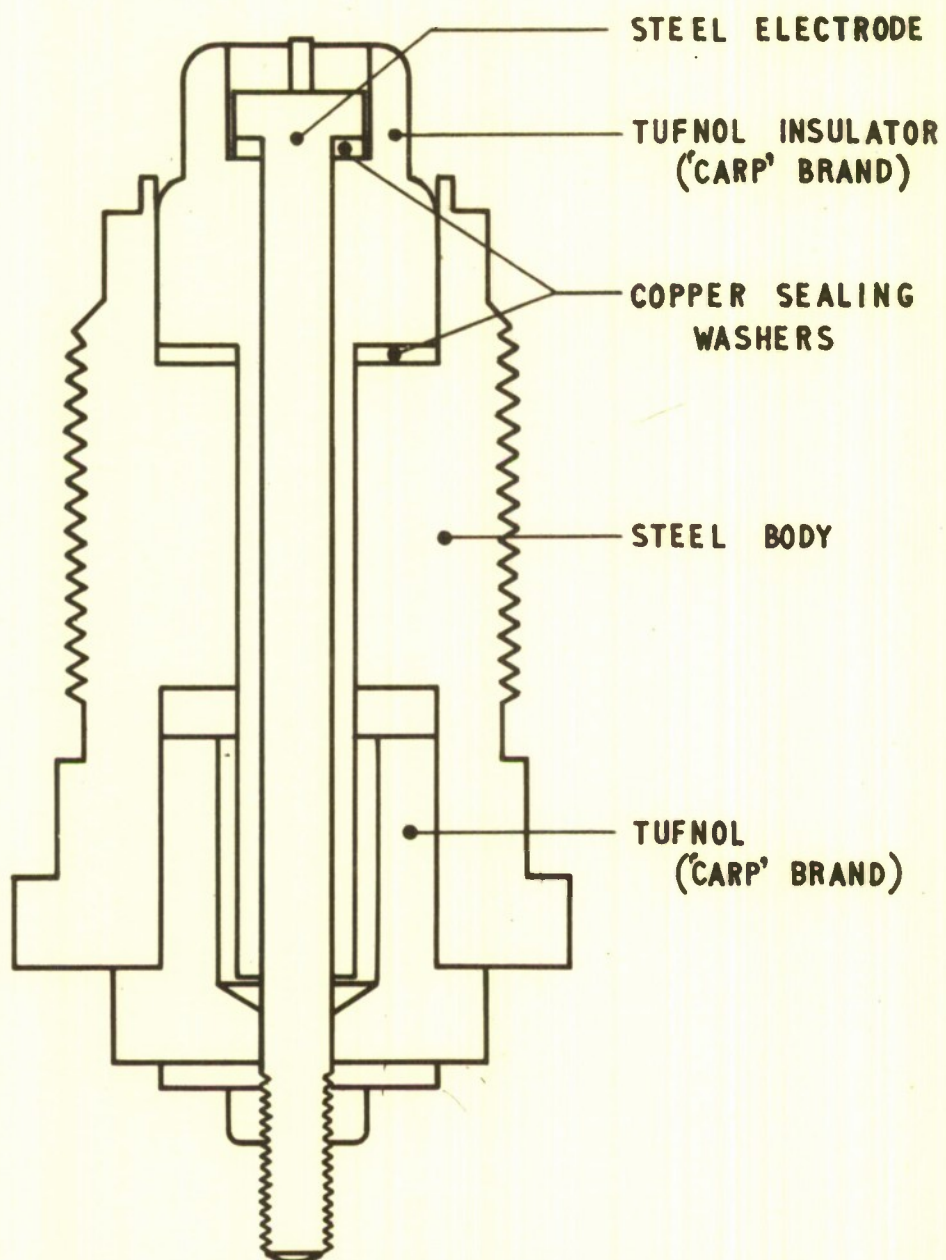


FIG.8 A.R.D.E. DESIGN TUFNOL INSULATION

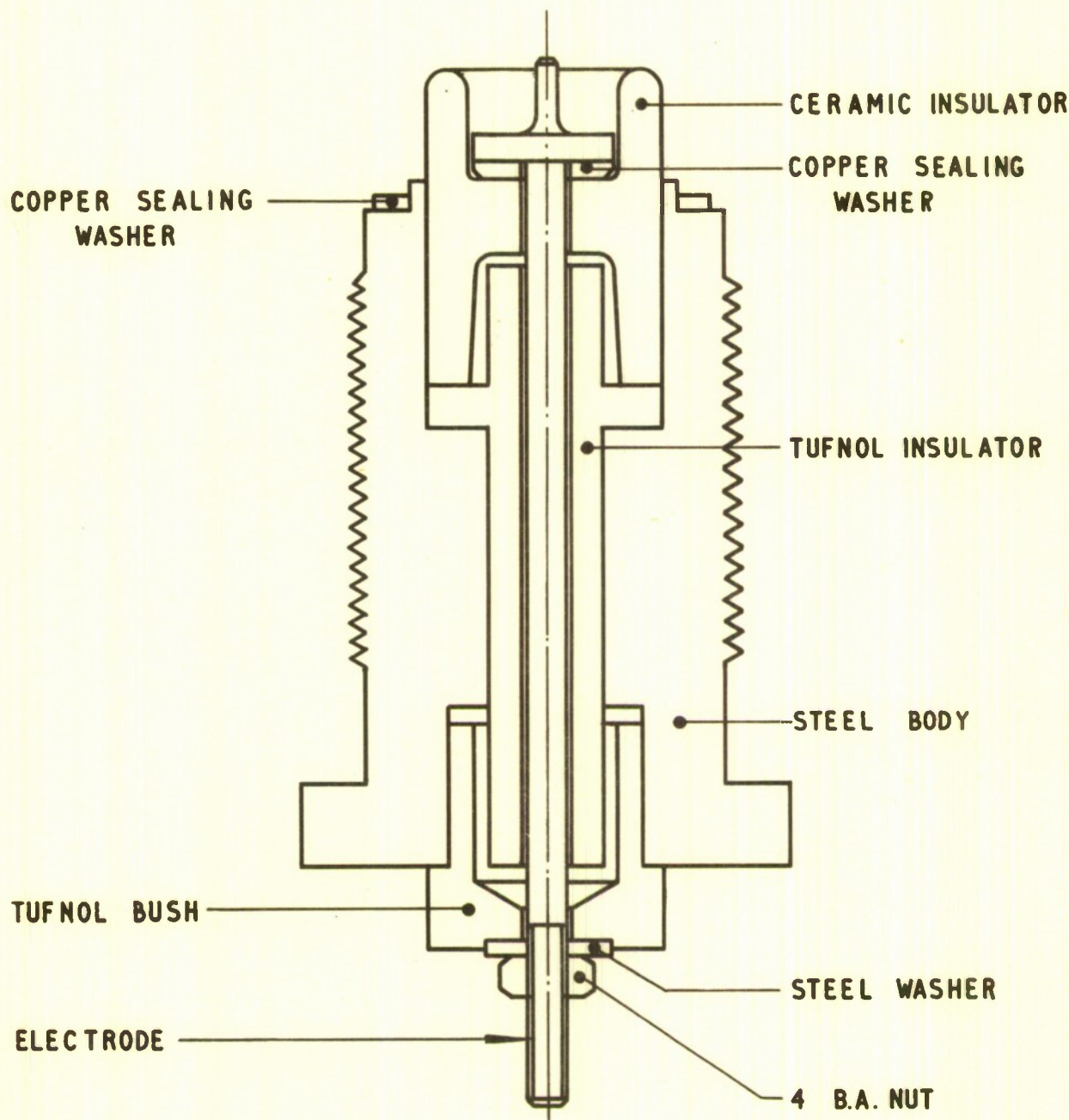


FIG. 9 K.L.G. TYPE Z221/5 (ARDE. DESIGN)

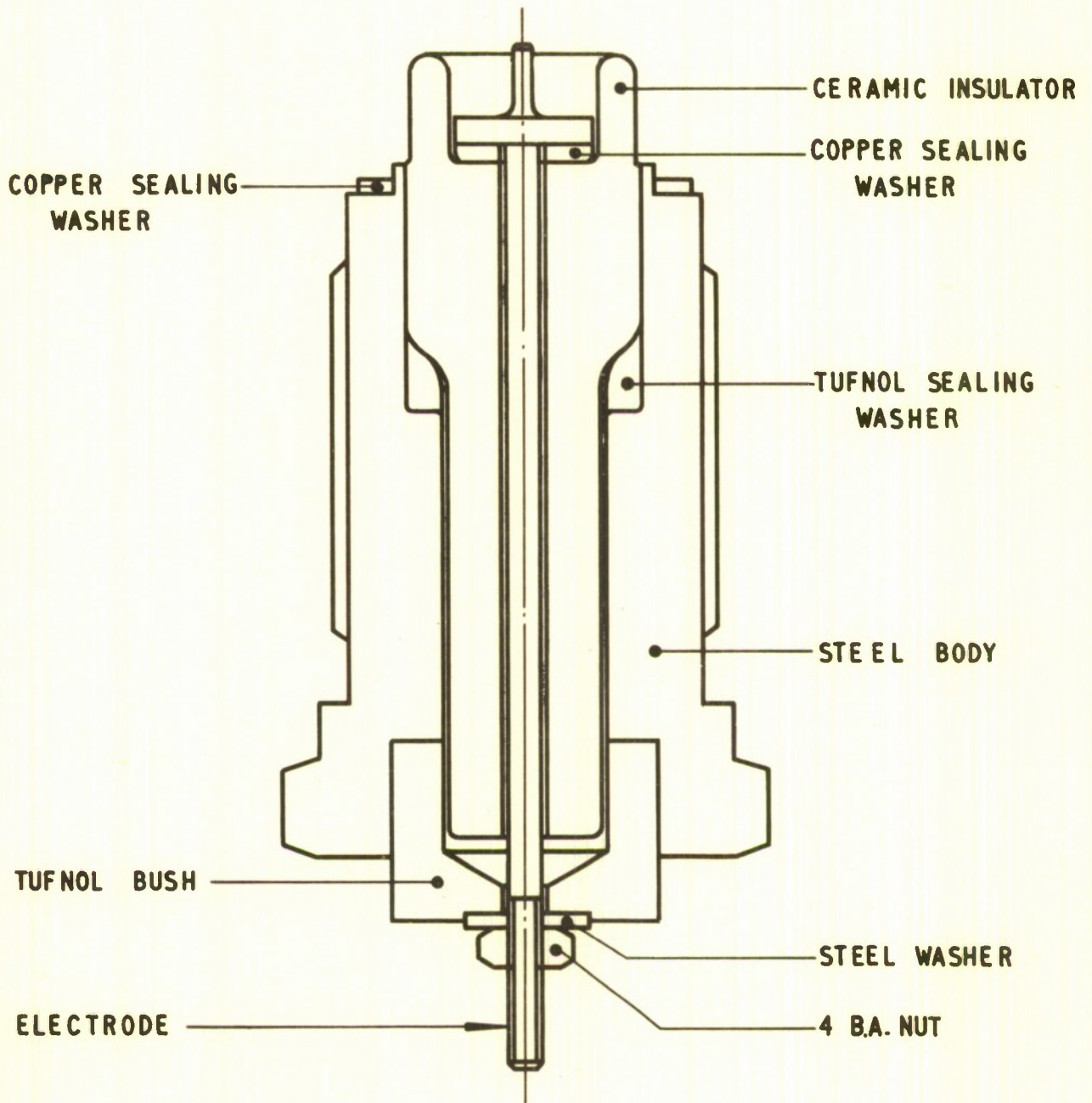


FIG.10 K.L.G. TYPE Z 221/6

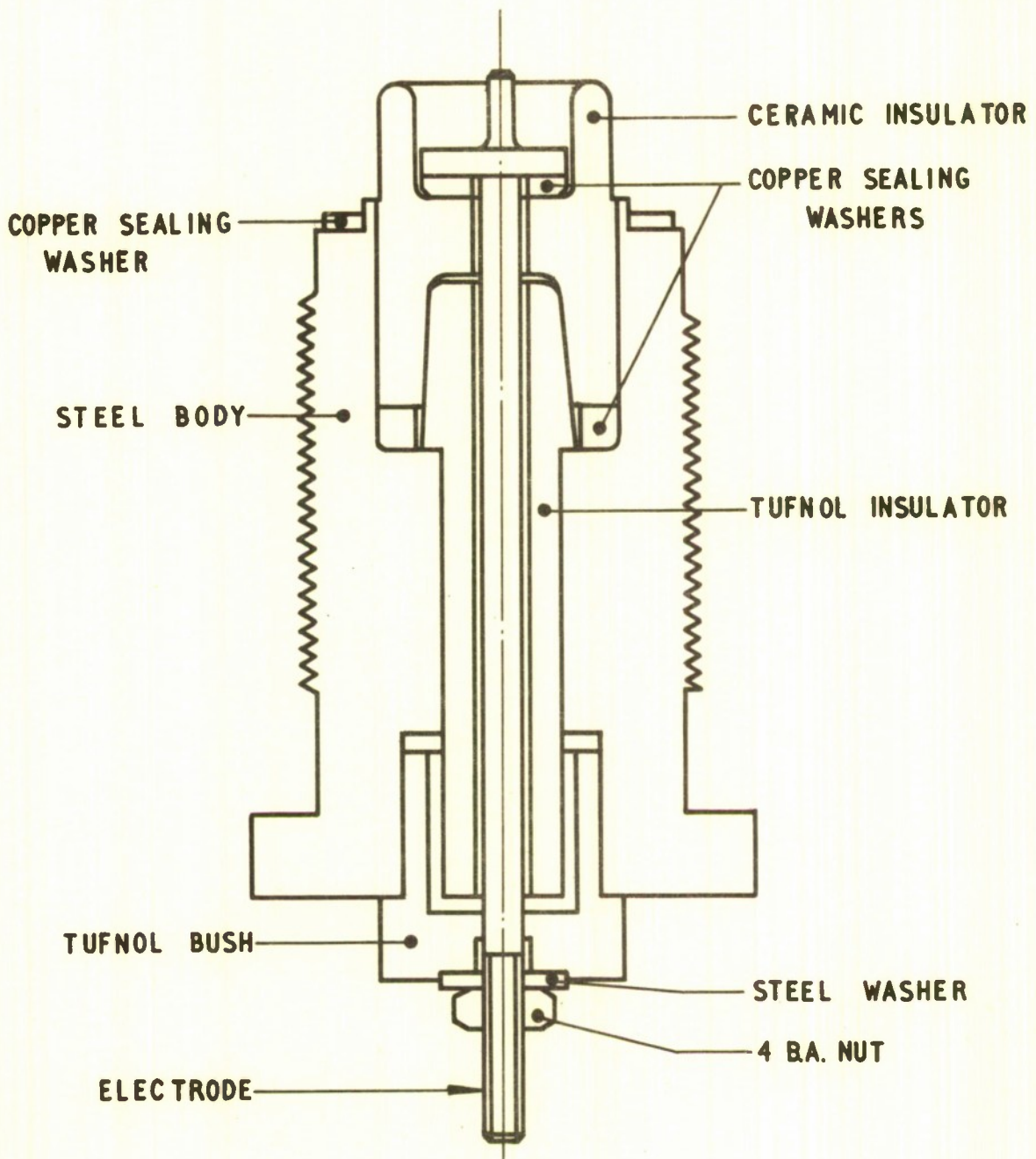


FIG. II K.L.G. TYPE Z 221/5 MODIFIED (AR.D.E. DESIGN)

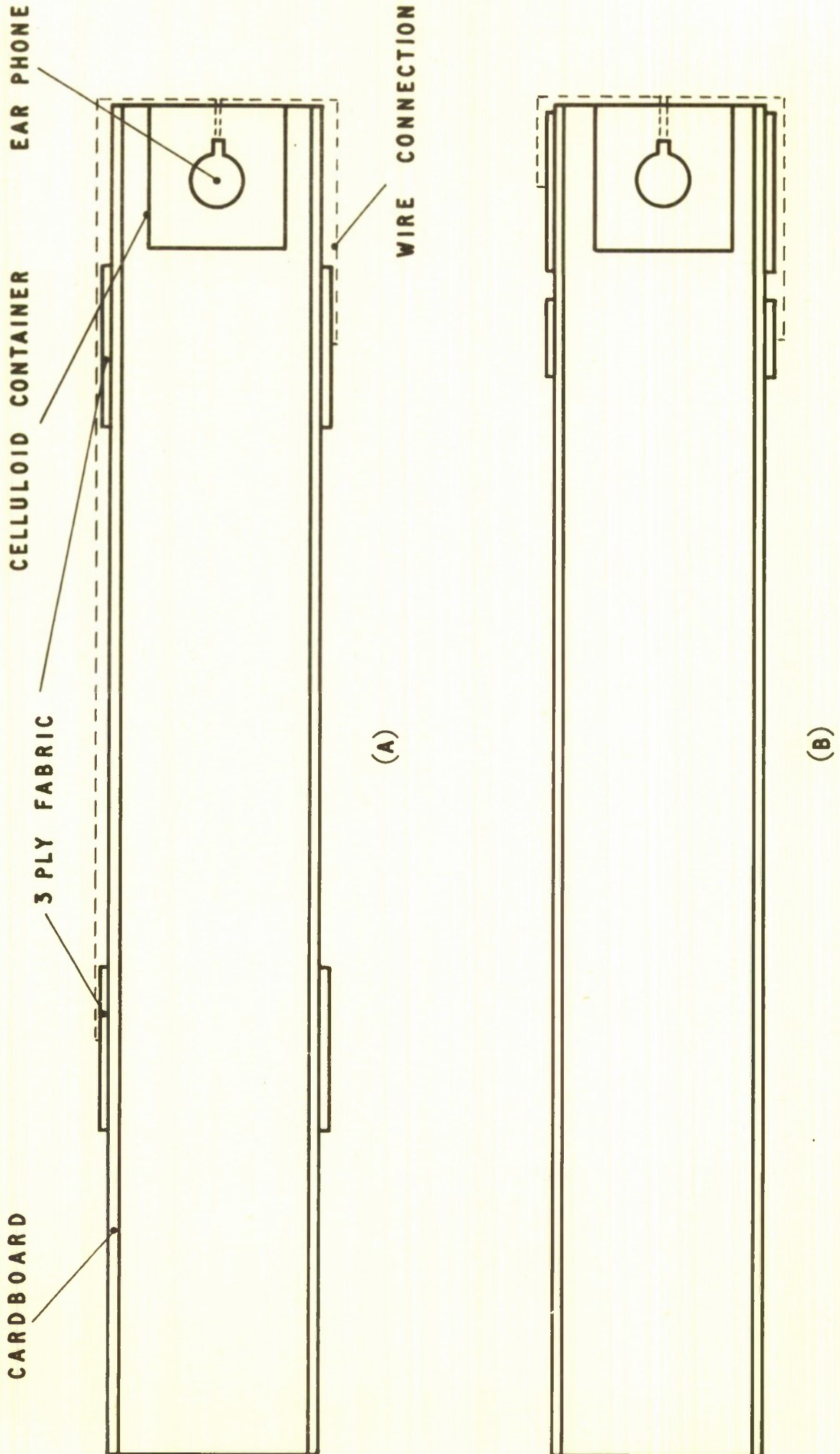


FIG.12 A AND B DUMMY CHARGES

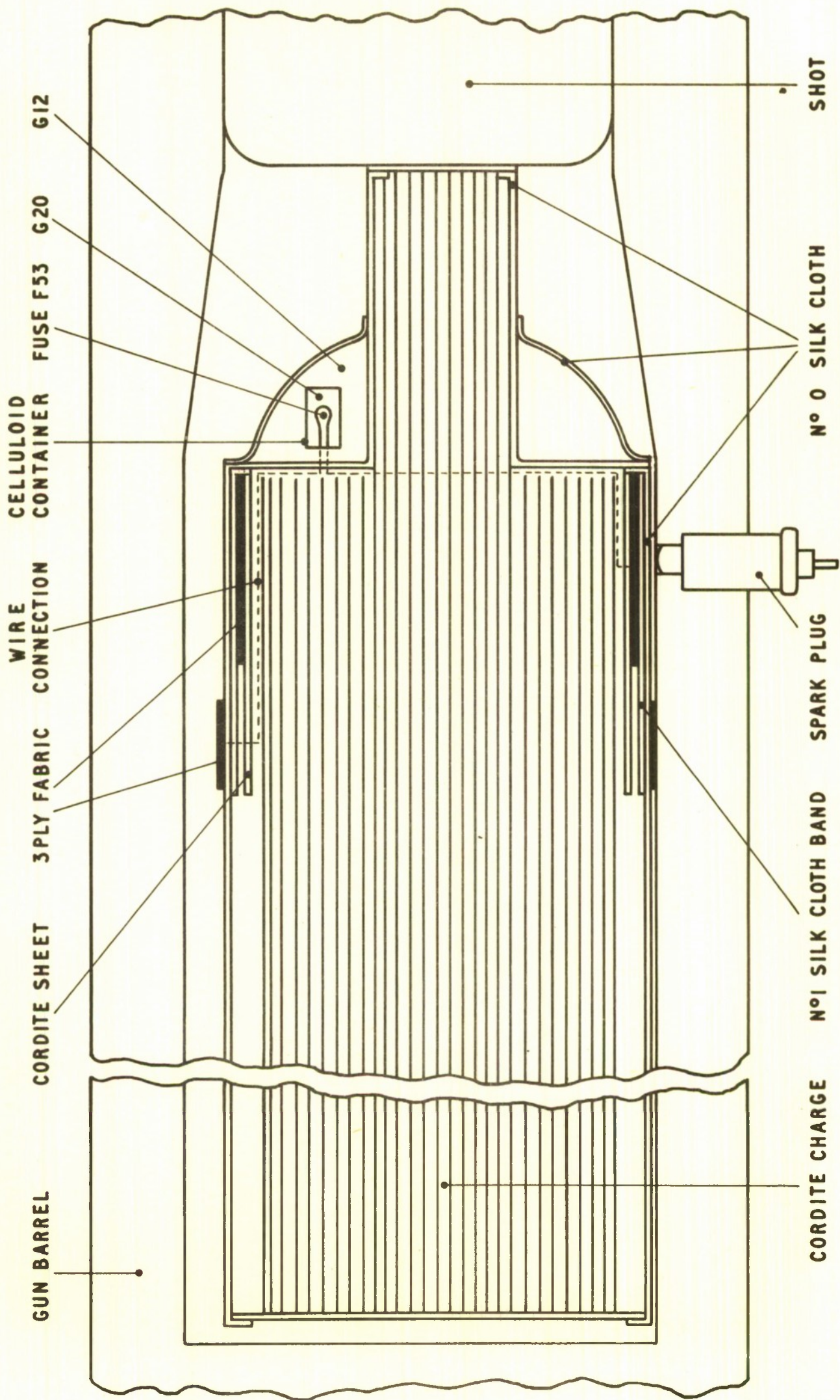


FIG.13 CHARGE DESIGN

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623.454.214-83:
623.412.6'120mm'

Development of a spark induction method of ignition
for the 120mm Tk. Gun X23.
First progress report.
J.R.Price.

December 1960

A novel method of electrical initiation of a gun charge by spark induction is described. Development work on its application to the 120mm Tk. gun X23 is reported. The main problems have been the mechanical design of the spark plug, and the electrical hazards - static and radio - inherent in the charge design; these have been largely overcome.

8pp. 13 figs. 2 refs.

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Covering dates 1960
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