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JET PROPULSION LABORATORY

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DESIGN AND FABRICATION

OF

FOUR PIN HIGH PRESSURE SQUIB

THIRD QUARTERLY REPORT

PREPARED UNDER CALIFORNIA INSTITUTE OF TECHNOLOGY
CONTRACT #951912

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DATE: July 8, 1968

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ABSTRACT

This report covers work performed by the Atlas Chemical Industries in developing, providing design and production drawings for, and manufacturing an initial developmental production quantity of squibs to withstand the extremes of thermal shock and other rigid environmental requirements of deep space probe vehicles.

The squib must be capable of withstanding heat sterilization of 293°F for 324 hours. It must be capable of functioning at any temperature from -200°F to +300°F, and must be suitable for exposures of up to one year at any temperature from -400°F to +250°F. In addition, the squib must withstand pressures of up to 30,000 psi without seal failure and must be capable of functioning normally after repeated discharges of 25 kv from a 500 picofarad capacitor. The squib will be a 1 amp, 1 watt no-fire, dual circuit squib, whose output and initiation characteristics will be as uniform as is possible within the current limitations of the state-of-the-art.

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INTRODUCTION

The objective of this program is to develop a squib suitable for use in deep space problems. This report is the third quarterly report under Contract #951912 with the Jet Propulsion Laboratory.

Reports one and two covered basic development work on the explosives, header design, end closure design, etc., but included very little studies on the squib itself. Some prototypes were assembled for individual tests but the overall design was not tested. This report includes some of the continuing investigations on the particular aspects of the design as mentioned, but also covers the complete squib in the prototype stage through the production version, and includes all of the production problems encountered at various stages.

During this phase of the program, the Glass-to-Metal and Ceramic Seal were thoroughly proofed and the design was shown to be basically sound. The nuisance problems were eliminated and the sealing process was finalized.

Static discharge tests indicated some severe faults in the ceramic design which required compensation in other areas to correct. Since all hardware had been received, compensation in this case amounted to different loading procedures which caused the functioning times of the squibs to be longer than originally anticipated. The basic cause of the problem

is understood and corrective action for future hardware will eliminate the problem. This area will be discussed later.

Our work to date indicates that more investigation into the static insensitive first ignition mix is necessary - particularly in the areas of increasing the burning rate while maintaining the insensitivity to static. The Boron/Potassium Perchlorate/Barium Nitrate Mix which has shown to be ideal from a static insensitivity viewpoint, has a comparatively slow burning rate versus, for example, Zirconium/Potassium Perchlorate or some of the other violent metal oxidant blends now commonly used. The height of the first ignition charge, therefore, greatly affects the function time of the squib. Again, this will be discussed in the technical section.

The electron-beam weld at first presented problems which had not been anticipated. These too were solved and the design of the end closure is now fairly well demonstrated. There are drawbacks to this area, which can be easily corrected, but again, the availability of hardware for the program and the schedule for completion made a design change in this phase impossible at this time.

Sterilization tests were completed in this quarter and the results were satisfactory. The squib will function normally after storage at the sterilization temperature for the complete cycle.

All-fire and no-fire studies were completed. The squib will reliably withstand the 1.0 amp, 1.0 watt no-fire level and will function in less than 10 ms. at 4.5 amp.

Prototype squibs have been subjected to all of the environments as required by the contract design studies, and have functioned successfully thereafter.

We consider that all of the requirements for the evolution of this design have been successfully accomplished. The design is not optimized from a practical assembly standpoint, but this presents no real problems, since changes would consist of simple value engineering or practical modifications which do not affect the present design in any functional sense.

TECHNICAL DISCUSSION

A. Header Development

The second quarterly report detailed the cycle finally chosen for making the header seal. This consisted of first making the ceramic-pin subassembly by brazing the pins into the ceramic with a silver/palladium brazing material. This is done merely to aid in the true positioning of the pins in the final header. This braze is not hermetic and by itself will not sustain any pressure.

The ceramic subassembly is then sealed in the inconel housing with a cycle as follows, which results in a squib housing fully hardened for maximum strength and yet completely hermetically sealed for environmental protection. The method of sealing consists of running a sealing-annealing soak at 1850°F for less than one hour. This flows the glass and also anneals the inconel 718 housing as step #1 in the heat treating cycle for the inconel. The furnace is then cooled to 1400°F and maintained for three hours, which is step #2 in the hardening of the inconel. The furnace is then allowed to cool to ambient which completes the aging of the inconel.

This cycle eliminated any thermal shocks and therefore prevented any leaks from developing due to thermal mismath of the glass and inconel 718. One hundred percent (100%) hermeticity has been

achieved by this method-hermeticity which has successfully withstood the most severe thermal and mechanical shock in repeated tests as shown.

One nuisance problem which occurred in trying this cycle, was that the long temperature exposure badly oxidized the inconel 718 housing and pins. Inconel 718 is normally heat treated under a highly reducing atmosphere to prevent this oxidation-atmospheres such as dissociated ammonia or pure hydrogen. However, these atmospheres cannot be used in the sealing cycle because of the extreme danger of igniting the hydrogen at temperatures below or near its auto-ignition point (with oxygen). This happens because normal hydrogen burn-off at the furnace exit is incomplete. The hydrogen then collects and the surrounding atmosphere becomes explosive.

This problem of oxidation was solved by pre-nickel plating the header and running the seal at nearly neutral atmospheres. The pre-nickel "fires in" the header during the seal, but it does protect the surface so that it can be easily cleaned and plated after the seal. Copper would be another material suited for this purpose and could be used in place of the nickel.

Tables I through III show the results of repeated tests on the header design -- all successful.

TABLE I

Pressure tests performed on seals made in the process described previously - 1850° for less than one hour, 1400°F for three hours, and cool to ambient. The seals were completely successful.

S/N	Type of Seal	Hardness Rc	Helium Leak	N_2 Pressure	Thermal Shock	Helium Leak	N_2 Pressure	Pressurize to Destruction
3163	Individual 4-pin	37	$<10^{-8}$ cc/sec	No leak to 10,000 psi	-300°F +300°F	$<10^{-8}$ cc/sec	No leak to 10,000 psi	No leak to 85 KSI*
3164	Individual 4-pin	38	$<10^{-8}$ cc/sec	No leak to 10,000 psi	-300°F +300°F	$<10^{-8}$ cc/sec	No leak to 10,000 psi	No leak to 85 KSI
3165	Individual 4-pin	38	$<10^{-8}$ cc/sec	No leak to 10,000 psi	-300°F +300°F	$<10^{-8}$ cc/sec	No leak to 10,000 psi	No leak to 85 KSI
3166	Individual 4-pin	39	$<10^{-8}$ cc/sec	No leak to 10,000 psi	-300°F +300°F	$<10^{-8}$ cc/sec	No leak to 10,000 psi	No leak to 85 KSI

After running the pressure tests up to 85,000 psi, the units were again checked for hermeticity and found to have leak rates $<10^{-8}$cc/sec helium.

*This test is performed by restraining the squib at the hex thus putting the entire load on the glass-ceramic seal. As demonstrated in the past, the threads begin to yield at approximately 70,000 psi so that the "O" ring extrudes and makes further pressure testing impossible.

TABLE II

Because of the proximity of the pins to the inconel case in the 4-pin seal, it was felt that the insulation resistance had to be measured in all modes. Consequently, all of the units of Table I were checked for insulation resistance as shown @ 100 vdc.

Unit #	Pin A-B	Pin A-C	Pin A-D	Pin B-C	Pin B-D	Pin C-D	Shorted Pins to Case
3163	1K meg	300 meg	2K meg	1.5K meg	400 meg	300 meg	60 meg
3164	600 meg	500 meg	600 meg	5.0 meg	500 meg	400 meg	55 meg
3165	5K meg	5K meg	5K meg	3K meg	600 meg	2K meg	65 meg
3166	5K meg	2K meg	3K meg	4K meg	4K meg	4K meg	300 meg

All were well within the spec requirements of 10,000 ohms pin-to-pin and 100,000 ohms pin-to-case.

TABLE III

Same as Table I - repeated test.

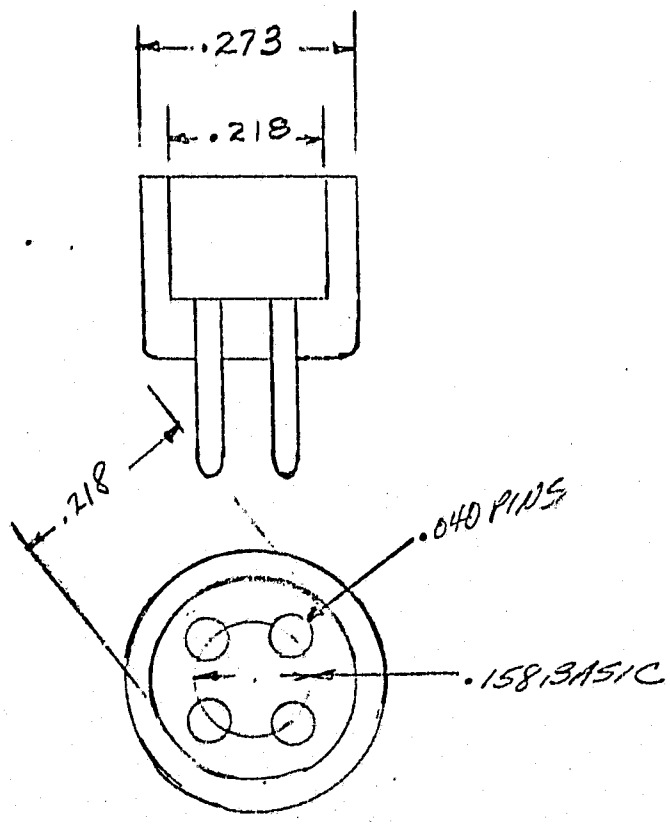
S/N	Hardness Rc	Helium Leak	N_2 Pressure	Thermal Shock	Helium Leak	N_2 Pressure	Destruction Pressure
3167	37.5	$<10^{-8}$ cc/sec	OK to 10,000 psi	-300°F +300°F	$<10^{-8}$ cc/sec	No leak to 10,000 psi	OK to 85,000 psi
3168	36.5	$<10^{-8}$ cc/sec	OK to 10,000 psi	-300°F +300°F	$<10^{-8}$ cc/sec	No leak to 10,000 psi	OK to 85,000 psi

After testing, the units were again subjected to electrical tests as in Table II with equally good results.

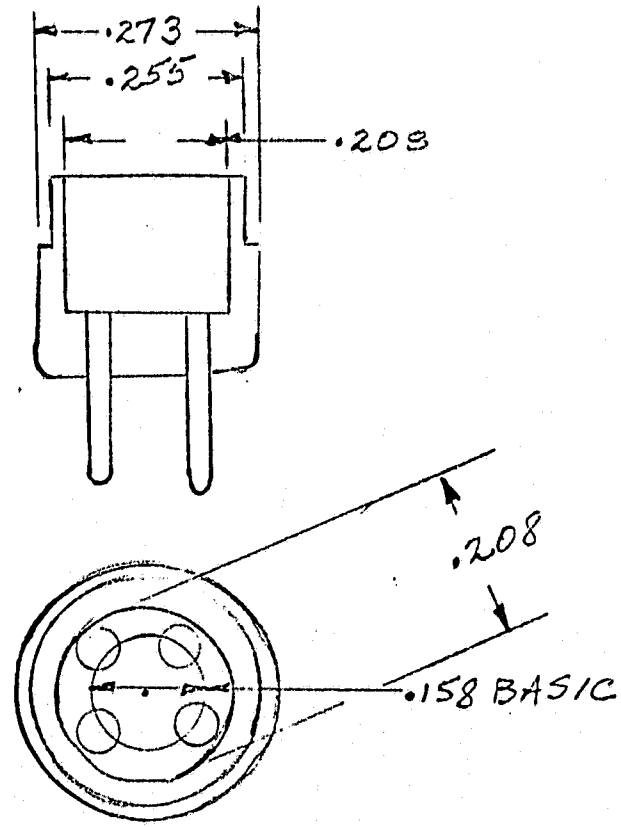
The tests of Tables I-II were run on other devices used for prototype squibs, or other development tests. In all cases, the squib header has passed all of the tabulated tests. The results are not given here because they were not formally recorded in all instances, but were used as a screening method for squibs prior to assembly.

B. Static Discharge Considerations

A total of ten prototype squibs were assembled so that the completed unit could be tested through all of the environments of the contract's design evolution requirements prior to assembling production hardware. Six out of these ten units fired upon the first discharge of 25KV, 500 $\mu\mu$fd. Since all of the earlier tests had indicated that there would be no problem in this area, there was immediate concern that some basic feature of the squib had been overlooked or misjudged, or that we had presumed upon some certain aspects of the explosive studies or static shunt studies. We, therefore, again ran separate tests in which the discharges were directed through the explosive with no shunt mix present, then again with the shunt mix present, and in all cases failed to ignite the powder. However, all of the separate tests in development were performed on ceramic subassemblies as in sketch #1 while the first prototypes were done on production hardware -- see sketch #2. There is a difference at first glance only in the I. D. of the ceramic; but this difference is a major one for the following reason:



#1



#2

The pin circle in the ceramic header is .158 basic. This results in an effective diameter around .040" pins of .198". Brazing can bring this diameter up to .210. True positioning variances can cause this effective diameter to be .214.

The I. D. of the header is only .208 nominal, and is machined after the pins are brazed in place. It is possible, therefore, to have thin slivers of the pins remaining in the ceramic bottom radius.

Our method of loading had been to press 15 milligrams of the first ignition mix over the wire. As mentioned previously, this resulting height of the mix is critical because of the slow burning rate of this material. The height of the 15 mg charge was $\cong$ .015", leaving the points of the machined pins exposed. That portion of the total energy which is not completely shunted by the shunt mix goes directly through the more sensitive second ignition mix which in this case is Titanium/Potassium Perchlorate. In fact, the pins become perfect point discharges because of the geometric shape resulting from machining a .208 diameter into the pins whose edges are on a possible .214 diameter.

This problem was corrected by increasing the height of the first ignition column to $\cong$ .050". The pins were therefore covered, but the functioning times of the squibs increased from approximately 2 ms to 5-7 ms. The pressure rise time is not affected so that the performance of the squib is not adversely affected with the exception of this slight lag in time from application of current to the first indication of squib function.

C. Squib Assembly

The final squib design is as shown in figure I. The sequence of assembly is as.follows:

1. The inconel housing (item 1) is impression stamped on the hex prior to sealing.

2. The housing is then preplated with nickel.

3. The inconel pins are brazed into the ceramic header (item 2) as a separate assembly and the I. D. is diamond point ground to the proper configuration.

4. This assembly is also pre-nickel plated.

5. The ceramic sub-assembly is then sealed into the housing under the conditions as described in the sealing cycle.

6. The header assembly is cleaned and gold-plated after sealing.

7. An epoxy sealant (item 3) is applied around the ceramic-housing interface to allow for dimensional difference in both of these assemblies which could leav a gap around the ceramic O. D.

8. The RTV/SiC static shunt mix (item 4) is applied in the cavity behind the pins. This completes the header assembly.

9. The bridgewire is welded to the pins.

10. The first charge of Boron/$KCLO_4$/$Ba(No_3)_2$ (item 5) is pressed over the wire @ 20,000 psi.

11. The second charge of Titanium/Potassium Perchlorate (item 6) is pressed over the Boron Mix @ 20,000 psi to fill the ceramic cavity.

12. An insulating disc (item 7) is placed over the ignition charge.

13. A steel ferrule (item 8) is force fit into the housing and firmly restrains the insulating disc.

14. Any further base charges (item 9) can be loaded into the ferrule.

15. The burst disc (item 10) is welded to the retaining ring (item 11) as a sub-assembly and this sub-assembly is placed over the ferrule-score mark out.

16. An electron-beam weld closes the squib at the O. D. of the retaining ring to make the hermetic closure.

Several problems have arisen in both the assembly techniques and the design of the hardware. The first was mentioned previously and is the inner diameter of the ceramic which causes the pins to protrude up to .025" above the ceramic bottom face. This diameter could not be machined any larger on the existing hardware because the web thickness at the top of the ceramic would become too thin. This forced a trade off in this area to increase the first ignition height to cover the pins. The trade off was continued insensitivity to static for an increase in the squib functioning time.

Problem #2 is the extreme difficulty in making good welds to the inconel pins which will remain integral and not cause a resistance change throughout the gamut of temperature cycling and shock. One way to compensate for this is to solder over the weld. This was unsuccessfully attempted on the second production lot of squibs because the high thermal conductivity of the 98% + aluminum ceramic drained heat away from the pins so rapidly, it was impossible to make

solder beads over the welded joints without heating the entire squib body to a dangerously high temperature.

A thorough review of the welding schedule indicated the need for a change in weld procedure in this area. This was performed and the welds themselves were, as a result, vastly improved. These welds in themselves withstood the most severe mechanical and thermal shock. However, when the first ignition material is pressed over the bridge-wire, the bridge resistance changes in some instances by as much as +0.05 ohms in a 1.00 ohm bridge. This is contrary to the normally expected trend, where, because of better contact with the pin, the resistance will tend to decrease after loading - not increase as happened here.

Thermal shock sometimes increases the resistance further in an upward trend. The cause for this phenomena is being investigated as of this report.

Problem #3 was to make good hermetic closures with the electron beam weld. The first production lot of squibs assembled were loaded in two ways. One group contained a reduced charge and therefore an open cavity in the top ferrule. This group was welded with good success. The weld looked very good under a mic inspection. However, the RTV/SiC shunt mix in the rear of the squib made mass spectrometer measurements for leak rate impossible because it absorbs the helium gas. It was, therefore, impossible to measure the closure leak rates except to subject the units to a water immersion under vacuum and observe for leakage. This was done and all of the units passed.

The fully loaded squibs welded very poorly in this first lot. The welds were pitted, evidence of some internal vaporization during the welding cycle. Whether this is from trace moisture present in the base charge or volatilization of the epoxy because of the better thermal contact through the base charge mix could not be determined. In any case, the problem was resolved by first making a hermetic assembly of the burst disc and retaining ring and then welded this sub-assembly at a reduced power. The second lot of squibs were successfully welded in this manner.

Problem #4 is the slow burning rate of the first ignition mix. This accentuates the defects of problems 1 and 2 in that the burning time varies directly with the column height, and since this height gets longer in order to cover pin points or solder beads, the squib functioning time gets longer. Atlas has investigated methods to change the burning rate by particle size control, percentage of ingredients and pressing force with limited, but encouraging success -- see explosive studies.

Problem #5 is a process problem in filling the gap around the ceramic with epoxy. The purpose of this epoxy is to compensate for dimensional differences in this area so that the thin webbed ceramic is supported around its O. D. to prevent fragmentation during firing and to keep the ceramic from cracking when the charges are pressed. It has no header static strength value as shown by the fact that all pressure tests in development were done with this epoxy omitted. The gap is only 0.010" wide in the maximum condition so that it is difficult to fill this void by normal potting procedures. This

problem was solved by using an extremely fine hypodermic needle and a very fluid epoxy. Under these conditions capillary actions assures that this gap is completely filled. This still is a tedious process and needs improvement in technique.

D. Explosive Studies

In this phase of the program testing continued on the Boron/Potassium Perchlorate/Barium Nitrate - 25%/55%/20% composition ignition mix as well as on other pyrotechnic formulations as possible back-up mixes.

1. STUDY OF VARIOUS PYROTECHNIC MIXES WITH BINDERS

Various pyrotechnic mixes with 10% "Viton" and 10% and 1% "Vistanex" were tested for sensitivity in a two pin glass seal header and for electrostatic discharge capability in phenolite fixtures and ceramic simulators. Results of the sensitivity test are recorded in Table 3. All pyrotechnic mixes with binders exhibited an increase in capability to withstand electrostatic discharge in phenolite fixtures (ref. Table 2). The Boron Mix with 10% "Viton" fired in a simulator during the 25 KV discharge between circuits, however, it survived with 10% and 1% Vistanex. Function times of two units with Vistanex binde were higher than 20 millisec @ 4.5 amp. An addition of 10% Vistanex to the molybdenum mix increased the resistance substantially between circuits in a simulator, and also, this unit survived the 25 KV discharge test without a decrease in the resistance. However, function times of the molybdenum mix with 10% Viton and 1% Vistanex were in upper twenties (millisec) and devices with the 10% Vistanex failed to fire with a 4.5 amp/5 millisec pulse. Zirconium/Potassium Chlorate/Barium Nitrate - (52.44/24.39/23.17) and Zirconium/Magnesium/Potassium Perchlorate (25%/15%/60%) blends with all three binders fired during the 25 KV discharge between circuits. Table 5 contains results of the 25KV discharge test in simulators.

The pin-to-pin resistance of the molybdenum mix in a dual cavity ceramic simulator was greater than 10Ω (measured on a Keithley electrometer) but in a cup shaped ceramic simulator resistance between circuits was very low. To observe the effect of loading pressure, this mix was pressed at 4,000 psi, 5,000 psi, 6,000 psi, 8,000 psi, and 10,000 psi and resistance recorded as $\angle 10^8\Omega$, $\angle 10^7\ \Omega$, $\angle 10^5\Omega$, $\angle 10^3\Omega$, and $\angle 10^2\Omega$ respectively. Two simulators loaded at 4,000 and 5,000 psi had the mix resistance drop to $\approx 60\Omega$ after the 25 KV discharge. The squib loaded at 4,000 psi did not fire with a 4.5 amp/5 ms pulse while the other squib had a high function time. Other attempts were made to increase the mix resistance. Diatomaceous earth, in 2% and 5% proportions was added to the molybdenum mix, and these two blends were pressed at 20,000 psi into simulators. An approximate 10^7 ohms resistance of the blend containing 5% D. E. dropped to a lower level following the 25 KV discharge test, and a $10^3\Omega$ resistance of the blend containing 2% D.E. dropped to even lower after the discharge test. Both simulators had high function times.

In all of these tests, therefore, the Boron Mix has been the only mix which has withstood all of the discharges and still retained its sensitivity.

No-fire failures during these tests merely indicate that particular powder in test was more or less sensitive when compared to others in the group. It is not an indication of a problem area since the system is not designed to withstand 1 amp no-firing current.

EFFECT OF PARTICLE SIZES IN THE BORON/POTASSIUM PERCHLORATE/BARIUM NITRATE (25%/55%/20%)

To study the effect of ball milling on the Boron Mix, 50 gms of this blend was milled in 100 ml of 3A alcohol for eight hours with twelve 7/8" diameter stainless steel bearings each weighing 44 gm. This ball-milled blend was tested for sensitivity in glass headers. Two units out of ten fired during the no-fire test, and one no-fire unit failed to fire during the all-fire. Results of this test are in Table 3.

A further study of particle size effects extended to the oxidants in the mix. Four Boron blends containing coarse and fine Potassium Perchlorates and coarse and fine Barium Nitrates were tested for function sensitivity in glass headers. Five units were tested in each group. One unit out of the group containing the fine potassium perchlorate and the fine barium nitrate did not pass a 1 amp/1 watt no-fire and one no-fired unit failed the all-fire. Function times of these four blends are in Table 3. It should be mentioned again that a no-fire failure indicates a difference in sensitivity to some extent but is no indication that the mix is marginal, since the system is not designed to withstand a one-amp firing current.

Sterilization Test

A single piece, four pin, glass-to-metal seal plug was designed to test the effect of a six cycle 135°C -- 56 hour sterilization storage.

Seventy-two plugs were charged each with 15 mg of the 25% Boron/55% Potassium Perchlorate/20% Barium Nitrate igniter mix and 150 mg of Zirconium (40%) Potassium Perchlorate 60% output mix at 20,000 psi. Forty-eight units were subjected to the sterilization storage cycle, and the remaining were stored in a desiccator to serve as control units. Four control units and eight sterilized units were removed at the end of each cycle. As a comparison for the effect of a no-fire in glass-seal headers, four out of eight sterilized units were all-fired at -65^{o} with a 4.5 amp/5 msec pulse, while the other four units were subjected to a 1 amp/1 watt no-fire at +160^{o}F and then all-fired. Control units were no-fired and all-fired at the respective temperatures.

In general, function times of no-fired units were higher than those of only all-fired units at the end of each cycle, for the reason mentioned previously -- the system is not designed for a 1 amp no-fire. One no-fired unit, removed at the end of the final (sixth) cycle, failed to fire on the first bridge; however, it fired when pulsed on the second bridge. Here again, it must be made clear that a no-fire failure is not a powder failure but a system failure since this system was not designed to withstand the 1 amp/1 watt firing current. Since no significant difference was observed in function times of control units and no-fired sterilized units, it can be concluded that the sterilization storage had no effect on pyrotechnic mixes. The average function times and bridgewire burn out times are in Table 4. Although statistically, there is no difference in

the numbers, there does appear to be a slow down of approximately 0.5 ms after sterilization. The cause for this is not understood at this time.

Output Testing:

The 41% Titanium/59% Potassium Perchlorate and 37% Molybdenum/13% Potassium Perchlorate/50% Potassium Nitrate Blends were tested for approximate pressure performance in simulators. Fifteen (15) mg 25% Boron/55% Potassium Perchlorate/20% Barium Nitrate was used as an igniter in each of ten squibs. Five squibs contained a base charge of 230 mg Ti/KCL04 pressed at 20,000 psi and the remaining five units contained 365 mg of Mo/KCL04/KN03 pressed at 20,000 psi. The base charges were loaded into phenolic sleeves (0.218 I. D.) which were press fitted on the ceramic within the squib. Units in the first test did not have end closures. In a repeat test of the above, units in this test, had stainless steel closure discs which were electron-beam welded into place.

Results obtained in both series of tests were not uniform; however, instantaneous peak pressures were obtained with the Titanium/Potassium Perchlorate blends whereas with the molybdenum mix the pressure rise time was very long, as much as 10-25 milliseconds. Consequently, study was discontinued on this mix.

Time-Current Characteristics

To study time-current characteristics of a small sample of squibs, 15 mg of the igniter mix (Boron 25%)/Potassium Perchlorate (55%) and Barium Nitrate (20%) and 150 mg of base charge - (Titanium (41%)/ Potassium Perchlorate (59%) was pressed at 20,000 psi into each of eleven squibs. Current applied to the first squib was increased very

slowly until it fired. This firing current was recorded and served as one point from which to test the remaining squibs at varying currents. Function times were recorded. This data is plotted on a log-log paper.

Twenty-five similarily loaded simulators were tested between 1.5 amp and 7.0 amp in 0.5 amp increments. Two simulators were tested at each level of current, and the function times and bridgewire burn out times were recorded. A log-log plot describes these time-current-characteristics.

The above mentioned test was repeated (with a smaller sample size) using two drops 1% RTV 112 in xylene - a binder solution on the Boron igniter charge. Log-log plots of the data obtained in this test is included herein.

Results of these tests indicate that a binder in the system increases the function times of squibs, and also, the lowest level of current required to actuate a squib.

Final Squib Design

To prove out the overall design, ten squibs were assembled and tested as follows. Five squibs were loaded each with 15 mg of the Boron igniter blend, an RTV 112 binder solution and 25mg of the Titanium base charge at 20,000 psi and the other five squibs were loaded 15 mg and 205 mg of the respective blends. These units were electron-beam welded.

Three out of five squibs in each group fired during the 25 KV discharge test. (See Static Discharge Section). The remaining four squibs were subjected to the thermal and mechanical shocks and to a 1 amp/1 watt no-fire +160°F and to a 4.5 amp/5 msec pulse all-fire ambient in the time pressure bomb.

To compensate for the undesirable pin condition described in the Static Discharge Section, 50 mg of the ignition charge was used. All but one unit passed the 25 KV discharge. This unit fired after the fifteenth discharge. The pins on this unit were known to be exceedingly high on the points before assembling and testing. These results indicate that if there is enough of the ignition charge to cover the pins ($\approx$0.015" above tallest pin), the igniter squib will meet 25 KV requirements.

To verify results obtained in ceramic headers, eight squibs were loaded each with 50 mg of the ignition charge. Four squibs were loaded each with 100 mg of the titanium base charge and the other four each with 225 mg. These eight units were electron-beam welded. These units passed the static discharge test before and after a thermal shock from +300°F to -200°F without degradation. Then they were subjected to a 1 amp no-fire and a 4.5 amp/5 ms pulse all-fire in the time pressure bomb. Time pressure values representing these data are in Table 6. Function times of these units were higher than obtained in previous tests. The increase to 50 mg in the ignition charge did reestablish the discharge capability, however, it was at the expense of a slight increase in function times.

In order to reecstablish the faster function times and maintain discharge capability various blends of Boron/Oxidants and the standard Boron mix as control, were tested for sensitivity in glass headers and for discharge in phenolite fixtures. The fastest function times were produced by a blend of 40% Boron/60% Potassium Perchlorate. Results of the sensitivity and discharge tests are in Tables 2 and 3.

Since the 40% Boron/60% Potassium Perchlorate had the lowest function time, tests were conducted to observe the influence of oxidant particle sizes and of ball milling the complete mix. Results of sensitivity and discharge tests are in Tables 2 and 3.

E. Conclusions and Recommendations

A number of significant design goals of this program have been realized as of this report.

1. Seals have been developed which are capable of withstanding pressures of up to 80,000 psi -- substantially higher than the minimum goal of 30,000 psi. These seals will withstand thermal shocks from -300°F to +300°F without degradation.
2. Materials have been developed which will enable the completed squib to withstand repeated discharge of up to and over 25 KV from a 500 μf capacitor in any mode of discharge -- pin-to-pin or pin-to-case.

   The explosive used as the ignition charge directly over the bridgewire is capable in itself of withstanding direct discharges without firing or changing insulation resistance. The use of silicon carbide in an RTV carrier, when potted

in the connector cavity of the squib, will act as a shunt to a high voltage discharge and yet maintain a high insulation resistance at voltages below its breakdown point.

3. A closure disc design has been firmed which utilizes a scored stainless steel disc with low rupture strength to avoid the peak pressure spikes so common to high strength squib seals. In addition, the use of an electron-beam weld precludes the need for crimping, soldering or brazing this disc into the squib housing, while assuring full hermeticity and high strength in the weld area.
4. The squib is completely non-magnetic. All metal parts are Inconel 718 -- pins and housing.
5. The development of the mix to withstand direct static discharges has a major significance in that it allows the use of a simple cup-shaped ceramic with no insulating material of any kind between two sets of pins in a four pin design. This greatly facilitates the ceramic design, removing the necessity for webs between pins, and making further processing of the squib vastly simplified -- including welding of bridgewires and loading of the explosive charge.
6. The squib has demonstrated a capability to withstand heat sterilization of 293°F for 342 hours without performance degradation.
7. The squib will withstand the application of one amp or one watt through both circuits simultaneously for five minutes without affecting functioning capability.

There are minor changes necessary, notably in the ceramic design, which will optimize the design from a functioning time standpoint. These were mentioned in this report. They consist of changing the ceramic I. D. to remove the possibility of pin points remaining in the charge cavity and causing static discharge problems, and, at the same time shortening the column length of the slow burning $B/KCLO_4/Ba(NO_3)_2$ first ignition charge.

A more basic area of investigation must also be in increasing the burning rate of the first ignition mix. This would minimize functioning time variations attributable to column length variations of this mix. This investigation has begun as of this report.

TABLE I

GENERAL INFORMATION

INGREDIENT	SPECIFICATION	IDENTIFICATION
Potassium Perchlorate	(Grade C, except through 250 (mesh per Jan-P-217	M
	(Grade C per Jan-P-217	N
	(Grade A Class 4 per MIL-217A	P
Barium Nitrate	(Class 2 per MIL-B-162C	X
	(Class 4 per MIL-B-162C	Y
	(Class 4 except through 250 (mesh per MIL-B-162C	Z

When otherwise mentioned Potassium Perchlorate (M) and Barium Nitrate (Y) were used in pyrotechnic mixes.

TABLE 2

RESULTS OF DISCHARGE TESTS IN PHENOLITE FIXTURES

Pyrotechnic Mixes (with Binders)	No. Units Fired / No. Units Tested	Lowest Discharge Voltage Level In KV's	Resistance In Ohms Before Test	Resistance In Ohms After Test
10% RTV 112				
$B/KCLO_4/Ba(NO_3)_2$ (25/55/20)	3/3	25*	$>10^9$	$>10^9$
$Mo/KCLO_4/CaCrO_4$ (44/34/22)	2/2	25*	$>10^{10}$	$>10^{10}$
$Zr/KCLO_3/Ba(NO_3)_2$ (52.44/24.39/23.17)	1/1	3	$>10^{10}$	--
$Zr/Mg/KCLO_4$ (25/15/60)	1/1	7	$>10^{10}$	--
10% VITON				
$B/KCLO_4/Ba(NO_3)_2$	1/1	15	$>10^9$	--
$Mo/KCLO_4/CaCrO_4$	2/2	25	$>10^{10}$	$>10^5$
$Zr/Mg/KCLO_4$	1/1	9	$>10^9$	--
$Zr/KCLO_3/Ba(NO_3)_2$	1/1	3	$>10^9$	--
10% VISTANEX				
$B/KCLO_4/Ba(NO_3)_2$	2/2	25*	$>10^9$	$>10^9$
$Mo/KCLO_4/CaCrO_4$	1/1	25*	$>10^{10}$	$>10^{10}$
$Zr/KCLO_3/Ba(NO_3)_2$	1/1	4	$>10^9$	--
$Zr/Mg/KCLO_4$	1/1	15	$>10^{10}$	--
1% VITON				
$B/KCLO_4/Ba(NO_3)_2$	1/1	20	$>10^9$	--
$Mo/KCLO_4/CaCrO_4$	1/1	25	$>10^6$	--
$Zr/KCLO_3/Ba(NO_3)_2$	1/1	1	$>10^9$	--
$Zr/Mg/KCLO_4$	2/2	12	$>10^{10}$	--

*Means did not fire.

TABLE 2

RESULTS OF DISCHARGE TESTS IN PHENOLITE FIXTURES

PYROTECHNIC MIXES (without Binders)	NO.UNITS FIRED@ LOWEST DISCHARGE VOLTAGE LEVEL / NO.UNITS TESTED	LOWEST DISCHARGE VOLTAGE LEVEL IN KV's	RESISTANCE IN OHMS BEFORE TEST	RESISTANCE IN OHMS AFTER TEST
$Ti/KClO_4/Ba(NO_3)_2$ (22/28/50)	1/1	8	$>10^{11}$	____
$Mo/KClO_4/Ba(NO_3)_2$ (25/20/55)	3/3	25*	$>10^{11}$	$>10^{11}$
$B/KClO_4/Ba(NO_3)_2$ (25/55/20)	4/5	10	$>10^{9}$	____
$B/Ba(NO_3)_2$ (30/70)	1/1	15	$>10^{8}$	____
$B/KClO_4$ (40/60)	1/1	10	$>10^{9}$	____
$B/KClO_4/Ba(NO_3)_2$ (18/70/12)	1/2	10	$>10^{8}$	____
$B/KClO_4/Ba(NO_3)_2$ (35/45/20)	2/2	10	$>10^{8}$	____
$B/KClO_4$ (50/50)	1/2	8	$>10^{9}$	____
$B/KClO_4$ (30/70)	1/2	8	$>10^{9}$	____
$B/KClO_4/Ba(NO_3)_2$ (40/40/20)	2/2	9	$>10^{10}$	____

*Means unit did not fire.

TABLE 3

SENSITIVITY TEST ON BINDERS

NO FIRE: 1AMP/5MIN @+160°F
ALL-FIRE 4.5AMP/5ms @-65°F
NO. OF UNITS TESTED WITH EACH BINDER: 3

PYROTECHNIC MIX & BINDER	NO. OF NO-FIRE REJECT	FUNCTION TIME IN MS 1	2	3
A. 10% VITON				
$B/KCLO_4/Ba(NO_3)_2$	None	1.82	0.72	1.69
$Mo/KCLO_4/CaCrO_4$	None	5.82	N.F.*	N.F.
$Zr/KCLO_3/Ba(NO_3)_2$	None	1.65	1.33	1.59
$Zr/Mg/KCLO_4$	1	2.28	N.F.	F.
B. 10% VISTANEX				
$B/KCLO_4/Ba(NO_3)_2$	None	N.F.	2.72	3.92
$Mo/KCLO_4/CaCrO_4$	1	F.	N.F.	22.77
$Zr/Mg/KCLO_4$	None	N.F.	N.F.	N.F.
$Zr/KCLO_3/Ba(NO_3)_2$	None	2.75	2.80	N.F.
C. 1% VISTANEX				
$B/KCLO_4/Ba(NO_3)_2$	None	3.59	4.87	4.51
$Mo/KCLO_4/CaCrO_4$	None	4.00	107.70	91.76
$Zr/KCLO_3/Ba(NO_3)_2$	None	4.41	2.78	2.07
$Zr/Mg/KCLO_4$	None	2.91	7.26	2.99

1. Not Fired = N.F.
2. No Fire Failure = F.

TABLE 3

PYROTECHNIC MIX (without Binder)	NO-FIRE REJECT	ALL-FIRE REJECT	AVERAGE FUNCTION TIME, IN MS	NO. of UNITS TESTED
(Mo/$KClO_4$/$Ba(NO_3)_2$/1%D.E.	NONE	NONE	5.344	5
B/$KClO_4$(N)/$Ba(NO_3)_2$(X)	NONE	NONE	5.250	5
B/$KClO_4$(N)/$Ba(NO_3)_2$(Z)	NONE	NONE	8.288	5
B/$KClO_4$(P)/$Ba(NO_3)_2$(X)	NONE	NONE	9.232	5
B/$KClO_4$(P)/$Ba(NO_3)_2$(Z)	1	1	6.556	5
B/$KClO_4$(M)/$Ba(NO_3)_2$(Y) (Ball-Milled)	2	1	5.827	10
B/$KClO_4$(M)/$Ba(NO_3)_2$(Y) (Control)	NONE	NONE	5.96	10
B/$Ba(NO_3)_2$(Y) [30/70]	NONE	NONE	12.72	5
B/$KClO_4$/$Ba(NO_3)_2$ [18/70/12]	NONE	3	9.74	5
B/$KClO_4$ [30/70]	NONE	NONE	4.73	5
B/$KClO_4$ [50/50]	NONE	NONE	4.72	5
B/$KClO_4$/$Ba(NO_3)_2$ [40/40/20]	NONE	NONE	5.75	5
B/$KClO_4$/$Ba(NO_3)_2$ [35/45/20]	NONE	NONE		
TEST#1	NONE	NONE	4.20	5
TEST#2	NONE	NONE	4.38	5
TEST#3	NONE	NONE	3.40	5
TEST#4	NONE	NONE	5.36	5
B/$KClO_4$ [40/60]				
TEST#1	NONE	NONE	2.99	5
TEST#2	NONE	NONE	2.72	5
TEST#3	NONE	NONE	4.02	25

TABLE 3

PYROTECHNIC MIX (without binder)	NO-FIRE REJECT	ALL-FIRE REJECT	AVERAGE FUNCTION TIME IN MS	NO. of UNITS TESTED
STUDY OF AN EFFECT OF VARIOUS PARTICLE SIZES ON B/$KCLO_4$(40/60)				
B/$KCLO_4$(M)	NONE	NONE	3.828	10
B/$KCLO_4$(N)	NONE	NONE	4.592	10
B/$KCLO_4$(P)	NONE	NONE	4.186	10
B/$KCLO_4$ (Ball-Milled)	NONE	NONE	3.748	10

TABLE 4

RESULTS OF STERILIZATION STORAGE

Test Vehicle:	4-Pin Glass-to-Metal Seal Plug (≈0.135" cavity, 0.218" I. D.)
Sterilization Temperature:	275°F
Storage Period @ 275°F:	56 hours
Storage Period @ Ambient at end of each sterilization period:	8 hours
Number of cycles:	6
Ignition Charge:	15 mg - 13/$KClO_4$/$Ba(NO_3)_2$ (25/55/20)
Base Charge:	150 mg - Zr/$KClO_4$ (40/60)

Ignition and Base Charges were pressed @ 20,000 psi

No Fire: 1 amp/5 min. @ +160°F thru both bridges

AVERAGE FUNCTION TIME IN MS

Cycle Number	Sterilized Units Only All-Fired	Sterilized Units No-Fired and All-Fired	Control Units No-Fired and All-Fired
1	2.31	4.36	3.95
2	2.32	5.75	5.52
3	2.44	4.95	3.80
4	2.35	5.95	4.85
5	2.30	5.09	5.14
6	2.27	6.25	4.26

TABLE 5

SENSITIVITY AND THE 25KV DISCHARGE TEST IN SIMULATORS

Ignition System	Units Potted in Back With	Resistance Between Circuits in OHMS Before Test	Resistance Between Circuits in OHMS After A25KV Discharge	Test in Simulators Function Time (Following a 1 amp/ 5 min. No-Fire @ +160°F) in MS
10% Viton:				
$B/KCLO_4/Ba(NO_3)_2$	Shunt Mix	10^7	Fired	--
$Mo/KCLO_4/CaCrO_4$	Shunt Mix	160	Very Low	27.05
$Zr/KCLO_3/Ba(NO_3)_2$	C-14	10^6	Fired	--
$Zr/Mg/KCLO_4$	Shunt Mix	10^{11}	Fired	--
10% Vistanex				
$B/KCLO_4/Ba(NO_3)_2$	Shunt Mix	10^9	10^9	31.51
$Mo/KCLO_4/CaCrO_4$	Shunt Mix	10^{10}	10^{10}	Did not fire
$Zr/KCLO_3/Ba(NO_3)_2$	C-14	10^{10}	Fired	--
$Zr/Mg/KCLO_4$	Shunt Mix	10^{11}	Fired	--
1% Vistanex				
$B/KCLO_4/Ba(NO_3)_2$	Shunt Mix	10^6	10^6	24.56
$Mo/KCLO_4/CaCrO_4$	C-14	100	Very Low	31.93
$Zr/KCLO_3/Ba(NO_3)_2$	C-14	320	Fired	--
$Zr/Mg/KCLO_4$	C-14	10^7	Fired	--

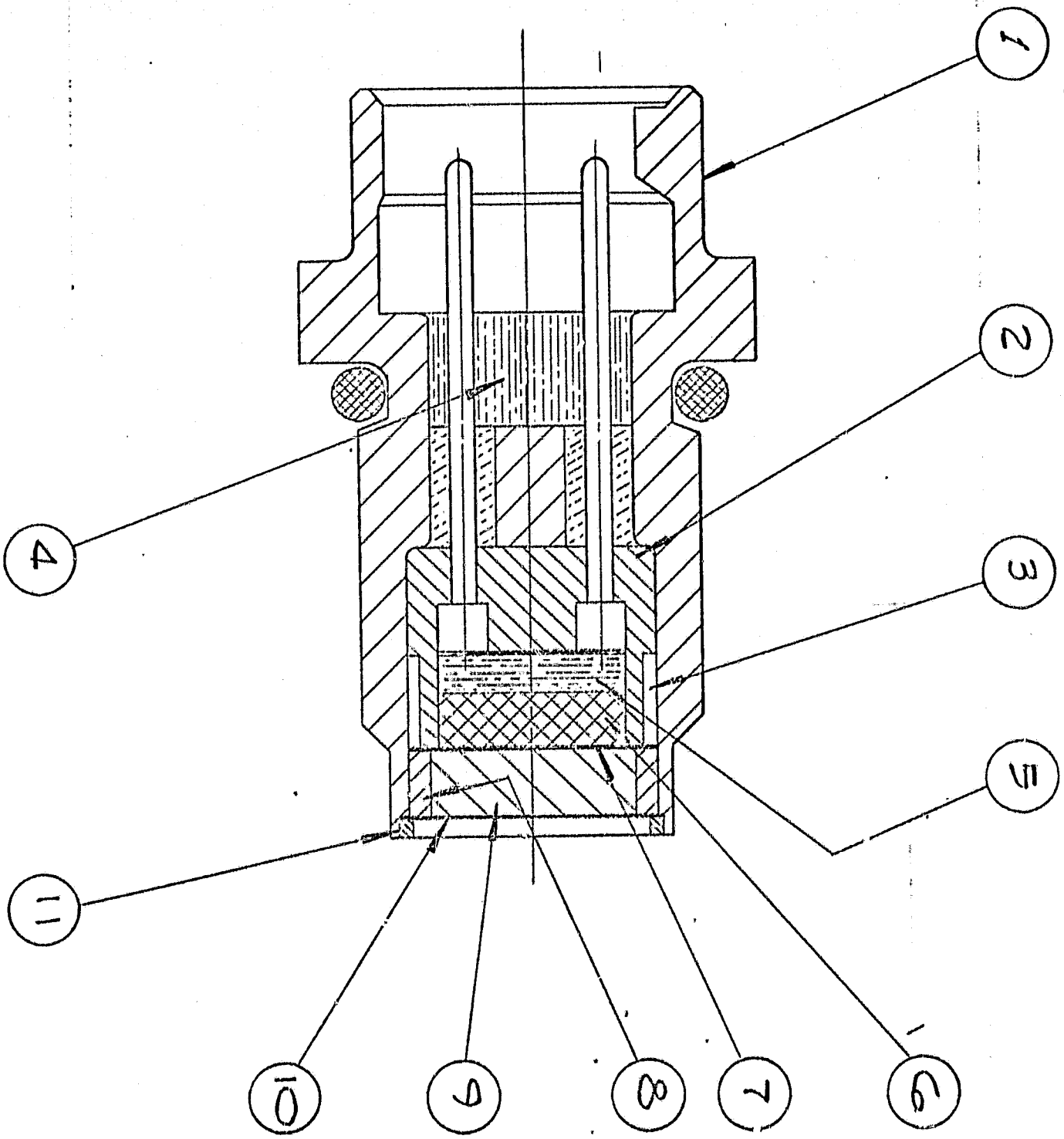
TABLE 6

OVERALL PROVE-OUT WITH 50 MG OF THE BORON/POTASSIUM PERCHLORATE/BARIUM NITRATE IGNITION CHARGE

ERIAL UMBER	$B/KClO_4/-Ba(NO_3)_2$ IGNITION CHARGE IN MG	$Ti/KClO_4$ BASE CHARGE IN MG	RESISTANCE IN OHMS BEFORE THERMAL & MECHANICAL SHOCKS				RESISTANCE IN OHMS AFTER THERMAL & MECHANICAL SHOCKS					FUNCTION TIME IN MS	PEAK PRESSURE IN PSI
			BETWEEN CIRCUITS PINS & CASE				BETWEEN CIRCUITS PINS & CASE						
			BEFORE TEST	AFTER 25KV DISCHG.	BEFORE TEST	AFTER DISCHG. TEST	BEFORE TEST	AFTER DISCHG. TEST	BEFORE TEST	AFTER DISCHG. TEST	NO-FIRE		
167	50	100	$>10^7$	$>10^7$	$>10^7$	$>10^7$	$>10^9$	$>10^9$	$>10^9$	$>10^9$	YES	6	6,000
106	50	100	THESE TWO UNITS WERE NOT SUBJECTED TO THE 25KV DISCHARGE BECAUSE								YES	6	*
105	50	100	THEY WERE NOT POTTED WITH THE SHUNT MIX								YES	10.5	7,500
168	50	100	$>10^7$	$>10^7$	$>10^9$	$>10^9$	$>10^7$	$>10^7$	$>10^8$	$>10^8$	YES	11.0	6,000
112	50	225	$>10^7$	$>10^7$	$>10^9$	$>10^9$	$>10^8$	$>10^8$	$>10^9$	$>10^9$	YES	4.5	11,000
154	50	225	$>10^7$	$>10^7$	$>10^8$	$>10^8$	$>10^8$	$>10^8$	$>10^9$	$>10^9$	YES	7.7	10,000
155	50	225			$>10^9$	$>10^9$			$>10^{10}$	$>10^{10}$	YES	6.8	9,800
1	50	225	$>10^7$	$>10^7$	$>10^9$	$>10^9$	$>10^8$	$>10^8$	$>10^{10}$	$>10^{10}$	YES	2.8	12,000

*Instrumentation Failure

FIGURE 1

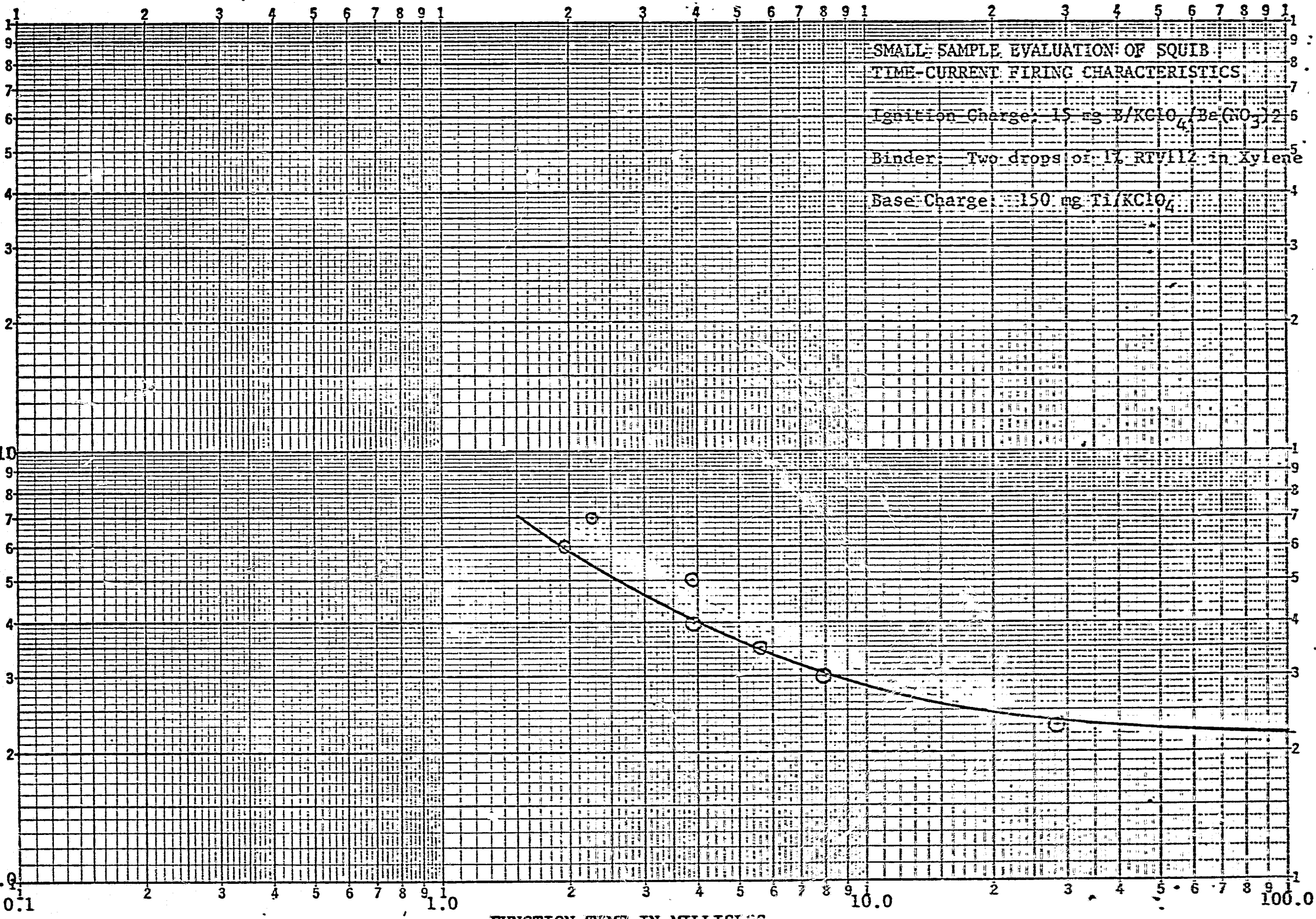


SMALL SAMPLE EVALUATION OF SQUIB
TIME-CURRENT FIRING CHARACTERISTICS

Ignition Charge: 15 mg B/$KClO_4$/$Be(NO_3)_2$

Binder: Two drops of 1% RTV112 in Xylene

Base Charge: 150 mg Ti/$KClO_4$

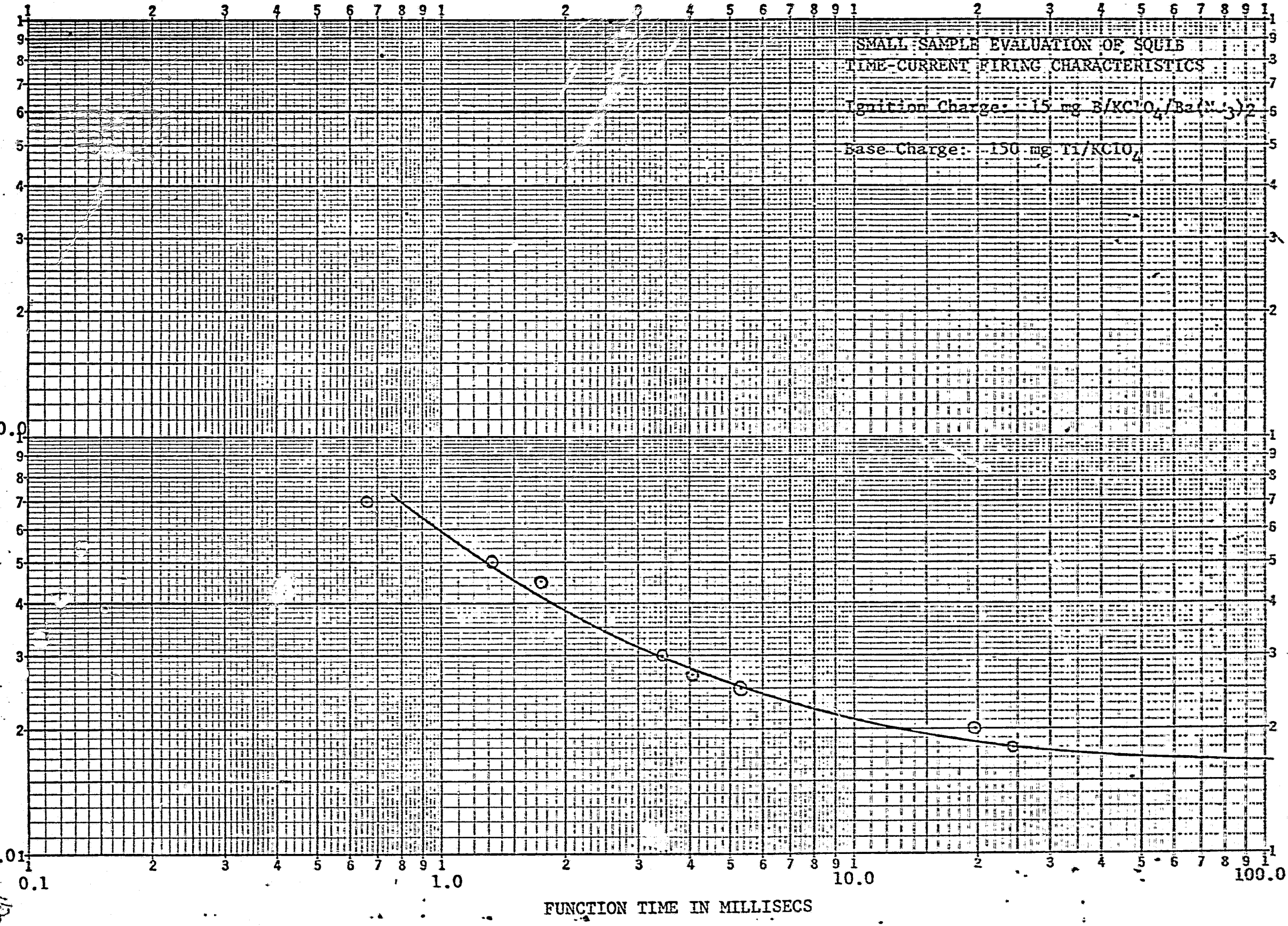


K&E LOGARITHMIC 46 7320
2 X 3 CYCLES MADE IN U.S.A.
KEUFFEL & ESSER CO.

SMALL SAMPLE EVALUATION OF SQUIB
TIME-CURRENT FIRING CHARACTERISTICS

Ignition Charge: 15 mg B/$KClO_4$/$Ba(NO_3)_2$

Base Charge: 150 mg Ti/$KClO_4$



TIME-CURRENT FIRING CHARACTERISTICS
WITHOUT A BINDER IN IGNITION SYSTEM

IGNITION CHARGE: 15 mg B/$KClO_4$/$Ba(NO_3)_2$

BASE CHARGE: 150 mg Ti/$KClO_4$

1.0

0.1

1.0

10.0

100.0

FUNCTION TIME IN MILLISECS