ORIGINAL

DESIGN AND FABRICATION

of

FOUR PIN HIGH PRESSURE SQUIB

SECOND QUARTERLY REPORT

Prepared under California Institute of Technology

Contract #951912

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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 probes. This report is the second quarterly report under Contract #951912 with the Jet Propulsion Laboratory. The first report covered the period from May, 1967 through September, 1967.

The requirements for the design are basically the same as reported previously. The squib must be capable of surviving the extremes of environment which a piece of exposed hardware might naturally see on Mars, Venus and on other targets of unmanned space vehicles.

These requirements are repeated here for further emphasis on their severity, and to give some indication of the design problems involved with this squib.

1. The squib will be nonmagnetic.
2. The squib will be capable of withstanding heat sterilization, consisting of exposure to 293°F ± 4°F for 324 hours without degradation.
3. The squib will be suitable for exposure to 10^{-7} mm hg pressure or lower at 200°F for 6 months. (As a goal, this capability should be demonstrated with open seals.)
4. The squib will be suitable for exposures of up to 1 year at -400° to +250°F.
5. The squib seals must be capable of withstanding pressures of 30,000 psi minimum.

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6. The squibs will be capable of withstanding a discharge of 25 kv from a 500 uuF capacitor from pins to case and between the two circuits.
7. The squib will not function nor be degraded when 1 amp or 1 watt is applied to both bridges simultaneously.
8. The squib shall have an end closure which makes the output and initiation characteristics as uniform as is now possible in the state-of-the-art, and these closures should rupture at low pressure to prevent large high peak/average pressure ratios.

As had been mentioned previously, Inconel was the logical choice of materials for the housing and contact pins because of its strength over a wide range of temperatures and because of it nonmagnetic susceptibility. Its fabrication posed some unique problems which had to be overcome before setting on this material as a firm choice. From a machining standpoint Inconel 718 is readily turned, bored or ground. However, drilling and milling become a problem, especially in smaller tool sizes. Tool wear is excessive. Small end mills - 1/32 or 1/16 simply do not work at all, and the maintaining of small corner radii and sharp definition is impossible. Therefore, normal machining practices do not work on this material (in the particular configuration of the housing under discussion). Atlas solved these problems by the use of electrostatic discharge machining (EDM) in these areas of housing where it was impossible to work normally. This particularly applied to the connector end in keyway slots, lugs, etc.

The first report discussed problems in making the seal with glass or ceramic while maintaining the Inconel housing in the hardened condition. These problems have been overcome by the use of a combination glass-to-metal and ceramic-to-metal seal which has successfully withstood pressures up to 80,000 psi without destroying the seal. In view of the small size of the housing, we feel that this is an accomplishment of some magnitude and marks a significant step in the design of an ultra high pressure squib for use in applications where only massive bodied squibs have to now been effective.

We feel confident that another major goal of this program has been reached. Atlas has developed an explosive mix which is capable of withstanding direct discharges of 25 kv from a 500 uuF capacitor. The use of this mix, in combination with the static shunt material potted around the squib terminals, makes the finished squib immune to discharges in any mode - pin to pin, or pin to case - discharges which can be repeated time and time again without detrimental effect in insulation resistance or functioning capability.

TECHNICAL DISCUSSION

A. Header Development

In the first quarterly report, we discussed two alternate approaches in making the housing-pin seals.

1. Approach #1 consisted of making the seal in the same cycle as would normally be used for heat treating the Inconel 718; i.e., flowing the glass and ceramic brazing materials during the annealing cycle of the Inconel (1900°F for one hour), then dropping the temperature of the furnace to 1400°F to age harden the Inconel for 8 hours. A further drop to 1200°F for 8 hours completes the cycle of hardening - after which the units are returned to ambient.

   The first series of seal tests were run in this manner. They were successful only on a limited scale, since the glass had a tendency to flow excessively because of the long aging cycles in the furnace. For example, the drop from 1900° annealing temperature to 1400° hardening temperature took 6-8 hours in a muffle type furnace with atmosphere retort. This cycle could not be shortened by switching to a conveyor type furnace because belts cannot be stopped at the specific annealing and hardening temperatures without damaging the belt material. The device sees total aging times of 30-36 hours as a consequence, and this excessive aging is detrimental to the glass.

The seals made under these conditions were gross leakers on hermetic seal testing. We were able to test them to destruction in some cases, and these results are in Table I.

2. The second approach consisted of first hardening the Inconel housing to Rc 41, the usage condition, then sealing the glass at 1400°F, which is the maximum temperature the Inconel 718 can see before losing a percentage of its hardness. A number of special glass formulations were tried in these series of tests but all proved unsuccessful because the lead in these glasses (which lowers flow temperature) had an adverse effect on the electrical characteristics of the sealed unit. There was poor dielectric strength between pin-to-case and sometimes pin-to-pin, especially after the normal post furnace cleaning operations. This defect is a major one which proved to be insurmountable after a number of seal attempts.

After a number of other alternate approaches, without success, it was decided to use a compromise between the two original approaches as follows:

1. The glass and ceramic are sealed in the housing by running the annealing cycle at 1850°F in a conveyor furnace, so that the glass is not exposed for more than 1 hour to the annealing temperature. This flows the glass, providing the hermetic seal for the unit.
2. The unit is then transferred to a muffle furnace with retort to complete the hardening cycle at 1325°F and 1150°F for eight hours each temperature. This temperature is below the flow temperature of the glass (although within the softening range) and therefore the glass does not

flow excessively as in approach #1. The pre-seal at 1850°F cured the drawbacks of approach #2 because it allowed the use of lead free glass to make the seal.

The use of this compromise approach made a fairly effective seal. However, the reject rate on hermeticity was still quite high. This can be traced to two major problems. One, the drastic mismatch of temperature coefficients of expansion of glass and Inconel, and two, the tendency of Inconel to oxidize even under the slightly reducing atmospheres used to make the seals. This oxidation, especially on the pin, contaminates the glass during the seal cycle at 1850°F. Then, when the units are hardened at 1400°F, the thermal shocks break the glass-to-pin seal (already contaminated by the oxide.)

The International Nickel Co. in Huntington, West Virginia was of considerable help in this program in suggesting various hardening techniques for the Inconel 718 - techniques which could be applied to the glass sealing cycle also. After consultation with their technical service group on the problems involved in the first three approaches, they suggested a fourth cycle which would harden the Inconel 718 to what they felt would be a slightly reduced level of hardness - approximately 32-36 Rc. In actual practice, the hardness experienced was $\cong$ 38 Rc - almost maximum Inconel 718 hardness. This fourth cycle consisted of a sealing-annealing soak at 1850°F for less than one hour, then furnace cool to 1400°F and age harden for three hours, after which the units are furnace cooled to ambient. To reduce the cool down times to a minimum, Atlas used a pusher type open hearth furnace rather than a retort type. As a result, the total soak time is reduced to approximately 8 hours, and most of this time is at temperatures below the

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softening point of the glass. In this approach, there is no thermal shock as experienced in the third cycle. The mismatch of Inconel and glass is therefore less of a problem. With the use of this approach, 100% hermeticity was achieved.

The type of header design as finally chosen is per sketch #1 - the individual four pin seal design. This design has held up consistently through thermal shock and high pressure, while the straight single bead seal has been erratic in strength - sometimes equal to the 4 pin design, then drastically lower the next seal. We have not found the cause for this erratic strength as yet but we will run a special series of tests to determine it if possible, since this could well prove to be a critical seal problem possibly having some bearing on the four-pin seal design.

One possible explanation for this erratic strength behavior in the single glass bead design is the fact that the ceramic sub-assembly must seat perfectly in the Inconel housing or the seal is ineffective. If, for example, the ceramic is seated on a small undetected burr in its accepting radius - burrs on the order of .001-.005 in size - the ceramic will act as a piston on the glass during the pressure test, making the glass take the entire load by itself - which it cannot do. In order to be effective the ceramic must seat fully on the Inconel, while the glass flows across its under surface. Under the pressure, the housing itself then takes the major load, while only a small area of glass can possibly be exposed to the pressure.

The data on pressure tests presented in the tables is self-explanatory. It represents increasing stages of improvement, first in the seal technique, then in striving for hermeticity.

The last seal test indicates we can now make both an effective high pressure seal and a hermetic seal with a low reject rate at sealing.

As mentioned previously, the results of the pressure tests indicate that under the ideal conditions, a single hole seal will withstand as high a pressure as the individual pin 4 hold seal design. This is so because the ceramic is either taking the entire pressure load itself, or in the event of a ceramic braze leak, reducing the pressure on the glass to a safe level. The braze between the pins and ceramic is not truly hermetic and in fact does allow the pressure to get by and act on the glass in some cases. However, the unit is fixtured in sealing such that the glass flows across the back surface of the ceramic during the seal cycle, thus both further supporting the ceramic and reducing the effective area of the glass on which the pressure can act. Since the variability in strength of the single bead seal is probably the result of improper ceramic seating, it represents a deviation from the ideal situation. Simple expediency forces us at this time to choose the four hole seal rather than spend a prohibitive amount of time and effort in making the single bead seal work.

In the present design, there appears to be no benefit from using a "head" on the pin which seats in a ceramic counterbore. When some straight pin seals were tested - see table #VI - the strength was equivalent to that of the headed design. To check the effect of removing the ceramic, pressure tests were run on glass seals alone with the identical pin and housing design. The strengths were predictably lower - see table #VII.

One point of interest about the mode of failure during pressure testing. We have not experienced any catostrophic seal failures in the present design. The seal usually develops a leak which does not allow the sustaining of high pressures - while in the pressure tests on the glass seals, the entire seal, including pins, was violently destroyed at the failure level.

TABLE I

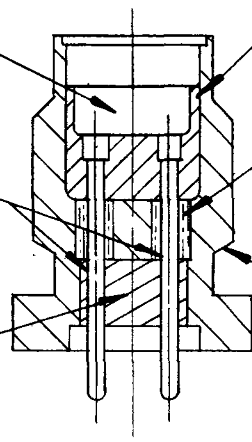
Pressure tests on units sealed and hardened by approach #1. Anneal at 1950°F, cool to 1400°F and age 8 hours, cool to 1200°F and age 8 hours, furnace cool to ambient. Total cycle time 36 hours. In appearance, the seals were poor, excessively flowed, leaving large voids and bad wicking up the pins - especially the 4 pin seals.

S/N	Type of Seal	Hardness Rc	Helium Leak	Pressurize to 30,000 psi	Helium Leak	Pressurize to Destruction
3001	Single Bead	40.4	$< 10^{-8}$ cc/sec.	No leak at 30,000 psi	$< 10^{-8}$ cc/sec.	48,000 psi
3002	Single Bead	39.7	$< 10^{-8}$ cc/sec.	No leak at 30,000 psi	$< 10^{-8}$ cc/sec.	59,000 psi
* 3005	Single Bead	38.6	$< 10^{-8}$ cc/sec.	No leak at 30,000 psi	$< 10^{-8}$ cc/sec.	67,000 psi
3006	Single Bead	39.0	$< 10^{-8}$ cc/sec.	Leaked at 5,000 psi	-	N/A
3009	Individual 4 pin	38.7	Gross leaker	Leaked at 2,500 psi	-	N/A
3010	Individual 4 Pin	39.4	Gross leaker	Gross leaker	-	N/A
3011	Individual 4 pin	39.0	Gross leaker	Leak at 12,000	-	N/A
3012	Individual 4 pin	39.7	Gross leaker	Leak at 2,500	-	N/A

* Missing serial numbers were units too badly flowed to be tested. They were stripped and re-used in other tests.

B. Static Discharge Considerations

The sketch below shows the various breakdown points in the squib under development. Voltage breakdown points are shown for each path.



Voltage breakdown paths

Path A - Pin to case externally

Path B - Pin to case through shunt

Path C - Pin to case through glass

Path D - Pin to case through explosive

Path E - Pin to pin through explosive

Voltage Breakdown value = V_B

V_B Path A = (Dielectric of Air) (air gap in mils)

= 70 volts/mil (13) = 910 volts

V_B Path B = Typically 600 to 900 volts (measured)

V_B Path C = (1000) (13) = 13,000 volts

V_B Path D = Typically 1200 volts (measured)

V_B Path E = Typically 1500 volts (measured)

Path C can be discounted entirely. It has a breakdown voltage 10 times greater than the other paths. Paths B, D and E are all measured points and are nominal values with some slight deviation.

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The breakdown points were determined using an AC Hipot dielectric tester set for maximum sensitivity on leakage current; i.e., the breakdown voltage is read at the lowest leakage current.

The leakage current through the explosive at paths D and E was typically 1-3 milliamperes at the breakdown level and was a constantly increasing function up to that point. The leakage through the static shunt mix at path B could not be measured at the voltage breakdown point because it approaches a direct short.

The breakdown path at the high voltage discharge level of 25 Kv will in all probability be through the shunt mix since this is the least arc resistant path. In addition, tests to date have shown that the explosive mix itself is capable of withstanding direct discharges of 25 Kv, 500 picofarads without firing. There is a double safety factor involved therefore which will fully protect the squib at any static discharge up to and over 25 Kv.

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Table II

Pressure tests on units sealed and hardened by approach #1. However, annealing and sealing was first done in a conveyor furnace for one hour maximum, then hardened by re-running the cycle of table #1. The purpose of the pre-seal was to try to prevent excessive flow.

S/N	Type of Seal	Hardness	Helium Leak	Pressure to 30,000 psi	Helium Leak	Pressure to Destruction
3004	Single Bead	41.0	$< 10^{-6}$ cc/sec.	No leak at 30,000 psi	$< 10^{-6}$ cc/sec.	"O" ring extruded at 61,000 psi but seal held.
3008	Single Bead	39.4	$< 10^{-6}$ cc/sec.	Leaked at 27,000 psi	Gross Leaker	-
3003	Single Bead	41.1	$< 10^{-6}$ cc/sec.	Leaked at 22,000 psi	Gross Leaker	-
3007	Single Bead	40.5	$< 10^{-6}$ cc/sec.	Leaked at 7,500 psi	Gross Leaker	-
3013	Individual 4 pin seal	41.0	Gross * Leaker	Leaked at 2,000 psi	Gross Leaker	-
3014	Individual 4 pin seal	39.8	Gross Leaker	Leaked at 3,000 psi	Gross Leaker	-
3015	Individual 4 pin seal	40.8	$< 10^{-6}$ cc/sec.	No leak at 30,000 psi	$< 10^{-6}$ cc/sec.	"O" ring extruded at 65,000 psi, but seal held
3016	Individual 4 pin seal	40.0	Gross Leaker	Gross Leaker	Gross Leaker	-

* Again, the 4 pin seals were badly flowed in appearance and the single pin seals were badly wicked up the pins.

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Table III

Pressure tests on units sealed by approach #1 with reduced aging times and temperatures. Annealed at 1850°F. for one hour, furnace cooled to 1325°F, and aged for 8 hours, furnace cooled to 1150°F and aged for 8 hours then rapidly cooled to ambient. There was still some excessive flow of glass after the cycle. Total cycle time 20 hours.

S/N	Type of Seal	Hardness	Helium Leak	(1) Thermal Shock + 300°F - 300°F	(4) Helium Leak	Pressure to 30,000 psi	Helium Leak	Destruction Pressure
3077	Single Seal	42.0	$<10^{-6}$(3) cc/sec	Yes	Leaker	No Leak	-	77,000(2)
3081	Single Seal	38.0	$<10^{-6}$ cc/sec	Yes	Leaker	No Leak	-	73,000
3079	Single Seal	39.5	$<10^{-6}$ cc/sec	Yes	Leaker	No Leak	-	70,000
3083	Single Seal	38.0	$<10^{-6}$ cc/sec	Yes	Leaker	No Leak	-	76,000

(1) Thermal shock was applied by cycling the devices from liquid nitrogen to heated glycerin three times each.

(2) In all cases, the "O" ring extruded but the seal held.

(3) Although the rates are recorded as less than 10^{-6} cc/sec., they do exhibit some leakage between 10^{-6} and 10^{-7} cc/sec which is indicating a poor glass seal since glass seals normally run $< 10^{-8}$ cc/sec.

(4) Although these units are recorded as leakers, the leak paths are so minute that they are impermeable to the hydraulic fluid (water) at 30,000 psi. Nonetheless, they were detectable by the mass spectrometer, which has a minimum sensitivity of 10^{-5} cc/sec.

Table IV

Pressure tests on units sealed by approach #3. Annealed and sealed at 1850°F in a conveyor type furnace for 1 hour. Then cooled, transferred to a muffle furnace and hardened by aging at 1325°F for 8 hours and 1150°F for 8 hours.

S/N	Type of Seal	Hardness	Helium Leak	Thermal Shock	Helium Leak	Pressure to 30,000 psi	Helium Leak	Destruction Pressure
3078	Single Bead	39.5	$<10^{-6}$ (2) cc/sec.	Yes	$<10^{-6}$ cc/sec	No Leak	$<10^{-6}$ cc/sec	66,000 (1)
3082	Single Bead	40.5	$<10^{-6}$ cc/sec	Yes	$<10^{-6}$ cc/sec	No Leak	$<10^{-6}$ cc/sec	70,000
3080	Single Bead	39.0	$<10^{-8}$ cc/sec	Yes	$<10^{-8}$ cc/sec	No Leak	$<10^{-8}$ cc/sec	70,000
3084	Single Bead	42.0	$<10^{-8}$ cc/sec	Yes	$<10^{-8}$ cc/sec	No Leak	$<10^{-8}$ cc/sec	77,000
3085	Single Bead	39.0	$<10^{-6}$ cc/sec	Yes	$<10^{-6}$ cc/sec	No Leak	$<10^{-6}$ cc/sec	71,000
3086	Single Bead	39.0	$<10^{-6}$ cc/sec	Yes	$<10^{-6}$ cc/sec	No Leak	$<10^{-6}$ cc/sec	74,000
3087	Single Bead	38.5	$<10^{-6}$ cc/sec	Yes	$<10^{-6}$ cc/sec	No Leak	$<10^{-6}$ cc/sec	74,000

(1) In all cases, the "O" ring extruded but the seal held.

(2) Although the rates are recorded as less than 10^{-6} cc/sec they do exhibit some leakage between 10^{-6} and 10^{-7} cc/sec which is indicating a poor glass seal since glass seals normally run $< 10^{-8}$ cc/sec.

Table V

Repeat of tests per Table IV, except that an attempt was made to improve the hermetic condition by pre-oxidizing the pins before sealing.

S/N	Type of Seal	Hardness	Helium Leak	Thermal Shock	N_2 (2) Pressurize	Helium Leak	Pressure to Destruct
3088	Single Bead	41.0	$<10^{-8}$ cc/sec	Yes	Leaked at 3,000	$<10^{-8}$ cc/sec	57,000 (3)
3091	Single Bead	42.5	$<10^{-8}$ cc/sec	Yes	O K to 10,000	$<10^{-8}$ cc/sec	43,000
3093	Single Bead	43.0	$<10^{-6}$ (1) cc/sec	Yes	Leaked at 1,000	$<10^{-8}$ cc/sec	48,000
3089	Single Bead	43.0	$<10^{-8}$ cc/sec	Yes	O K to 10,000	$<10^{-6}$ cc/sec	42,000
3090	Single Bead	42.5	$<10^{-6}$ cc/sec	Yes	Leaked at 1,000	$<10^{-8}$ cc/sec	48,000
3092	Single Bead	42.0	$<10^{-8}$ cc/sec	Yes	O K to 10,000	$<10^{-8}$ cc/sec	51,000

(1) See comment on Table IV. There is still evidence of a poor sealing condition although the leak rates are acceptable. See S/N's 3093 and 3090.

(2) An attempt was made to check the integrity of the seal by pressurizing with dry nitrogen up to 10,000 psi and observing for leakage.

(3) The seals leaked at this point.

Table VI

Repeat of tests per Table V except with the use of individual 4 pin seals with straight (non-headed) pins.

S/N	Type of Seal	Hardness	Helium Leak	Thermal Shock	N_2 Pressurize	Helium Leak	Pressure to Destruct
3105	Individual 4 Pin	36.0	Gross Leaker	Yes	Leak <1000 psi	Gross Leaker	-
3106	Individual 4 Pin	41.5	$<10^{-8}$ cc/sec	Yes	O K to 10,000	$<10^{-8}$ cc/sec	88,000 (3)
3107	Individual 4 Pin	42.0	$<10^{-8}$ cc/sec	Yes	O K to 10,000	$<10^{-8}$ cc/sec	82,000
3108	Individual 4 Pin	39.0	$<10^{-6}$ (1) cc/sec	Yes	O K to 10,000	$<10^{-8}$ cc/sec (2)	90,000

(1) See comments on Tables IV and V

(2) Evidently the thermal shock improves the seal - probably because glycerine is trapped in any seal voids when the device is shocked from +300°F. glycerine to -300°F liquid nitrogen.

(3) Seals leaked at this point.

Table VII

Pressure tests run on glass seals alone - no ceramics; units were hardened as in Table V.

S/N	Type of Seal	Hardness	Helium Leak	Thermal Shock	N_2 Pressurize	Helium Leak	Pressure to Destruct
3109	Individual 4 Pin	41.0	$<10^{-8}$ cc/sec	Yes	0 K to 10,000	$<10^{-8}$ cc/sec	69,000 (3)
3110	Individual 4 Pin	41.0	$<10^{-8}$ cc/sec	Yes	0 K to 10,000	$<10^{-8}$ cc/sec	80,000
3115	Single Pin Seal	43.5	$<10^{-6}$ cc/sec (1)	Yes	Leaked at 1,000	$<10^{-8}$ cc/sec (2)	28,000
3117	Single Pin Seal	43.0	Gross Leak	Yes	Gross Leaker	-	-
3118	Single Pin Seal	42.0	$<10^{-6}$ cc/sec	Yes	Leaked at 3,000	$<10^{-8}$ cc/sec	35,000

(1) See comments on Tables IV and V

(2) See comment #2, Table VI

(3) Seals blew out catastrophically - pins and glass.

Table VIII

Pressure tests on units sealed and hardened per approach #3, to check the effect of using a carbon box completely enclosing the units during sealing - which acts to both control atmosphere and to serve as a thermal "buffer" to prevent rapid furnace temperature changes from affecting the seal.

S/N	Type of Seal	Hardness	Helium Leak	N_2 Pressure	Pressure to Destruct
3144	Individual 4 Pin	37.0	$<10^{-8}$ cc/sec	0 K to 10,000	80,000
3145	Individual 4 Pin	40.0	$<10^{-8}$ cc/sec	Leaked at 2,000	- sectioned
3146	Single bead seal	42.0	$<10^{-8}$ cc/sec	Leaked at 2,000	83,000
3147	Single bead seal	39.0	$<10^{-6}$ cc/sec	Leaked at 2,000	- sectioned
3148	Single bead seal	40.0	$<10^{-6}$ cc/sec	Leaked at 2,000	63,000
3149	Single bead seal	43.0	$<10^{-6}$ cc/sec	Leaked at 2,000	- sectioned
3150	Single bead seal	42.0	$<10^{-6}$ cc/sec	Leaked at 2,000	60,000
3151	Single bead seal	39.0	$<10^{-6}$ cc/sec	Leaked at 2,000	30,000

This series of seals was poor in general, indicating a lack of control in the process in some aspect. However, there was no attempt to locate the cause since it was the feeling of glass to metal sealing engineering that it was impractical to try to refine this particular process because of a number of "in-house" furnace problems.

Table IX

Pressure tests run on seals made with approach #4. The seals were made by running the annealing cycle at 1850° for less than one hour, then rapidly dropping furnace to 1400°F and aging for three hours, then cooling to ambient.

This series was completely successful as can be seen in the data. The single bead seals are considerably weaker than the 4 pin seals. As of this report date, the reason for this being investigated since this conflicts with previous test data - see Tables I, II, III, IV, V and VIII.

S/N	Type of Seal	Hardness	Helium Leak	N_2 Press	Thermal Shock	Helium Leak	N_2 Press	Destruct Pressure
2003	Single Bead	38.0	10^{-8} cc/sec.	OK to 10,000	3 cycles	10^{-8} cc/sec.	OK to 10,000	32,000
2004	Single Bead	38.5	10^{-8} cc/sec.	OK to 10,000	3 cycles	10^{-8} cc/sec.	OK to 10,000	40,000
3156	Single Bead	38.5	10^{-8} cc/sec.	OK to 10,000	3 cycles	10^{-8} cc/sec.	OK to 10,000	35,000
3158	Individual 4 Pin	39.0	10^{-8} cc/sec.	OK to 10,000	3 cycles	10^{-8} cc/sec.	OK to 10,000	85,000
3159	Individual 4 Pin	36.0	10^{-7} cc/sec.	OK to 10,000	3 cycles	10^{-8} cc/sec.	OK to (1) 10,000	86,000
3160	Individual 4 Pin	38.5	10^{-8} cc/sec.	OK to 10,000	3 cycles	10^{-8} cc/sec.	OK to 10,000	81,000
3161	Individual 4 Pin	39.5	10^{-8} cc/sec.	OK to 10,000	3 cycles	10^{-8} cc/sec.	OK to 10,000	81,000
3162	Single Bead	39.0	10^{-7} cc/sec.	OK to 10,000	3 cycles	10^{-8} cc/sec.	OK to (1) 10,000	28,000

(1) See comment #2, Table VI

Because of apparent improvement of the seals' hermeticity when the units are thermally shocked in glycerine and nitrogen, thermal tests will be conducted in the future by shocking the units in an oven stabilized at 300°F to substitute for the heated glycerine used to date.

C. Static Shunt Development

During this period work was continued on fully categorizing the properties of the shunt mix used in the present design. Various particle sizes of silicon carbide were mixed with RTV 615 and inserted into the shunt simulators - see figure #3. Particle sizes investigated were 60 mesh, 80 mesh, 120, 240, 320 400 and an unclassified mesh called "F". Ratios of the silicon carbide to RTV were constant at 2.3/1 by weight. The ease of handling the mixes was very poor at mesh levels below 320. In addition, breakdown levels were variable and not sharp below 320 mesh.

The data are presented in the following tables. Five simulators each were loaded with the various mixes, cured and subjected to all the tests in the order shown in the tables. The data show that acceptable particle sizes are 320 and 400 mesh. Both of these particle sizes can be handled easily when mixed with the RTV and both possess approximately equal characteristics. The 320 mesh is somewhat more consistent on breakdown values but this is subject to question from a reproducibility standpoint.

Investigations on meshes 240 and 400 were previously reported in the first quarterly report.

TABLE X

Anti static shunt simulators per figure #3 with the shunt mix, cured and subjected to a series of tests consisting of insulation resistance prior to loading, insulation resistance after loading, dielectric breakdown tests, static discharge and insulation resistance after testing. Insulation resistance is measured at 100 VDC and dielectric breakdowns are at VAC. Discharges of 25 KV were imposed and observed for any external arcing indicating external breakdown.

MESH 60

Serial #	Test	Pin A to Case	Pin B to Case	Pin C to Case	Pin D to Case	A to B	A to C	A to D	B to C	B to D	C to D
6036	I.R. (Preload)	1.2KM	1.6KM	1.6KM	2KM	800M	1.4KM	1.4KM	1.2KM	1.4KM	800KM
	Ins.Res.(Postload)	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M
	Dielectric (Postload)	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
	25 KV (Postload)	← Very small arc Pin C to Case →				← Small Arc Pin C to Case →					
	Ins.Res.(Postload)	<1M	<1M	<1M	3M	<1M	<1M	3M	<1M	4M	20M
6037	I.R. (Preload)	80M	650M	2KM	600M	550M	1.6KM	600M	1.6KM	1KM	1.8KM
	Ins.Res.(Postload)	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M
	Dielectric (Postload)	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
	25 KV (Postload)	← Arced Pin A, C to case →				← Arced Pin A to Case →					
	Ins.Res. (Postload)	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M
6038	I.R. (Preload)	5KM	5KM	3.5KM	5KM	5KM	5KM	5KM	5KM	5KM	5KM
	Ins.Res. (Postload)	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M
	Dielectric (Postload)	← Did not take →									
	25KV (Postload)	← Arced Pin A, C to Case →				← Arced Pin C to Case →					
	Ins.Res. (Postload)	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M

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TABLE X (Cont.)

MESH 60

Serial #	Test	Pin A to Case	Pin B to Case	Pin C to Case	Pin D to Case	A to B	A to C	A to D	B to C	B to D	C to D
6039	I.R. (Preload)	4KM	200M	5KM	5KM	5KM	5KM	5KM	5KM	5KM	5KM
	Ins.Res (Postload)	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M
	Dielectric (Postload)	D I D N O T T A K E									
	25 KV (Postload)	← Arced Pin A & D to Case →				← Arced Pin A & D to Case →					
	Ins. Res. (Postload)	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M
6040	I.R. (Preload)	1.6KM	1.8KM	2KM	2KM	1.3KM	1.5KM	1.4KM	1KM	1.6KM	1.2KM
	Ins.Res. (Postload)	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M
	Dielectric (Postload)	D I D N O T T A K E									
	25 KV (Postload)	← NO ARCS →				← NO ARCS →					
	Ins.Res. (Postlaod)	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M	<1M

MESH 80

Serial #	Test	Pin A to Case	Pin B to Case	Pin C to Case	Pin D to Case	A to B	A to C	A to D	B to C	B to D	C to D
6021	I.R. (Preload)	3KM	3.5KM	1.4KM	1.3KM	3.5KM	3KM	3KM	3KM	3.5KM	1.3KM
	Ins.Res. (Postload)	16M	800M	2KM	Short	5KM	5KM	300M	5KM	500M	1.8KM
	Dielectric (Postload)	<200	<200	<200	<200	<200	<200	<350	<200	<200	<200
	25 KV (Postload)	← D to Case →				← A, C & D to Case →					
	Ins.Res. (Postload)	<1M	<1M	<1M	<1M	<1M	<1M	1.5M	1M	3M	3.2M
6022	I.R. (Preload)	5KM	5KM	5KM	5KM	5KM	5KM	5KM	5KM	5KM	5KM
	Ins.Res. (Postload)	3.6M	2M	5KM	2KM	400M	5KM	5KM	5KM	5KM	5KM
	Dielectric (Postload)	<200	<200	250	<200	<200	300	<200	250	<200	300
	25 KV (Postload)	← B & C to Case →				← A & B to Case →					
	Ins.Res. (Postload)	<1M	<1M	28M	<1M	<1M	160M	<1M	45M	<1M	36M
6023	I.R. (Preload)	5KM	5KM	5KM	5KM	5KM	5KM	5KM	5KM	5KM	5KM
	Ins.Res. (Postload)	<1M	5M	600M	1KM	2M	2M	7M	3M	5KM	5KM
	Dielectric (Postload)	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200
	25 KV (Postload)	← D to Case →				← D to Case →					
	Ins.Res. (Postload)	<1M	<1M	<1M	20M	8M	<1M	650M	1M	800M	500M

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TABLE X (Cont.)

MESH 80

Serial #	Test	Pin A to Case	Pin B to Case	Pin C to Case	Pin D to Case	A to B	A to C	A to D	B to C	B to D	C to D
6024	I.R. (Preload)	5KM	5KM	5KM	5KM	5KM	5KM	5KM	5KM	5KM	5KM
	Ins.Res. (Postload)	5KM	2M	5KM	<1M	5KM	5KM	5KM	5KM	6M	5KM
	Dielectric (Postload)	300	<200	<200	<200	<200	300	250	<200	<200	<200
	25 KV (Postload)	OK	OK	OK	OK	←— OK —→					
	Ins.Res. (Postload)	20M	<1M	5M	<1M	7M	2KM	20M	2KM	<1M	1.8KM
6025	I.R. (Preload)	1.6KM	900M	5KM	550M	1.6KM	5KM	2.5KM	5KM	1.3KM	5KM
	Ins.Res.(Postload)	200M	<1M	3M	50M	1KM	2KM	3KM	300M	75M	50M
	Dielectric (Postload)	<200	<200	<200	<200	<200	<200	<200	300	<200	<200
	25 KV (Postload)	←— A to Case —→				←— A & B to Case —→					
	Ins.Res. (Postload)	<1M	<1M	240M	<1M	14M	30M	18M	16M	<1M	200M

MESH 120

Serial #	Test	Pin A to Case	Pin B to Case	Pin C to Case	Pin D to Case	A to B	A to C	A to D	B to C	B to D	C to D
6031	I.R. (Preload)	4KM	4KM	4KM	4KM	3.5KM	4KM	3KM	2KM	3KM	3KM
	Ins.Res.(Postload)	2.6M	1KM	1M	2.4M	1.8KM	120M	450M	1.6KM	3KM	5M
	Dielectric (Postload)	<200	350	<200	<200	<200	250	<200	250	400	300
	25 KV (Postload)	←— No Arcs —→				←— Arced Pin D to Case —→					
	Ins.Res. (Postload)	<1M	4M	<1M	1M	50M	5M	15M	24M	68M	12M
6032	I.R. (Preload)	1.2KM	800KM	700M	1KM	1.3KM	1.3KM	1KM	600M	900M	600M
	Ins.Res. (Postload)	1.4KM	<1M	300M	<1M	1.6KM	2.5KM	1.6KM	700M	50M	1KM
	Dielectric (Postload)	400	<200	300	<200	500	600	500	350	<200	200
	25 KV (Postload)	←— No Arcs —→				←— Small Arc - Pin A to Case —→					
	Ins.Res.(Postload)	75M	30M	300M	<1M	1.2M	1.8M	320M	700M	100M	550M
6033	I.R. (Preload)	5KM	2KM	2KM	5KM	5KM	5KM	5KM	3KM	5KM	5KM
	Ins.Res. (Postload)	5M	1M	<1M	200M	1.8KM	55M	1.2KM	1.6KM	3.5KM	700M
	Dielectric (Postload)	<200	300	<200	300	<200	<200	<200	<200	<200	<200
	25 KV (Postload)	←— Arced Pin B to Case —→				←— Arced Pin B, C, D to Case —→					
	Ins.Res. (Postload)	<1M	30M	<1M	10M	60M	5M	5M	400M	500M	4M

Dielectric Breakdown was not sharp

TABLE X (Cont)

MESH 120

Serial #	Test	Pin A to Case	Pin B to Case	Pin C to Case	Pin D to Case	A to B	A to C	A to D	B to C	B to D	C to D
6034	I.R. (Preload)	1.6KM	2KM	2KM	1.8KM	1.4KM	1.4KM	900M	1.2KM	1.4KM	1KM
	Ins.Res. (Postload)	900M	<1M	50M	24M	1KM	1.5KM	2.5KM	65M	26M	1KM
	Dielectric (Postload)	300	<200	250	<200	400	550	450	300	<200	300
	25 KV (Postload)	←Small Arc - Pin C to Case →				← No Arcs →					
	Ins. Res. (Postload)	20M	<1M	7M	<1M	100M	300M	100M	50M	14M	120M
6035	I.R. (Preload)	5KM	5KM	750M	2KM	5KM	5KM	5KM	5KM	5KM	2.5KM
	Ins. Res. (Postload)	<1M	1.3M	<1M	4M	1.4KM	<1M	3M	1.3KM	1.6KM	1.2M
	Dielectric (Postload)	<200	400	<200	<200	450	<200	<200	400	<200	<200
	25 KV (Postload)	← No Arcs →				←Arced Pin B to Case →					
	Ins. Res. (Postload)	<1M	45M	24M	1.5M	130M	200M	11M	1.3M	280M	400M

Dielectric Breakdown was not sharp

MESH 320

Serial #	Test	Pin A to Case	Pin B to Case	Pin C to Case	Pin D to Case	A to B	A to C	A to D	B to C	B to D	C to D
6016	I.R. (Preload)	5KM	3.5KM	750M	5KM	4KM	5KM	5KM	2.5KM	5KM	5KM
	Ins.Res (Postload)	5KM	4KM	3.5KM	5KM	5KM	5KM	5KM	5KM	5KM	5KM
	Dielectric (Postload)	800	350	450	600	800	900	1050	650	800	1150
	25 KV (Postload)	← O K →									
	Ins.Res. (Postload)	100M	1M	50M	5KM	600M	4KM	5KM	1.4KM	5KM	5KM
6017	I.R. (Preload)	5KM	5KM	5KM	5KM	2KM	2.5KM	1.8KM	1.8KM	2.5KM	1.6KM
	Ins.Res (Postload)	5KM	5KM	5KM	5KM	5KM	5KM	5KM	4KM	5KM	4KM
	Dielectric (Postload)	450	500	650	550	600	1100	550	1000	700	600
	25 KV (Postload)	OK	OK	OK	OK	← Arced A to Case →					
	Ins.Res.(Postload)	4KM	3.5KM	4KM	4KM	4KM	5KM	4KM	5KM	5KM	5KM
6018	I.R. (Preload)	5KM	5KM	5KM	5KM	5KM	5KM	2KM	5KM	5KM	5KM
	Ins. Res.(Postload)	5km	5KM	5KM	5KM	5KM	5KM	5KM	5KM	5KM	5KM
	Dielectric (Postload)	550	550	600	700	1300	700	650	700	600	800
	25 KV (Postload)	← B to Case →				← D to Case →					
	Ins.Res. (Postload)	4KM	5KM	1.3KM	5KM	5KM	5KM	5KM	5KM	5KM	5KM

TABLE X (Cont.)

MESH 320

Serial #	Test	Pin A to Case	Pin B to Case	Pin C to Case	Pin D to Case	A to B	A to C	A to D	B to C	B to D	C to D
6019	I.R. (Preload)	5KM	5KM	5KM	5KM	2KM	3KM	3KM	2KM	3KM	3KM
	Ins. Res. (Postload)	4KM	4KM	5KM	5KM	4KM	5KM	5KM	4KM	5KM	5KM
	Dielectric (Postload)	800	600	400	800	800	850	1050	650	700	950
	25 KV (Postload)	OK	OK	OK	OK	←		OK			→
	Ins. Res. (Postload)	1.3KM	400M	2KM	100M	4KM	5KM	5KM	4KM	5KM	5KM
6020	I.R. (Preload)	5KM	5KM	5KM	5KM	5KM	5KM	5KM	5KM	5KM	3KM
	Ins. Res. (Postload)	5KM	5KM	5KM	5KM	5KM	5KM	5KM	5KM	5KM	5KM
	Dielectric (Postload)	700	650	650	650	500	800	950	800	1250	1100
	25 KV (Postload)	OK	OK	OK	OK	←	A	T O	C A S E		→
	Ins. Res. (Postload)	5KM	5KM	5KM	5KM	5KM	5KM	5KM	5KM	5KM	5KM
6041	I.R. (Preload)	200M	100M	85M	200M	210M	240M	300M	140M	240M	220M
	Ins. Res. (Postload)	3 KM	3KM	3KM	3KM	3.5KM	4KM	4KM	2KM	4KM	4KM
	Dielectric (Postload)	900	700	750	800	700	500	750	600	600	350
	25 KV (Postload)	← No	Arcs Observed		→	←		No Arcs	Observed		→
	Ins. Res. (Postload)	600M	240M	1.2KM	100M	2KM	3KM	3KM	1.4KM	1.4KM	3KM
6042	I.R. (Preload)	160M	130M	150M	150M	220M	250M	230M	230M	260M	260M
	Ins. Res. (Postload)	4KM	3KM	4KM	3KM	4KM	4KM	4KM	4KM	4KM	4KM
	Dielectric (Postload)	850	800	950	800	700	550	700	450	650	600
	25 KV (Postload)	← No	Arcs Observed		→	←		No Arcs	Observed		→
	Ins. Res. (Postload)	100M	60M	2.5KM	65M	900M	4KM	900M	3KM	800M	4KM
6043	I.R. (Preload)	50M	120M	220M	130M	170M	270M	160M	280M	230M	280M
	Ins. Res. (Postload)	2KM	1.8KM	3KM	3KM	3.5KM	4KM	3KM	4KM	4KM	4KM
	Dielectric (Postload)	850	600	800	900	550	500	600	550	450	550
	25 KV (Postload)	← No	Arcs Observed		→	←		No Arcs	Observed		→
	Ins. Res. (Postload)	2.6M	550M	500M	55M	1.6KM	900M	100M	3KM	3KM	2KM

Dielectric had sharp breakdown

TABLE X (Cont)

MESH 320

Serial #	Test	Pin A to Case	Pin B to Case	Pin C to Case	Pin D to Case	A to B	A to C	A to D	B to C	B to D	C to D	
6044	I.R. (Preload)	120M	230M	220M	220M	320M	320M	340M	430M	450M	430M	Dielectric had sharp breakdown
	Ins.Res.(Postload)	2KM	3KM	1.8KM	2KM	4KM	4KM	4KM	4KM	5KM	5KM	
	Dielectric (Postload)	750	800	700	800	600	600	800	500	550	550	
	25 KV (Postload)	← No	Arcs	Observed	→	← No		Arcs	Observed		→	
	Ins.Res. (Postload)	450M	5M	6M	150M	900M	1KM	2KM	22M	200M	260M	
6045	I.R. (Preload)	340M	330M	320M	320M	500M	550M	500M	450M	450M	400M	
	Ins.Res. (Postload)	3.5KM	1KM	1.4KM	1.8KM	5KM	4KM	4KM	4KM	4KM	4KM	
	Dielectric (Postload)	900	750	650	650	750	800	700	650	400	450	
	25 KV (Postload)	←	No Arcs	Observed	→	←	No	Arcs	Observed		→	
	Ins.Res. (Postload)	120M	80M	100M	120M	1KM	1.6KM	1KM	1.2KM	800M	1KM	

MESH F

Serial #	Test	Pin A to Case	Pin B to Case	Pin C to Case	Pin D to Case	A to B	A to C	A to D	B to C	B to D	C to D	
6026	I.R. (Preload)	1.8KM	2KM	400M	300M	2.5KM	3KM	2KM	2KM	2KM	550M	Dielectric breakdown was sharp
	Ins.Res.(Postload)	600M	140M	400M	80M	4KM	4.5KM	3.5KM	4KM	3.5KM	4KM	
	Dielectric (Postload)	350	450	400	300	750	750	550	600	900	700	
	25 KV (Postload)	← Arced	Pin B	to Case	→	← Arced		Pin	B to	Case	→	
	Ins.Res.(Postload)	70M	4KM	50M	4KM	4KM	1.6KM	4KM	5KM	5KM	5KM	
6027	I.R. (Preload)	3KM	3KM	3KM	3KM	750M	750M	850M	450M	800M	550M	
	Ins.Res. (Postload)	24M	220M	300M	100M	1.4KM	1.6KM	1.3KM	1.3KM	1.6KM	1.4KM	
	Dielectric (Postload)	300	300	700	<200	400	700	900	800	450	600	
	25 KV (Postload)	←	No Arcs		→	←	No	Arcs			→	
	Ins.Res.(Postload)	10M	1.6M	50M	32M	38M	700M	430M	240M	140M	850M	
6028	I.R. (Preload)	3KM	4KM	1.4KM	2KM	4KM	3KM	1.8KM	4KM	4KM	1.4KM	
	Ins.Res.(Postload)	300M	300M	425M	9M	4KM	4KM	1.8KM	4KM	2KM	2.5KM	
	Dielectric (Postload)	300	650	500	<200	900	900	650	450	450	750	
	25 KV (Postload)	← Arced	Pin D	to Case	→	←	Arced	Pin D	to Case		→	
	Ins.Res. (Postload)	110M	2M	90M	1.5M	500M	2.5KM	750M	300M	38M	550M	

This mesh is reported by the manufacturer to be approximately five times the average particle size of a 320 mesh classification.

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TABLE X (Cont)

MESH F

Serial#	Test	Pin A to Case	Pin B to Case	Pin C to Case	Pin D to Case	A to B	A to C	A to D	B to C	B to D	C to D	
6029	I.R. (Preload)	650M	2KM	5KM	4KM	3KM	5KM	5KM	5KM	5KM	5KM	Dielectric breakdown was sharp
	Ins.Res.(Postload)	3KM	36M	26M	180M	4KM	5KM	5KM	2KM	2KM	3KM	
	Dielectric (Postload)	500	400	500	550	550	350	550	400	450	400	
	25 KV (Postload)	← No Arcs →				← Arced Pin C to Case →						
	Ins.Res.(Postload)	170M	1M	17M	3.6M	420M	1KM	500M	85M	22M	1.3KM	
6030	I.R. (Preload)	2KM	4KM	3.5KM	4.5KM	4.0KM	4.0KM	5.0KM	5KM	5KM	5KM	
	Ins.Res.(Postload)	70M	10M	14M	18M	1.3KM	1.4KM	1.7KM	900M	1.2KM	1.2KM	
	Dielectric (Postload)	500	500	450	500	450	350	450	400	500	400	
	25 KV (Postload)	← No Arcs →				← Arced Pin C to Case →						
	Ins.Res.(Postload)	2.4M	3.4M	<1M	5M	27M	15M	32M	20M	60M	30M	
6046	I.R. (Preload)	90M	100M	90M	95M	180M	180M	180M	160M	180M	150M	Dielectric had moderately sharp breakdown
	Ins.Res.(Postload)	260M	45M	22M	700M	1.8KM	2KM	3KM	1.4KM	3KM	2KM	
	Dielectric (Postload)	600	500	550	750	900	500	650	550	500	550	
	25 KV (Postload)	← No Arcs Observed →				← No Arcs Observed →						
	Ins.Res.(Postload)	32M	6M	5.5M	25M	260M	300M	400M	160M	250M	240M	
6047	I.R. (Preload)	150M	180M	170M	220M	320M	320M	340M	320M	380M	340M	
	Ins.Res.(Postload)	10M	4M	1.4KM	270M	850M	4KM	3KM	4KM	2KM	4KM	
	Dielectric (Postload)	500	400	600	650	500	550	400	450	350	450	
	25 KV (Postload)	← No Arcs Observed →				← Arced Pin C to Case →						
	Ins.Res. (Postload)	2M	1M	50M	22M	18M	120M	150M	100M	130M	500M	
6048	I.R. (Preload)	100M	140M	150M	150M	250M	280M	270M	260M	300M	280M	
	Ins.Res. (Postload)	1.3KM	120M	15M	1.2KM	3KM	3KM	4KM	1.8KM	3KM	3KM	
	Dielectric (Postload)	750	550	450	700	500	500	700	400	500	400	
	25 KV (Postload)	← No Arcs Observed →				← No Arcs Observed →						
	Ins.Res. (Postload)	6M	4M	6M	32M	80M	75M	200M	120M	300M	400M	

TABLE X (Cont.)

MESH F

Serial #	Test	Pin A to Case	Pin B to Case	Pin C to Case	Pin D to Case	A to B	A to C	A to D	B to C	B to D	C to D
6049	I.R. (Preload)	100M	150M	130M	75M	280M	260M	200M	250M	230M	180M
	Ins.Res.(Postload)	1.3KM	700M	240M	340M	3KM	3KM	3KM	2KM	3KM	2KM
	Dielectric (Postload)	650	750	550	500	500	450	400	600	450	450
	25 KV (Postload)	←	No Arcs	Observed	→	←	No	Arcs	Observed	→	
	Ins.Res.(Postload)	13M	10M	40M	12M	130M	1KM	160M	900M	170M	1KM
6050	I.R. (Preload)	110M	260M	100M	120M	380M	240M	240M	360M	350M	200M
	Ins.Res. (Postload)	800M	500M	3KM	1.4KM	4KM	4KM	3.5KM	4KM	3KM	4KM
	Dielectric (Postload)	550	650	800	700	500	500	450	750	550	750
	25 KV (Postload)	←	No Arcs	Observed	→	←	Arced	Pin D	to Case	→	
	Ins.Res.(Postload)	20M	24M	14M	40M	380M	150M	380M	300M	700M	240M

Dielectric had moderately sharp breakdown

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D. Explosive Charge Studies

In this phase of the program, testing continued on pyrotechnic mixes with and without binders in various test vehicles. One of the test vehicles is a dual cavity ceramic squib. A practical way of pressing dry powder into a cavity is to fabricate a die-set to guide a press pin into the cavity. However, considering the size of the ceramic cavity in the dual cavity squib, it will be difficult to fabricate a die-set with very close tolerances. It is vital to have the powder pressed uniformly across the bridgewire to assure consistent test results. To overcome all these difficulties, initially, if a powder is pressed into a pellet shape with the slip fit dimensions of the ceramic cavity, this pellet can be reconsolidated and so a uniform pressure can be assured against the bridgewire. Therefore, efforts were directed towards producing dry, shaped pellets possessing the necessary physical strength characteristics for handling, loading, and reconsolidation at a higher pressure.

A die set was fabricated to yield a contour shaped pellet having dimensions which permit loading into the dual cavity ceramic. Difficulties were encountered with inserting the pellets into the cavities. A dimensional analysis of the interior surfaces of the ceramic cavities revealed a substantial degree of dimensional irregularity which interferes with the pellet. Since the pellet size was already rather minute, 17 mg., it was felt a further decrease in size would present additional complications. Also, the procurement and fabrication of new tooling would be time consuming and possibly unnecessary since the boron ignition mix has demonstrated capability of withstanding high voltage discharge in the alternate design (a simple cup-shaped ceramic).

All investigations to date have shown the superiority of a mix of Boron/$KClO_4$/$Ba(NO_3)_2$ over any other mixes tested. Recent work has concentrated on this mix.

Samples of this mix were tested for sensitivity to static discharges employing the standard Bureau of Mines tester with both a variable voltage with a fixed capacitance and a fixed voltage with variable capacitance. The tests were conducted so as to determine the lowest voltage or energy level for ten no powder ignitions in ten trials. A spark gap distance of 0.080" was used in all the tests. Sample size was 10 mgs.

Test results:

Fixed capacitance - of 500 pfd's - 5 KV (0.0063 joule)

Fixed voltage - of 5 KV - 900 pfd's (0.0113 joule)

Fixed voltage variable capacitance tests were conducted on dry, cylindrical pellets of the same mix weighing approximately 75 mgs. each. One group was pressed at 10,000 psi and the other at 20,000 psi.

The results for ten no ignitions in the trials are as follows:

10,000 psi pellets: 15 KV - 60,000 pfd's (6.75 joules)

20,000 psi pellets: 15 KV - 90,000 pfd's (10.125 joules)

From these results it is evident that powder sensitivity is affected by degrees of compaction, and that the explosive becomes less sensitive with higher compaction - a result verified in squib testing.

Some additional testing has yielded the following information pertinent to the boron mix.

1. Heat of combustion - 1.63 K cal/gm.
2. Autoignition temperature - 1 sec. approx. 975°F.

A Bruceton test was conducted using simulators to establish the sensitivity of the powder at some base level. It is not the level at which the finished squib will fire, but merely gives us a gauge for comparison.

Following a no-fire of 1 amp for 5 min. at +160°F., the all-fire at -65°F. has a value for $\overline{X}$ + 4 sigma of 3.49 amps.

Test results on different pyrotechnic mixes with and without binders in various test vehicles are tabulated as follows:

A. Static Sensitivity Test in the Phenolite Fixture (per figure #4)

	Powder	Lowest Level at Which Unit Fired in KV's	# Tested	Resistance in Ohms (before test)
1.	$B/KClO_4/Ba(NO_3)_2$ 40/45/15 B treated with HF	13.5 KV	2	$>10^8$
2.	$B/KClO_4/Ba(NO_3)_2$ 25/55/20 B treated with HF	15 KV	1	$>10^8$
3.	$B/KClO_4/KNO_3$ 25/55/20	15 KV	3	$>10^7$
4.	$Zr/KClO_3/Ba(NO_3)_2$ 52.44/24.39/23.17 (Percentages calculated without a binder per JPL Drawing No. 10000597)	2 KV	2	$>10^8$
5.	$Mn/KNO_3/KClO_4$ 23.3/19.5/57.2	Did not fire at 25 KV	1	$>10^9$

Adding Approximately 1% RTV

	Powder	Lowest Level at Which Unit Fired in KV's	# Tested	Resistance in Ohms (before test)
1.	$B/KClO_4/Ba(NO_3)_2$ 25/55/20	Did not fire at 25 KV	3	$>10^{10}$
2.	$Zr/Mg/KClO_4$ 25/15/60	10 KV	1	$>10^9$
3.	$Mo/KClO_4/CaCrO_4$ 44/34/22	Did not fire at 25 KV	3	$>10^9$
4.	$Zr/KClO_3/Ba(NO_3)_2$ Per Dwg.	4 KV	1	$>10^{10}$
5.	$B/KClO_4/KNO_3$ 25/55/20	Did not fire at 25 KV	2	$>10^{10}$

B. Sensitivity Test in A Simulator Using Various Binders

All units were no-fired at +160°F. for 5 min. with 1 amp, and all-fired at -65°F. with 4 amps 5 millisecond pulse.

Powder	Dry Charge	10%RTV Sol. in Xylene	Viton Solution	Epoxylite	Skybond 700
No. of Units Tested	5	1	1	1	1
$Zr+KClO_3/Ba(NO_3)_2$	X	X	X	X	X
$B+KClO_4+KNO_3$	X	X	X	Y	Y
$B+KClO_4+Ba(NO_3)_2$	X	X	X	Y	Y
$Zr+Mg+KClO_4$	X	X	X	Y	Y
$Mo+KClO_4+CaCrO_4$	X	X	X	Y	Y

X: Passed all tests Y: Did not pass all-fire

C. $B/KClO_4/Ba(NO_3)_2$ pressed at 20,000 psi into 5 each cup-shaped ceramics simulating the actual squib design (without shunt mix) was subjected to the following tests:

Serial No.	Resistance in Ohms (Before Discharge)	KV Discharge From a 500 pfd Capacitor 1st Discharge	2nd Discharge	Resistance after Discharge in Ohms 1st Discharge	2nd Discharge
4001	$>10^6$	5	25	$>10^6$	$>10^6$
4002	$>10^6$	10	25	$>10^6$	$>10^6$
4003	$>10^6$	15	25	$>10^6$	$>10^6$
4004	$>10^6$	20	25	$>10^6$	$>10^6$
4005	$>10^6$	25	25	$>10^6$	$>10^6$

D. The previous units were then all fired at -65°F, 4 amp for 5 msec. pulse.

Serial No.	Bridgewire Resistance in Ohms	No Fire at +160°F. 1 amp for 5 Min.	B.W. Burnout Time from Oscilloscope in MS
4001	0.98	Pass	1.8
4002	1.19	Pass	1.7
4003	1.006	Pass	1.5
4004	1.07	Pass	2.0
4005	1.07	Pass	2.0

It appears that the boron mix satisfies most of the requirements pertaining to sensitivity.

The $Mn/KNO_3/KClO_4$ mix in paragraph A has yet to be tested for firing sensitivity.

The $Mo/KClO_4/CaCrO_4$ mix in paragraphs A & B will be tested for discharge capability in the simulator with varying percentages of binder in the near future.

At this time in the development of the appropriate pyrotechnic combination it is important that testing be performed in simulators to establish more precisely, certain characteristics. A hindrance in the progress of this evaluation has been the lack of a sufficient quantity of simulators because of their relatively great expense. This compels us to rely heavily on a meager accumulation of test data and to use this data as a screening process at this stage.

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 discharges of up to and over 25 KV from a 500 uuf 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 bridge wires and loading of the explosive charge.

Still to be realized - or rather demonstrated - is the capability of the complete squib to withstand heat sterilization, exposure to hard vacuum for extended periods, exposure to long term storage from -400°F. to +250°F. and the capability of functioning at any temperature from -200°F. to +300°F.

The demonstation of these capabilities may be accomplished within the next reporting period. Production hardware is expected to be received early February, 1968. At that time complete squibs can be assembled and tested for all of the above.

All-fire and no-fire investigations are not yet complete, although the ignition mix presently being used is capable of withstanding the no-fire level of one amp, one watt and firing within 10 ms. at 4.5 amps.

Although the dry charge $B/KClO_4/Ba(NO_3)_2$ seems most effective, it is recognized that a binder in the pyrotechnics might provide better adhesion to the bridgewire and result in a higher degree of reliability. Problems such as compatibility, outgassing, and high temperature degradation have limited the range of binder additives to those with inert properties. As a result most of these materials have little or no combustibility. The condition leads to interference with pyrotechnic reaction functions, particularly the critical function time (10 ms.). Obviously, more test simulators are needed to establish the practicality of this approach and then, the optimum combination level with some degree of reliability.

DEVELOPMENT HEADER DESIGN

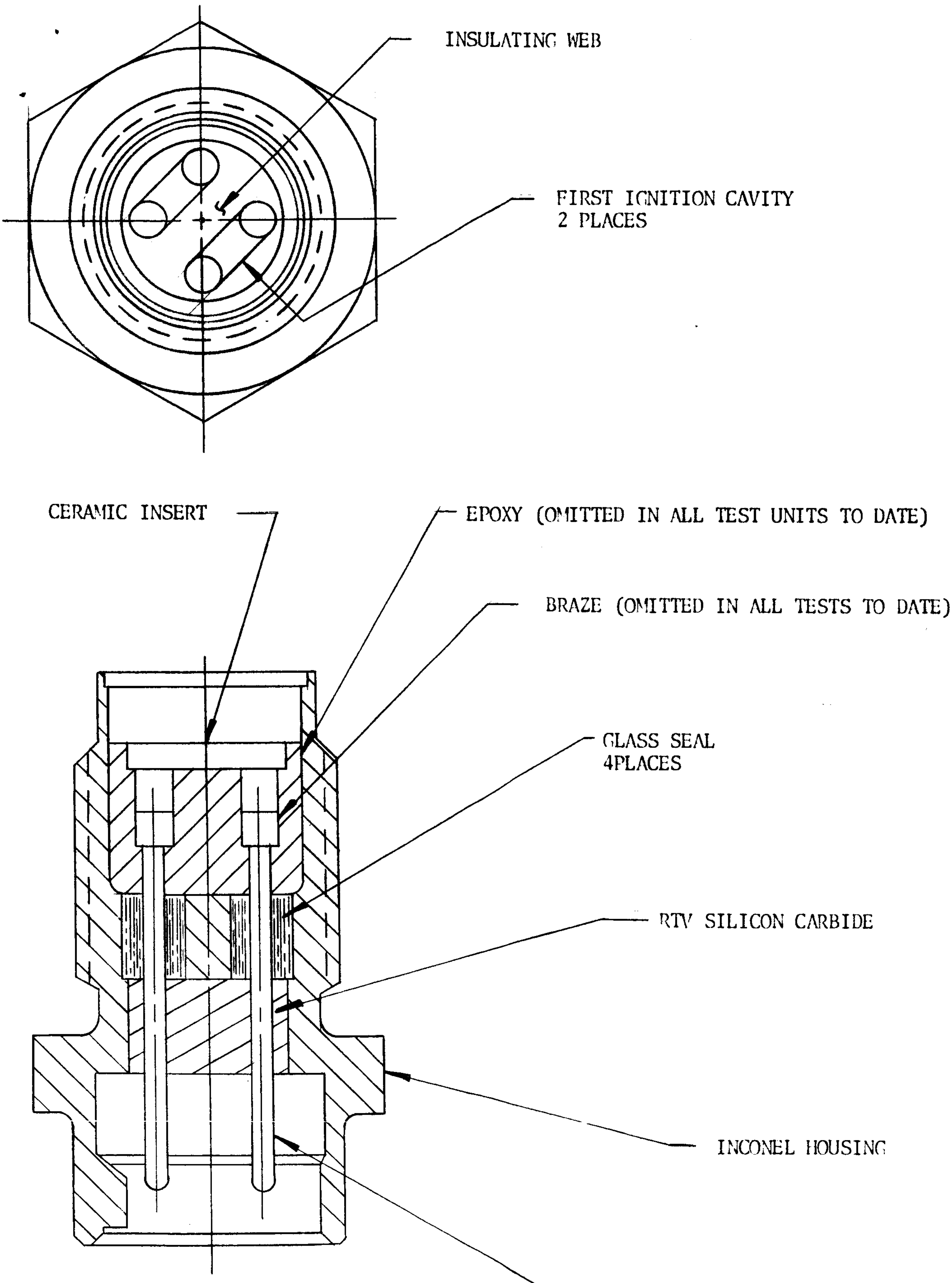
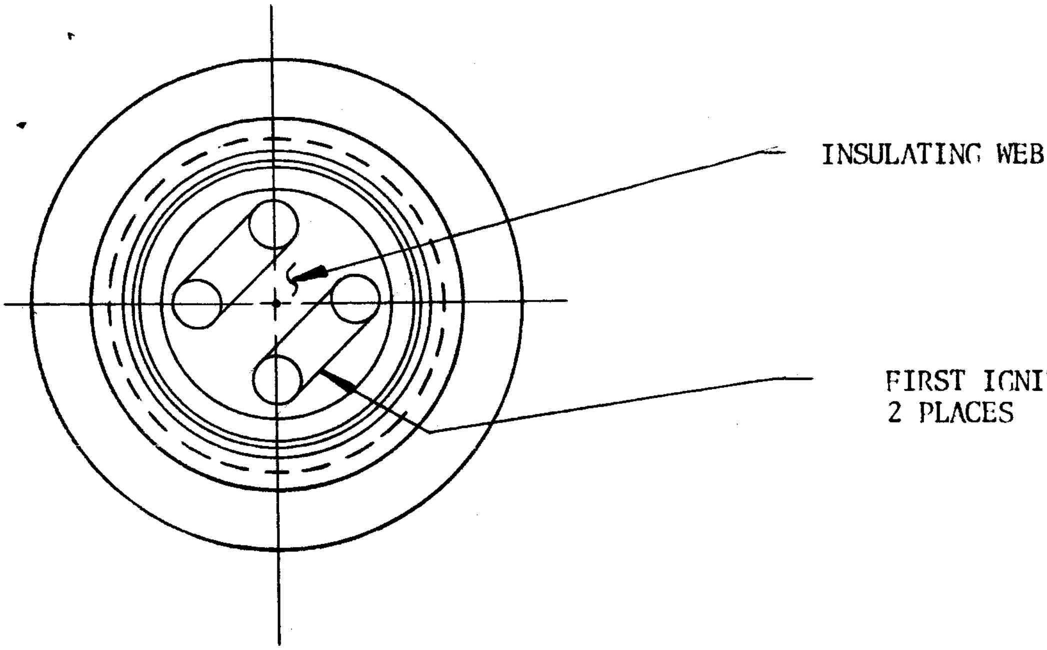


FIGURE 1

DEVELOPMENT HEADER DESIGN



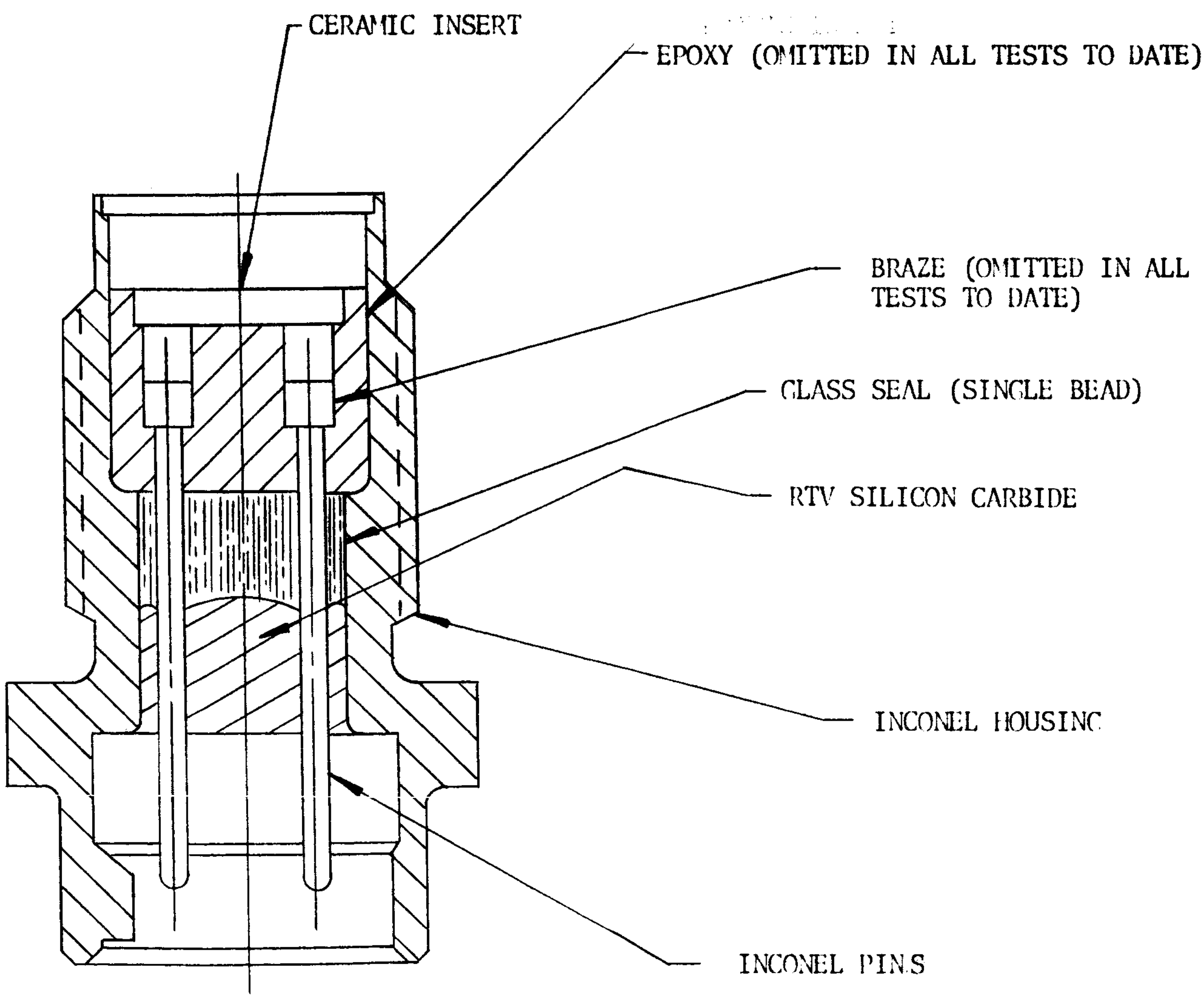


FIGURE 2

TEST BLOCK FOR ANTI-STATIC SHUNT MIX

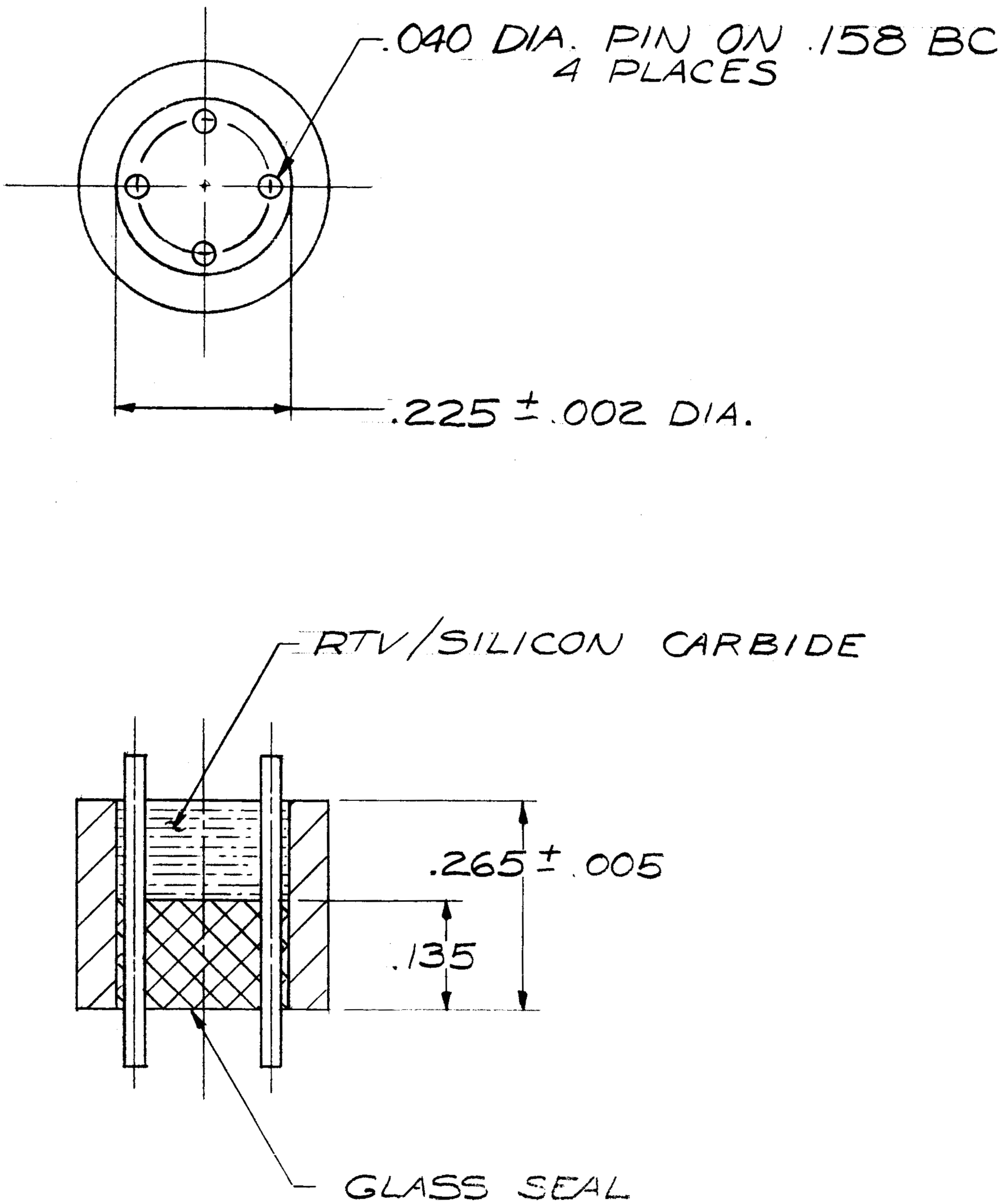


FIGURE 3

ELECTRO STATIC FIXTURE
EXPLOSIVE TEST

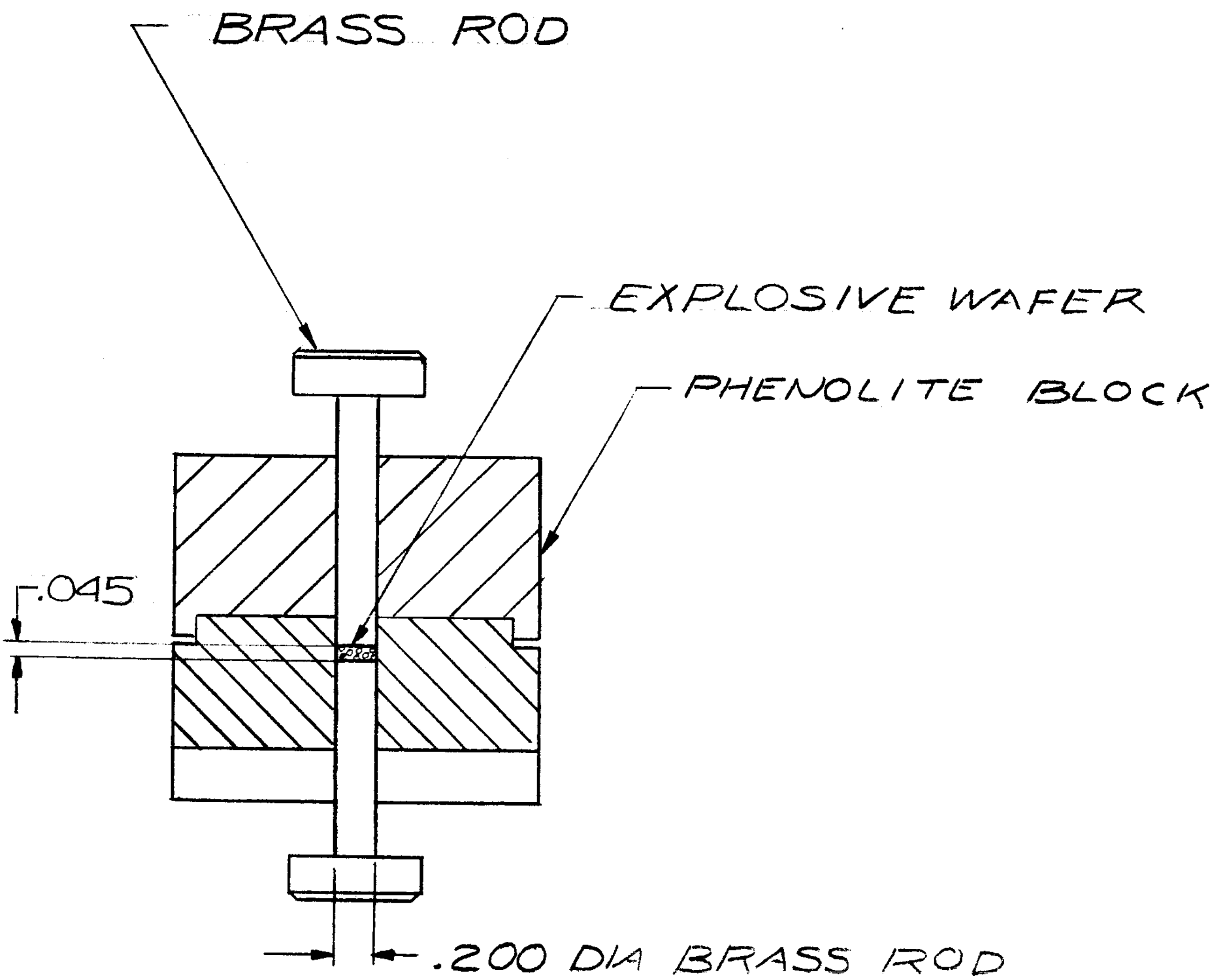


FIGURE 4

DEVELOPMENT HEADER DESIGN

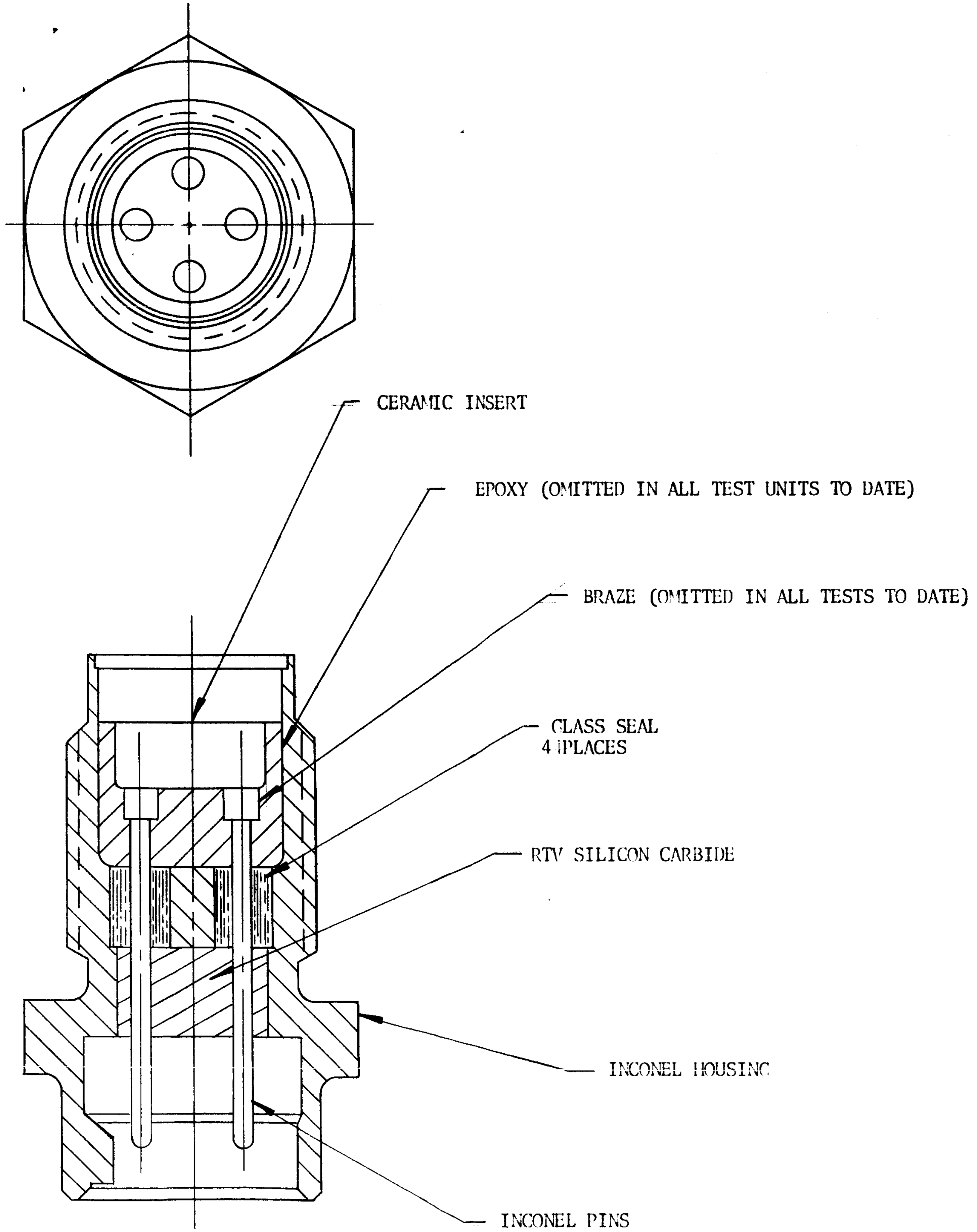


FIGURE 5