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# Titanium-Boron Mixtures as Variable Heat Sources

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## ABSTRACT

The reaction between titanium and boron to form titanium diboride is one of the hottest pyrotechnic reactions in common usage and offers the advantage of being a solid state gasless reaction. Based on the work of Hart[1,2], a heat source with a variable output has been developed that utilizes this pyrotechnic. The device was designed to deliver the heat across a 0.26 inch inner diameter hemispherical bulkhead of a material and thickness that can be specified by the user. For evaluation purposes, the bulkhead was 0.036 inches thick stainless steel. The maximum temperature on the tip of the bulkhead was 950°C for the pure reactants and 680°C for blends diluted with 30 weight percent of alumina. Further, the temperature was uniform within +/- 20°C across a 2 millimeter diameter on the tip of the bulkhead, and the temperature rise characteristics were repeatable. For example, the bulkhead temperature showed a thermal rise of 530°C at 0.2 seconds for the undiluted mix and 0.6 seconds for the 30 wt% diluted mix. In both cases, the sigma less than 20% of the mean. The calorific output of the two blends was 1040 +/- 10 calories/gram and 725 +/- 10 calories/gram respectively, and the behavior for intermediate dilutions was linear.

Ignition of the titanium/boron heat powder was accomplished by first igniting an adjacent charge of titanium subhydride/potassium perchlorate with a one ohm bridge wire. The header was constructed of inconel, a glass ceramic insulator, and hastelloy pins. The ignition and subsequent burn of the titanium/boron was nearly instantaneous, thus the thermal output was dependent only on the heat transfer properties of the materials and geometry involved. Therefore, the user can tailor the blend dilution and the bulkhead characteristics to provide a large range of precise heat outputs. Typical uses of this heat source include timely ignition of other materials, or heating confined gas to perform useful mechanical work.

Acheivment of the precise heat output required special attention to the purity of the titanium and boron and to the blending process. These aspects, as well as those described above will be described.

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## INTRODUCTION

Explosive subsystem design engineers at Sandia National Laboratories and EG&G/Mound Applied Technologies have found recurring need for a free-standing heat source, primarily for through-bulkhead-ignition (TBI) of other materials. The free-standing nature of the heat source would allow installation, removal, and reinstallation at any time, thus eliminating safety concerns of accidental ignition during processing operations or storage. Another possible use is the heating of small volumes of gas to perform mechanical work such as moving a piston. Such a heat source has been developed and is called the Insertable Ignitor.

The feasibility of an Insertable Ignitor was established in 1982 by Munger et al.[1] In the early work, ignition was accomplished by first igniting a mixture of $B/CaCrO_4/Ti/B$ with a one ohm Tophet C bridge wire. This ignition mix in turn ignited a pressing of $Al/Fe_2O_3$ thermite, $Al/Ni/Fe_2O_3$ pyronol thermite, or $Fe/KClO_4$, (FEK), heat powder. The heat powder or thermites were the active element that provided the heat for transfer across the bulkhead. Munger, et al. satisfied their goal of providing bulkhead temperatures in the range of 850 to 950°C, however they also found shot to shot variabilities on the order of 150°C. The recent emphasis has been to improve this variability and provide more flexibility in the range of available thermal output. By using a hot gas producing ignition charge of $TiH_{1.65}/KClO_4$, (TiHKP), and various dilutions of titanium/boron for the active element, bulkhead temperatures in the range of 680 to 950°C can be provided with a variability on the order of +/-30°C. Acheiving these improvements required an understanding of the parameters that affect the thermal output of titanium/boron heat powders. The work that led to the current design of the Insertable is the basis of this report.

## MECHANICAL DESIGN

A cross section of the Insertable Ignitor is shown on Figure 1. The design uses an integral header/charge holder that is fabricated with an Inconel-718 shell and S-glass ceramic. The header is a 3-pin device which provides redundant hot wire bridges. The pins are Hastalloy C-276, and they are sealed in place during the glassing and ceramic formation process. The charge holder cavity is ground in the header exposing the Hastelloy pins for attachment of the bridgewires. The bridges are 0.0019 inch diameter Tophet-C wire of the correct length to yield a bridge resistance of 1 +/- 0.1 ohms, and these are welded to the exposed pins.

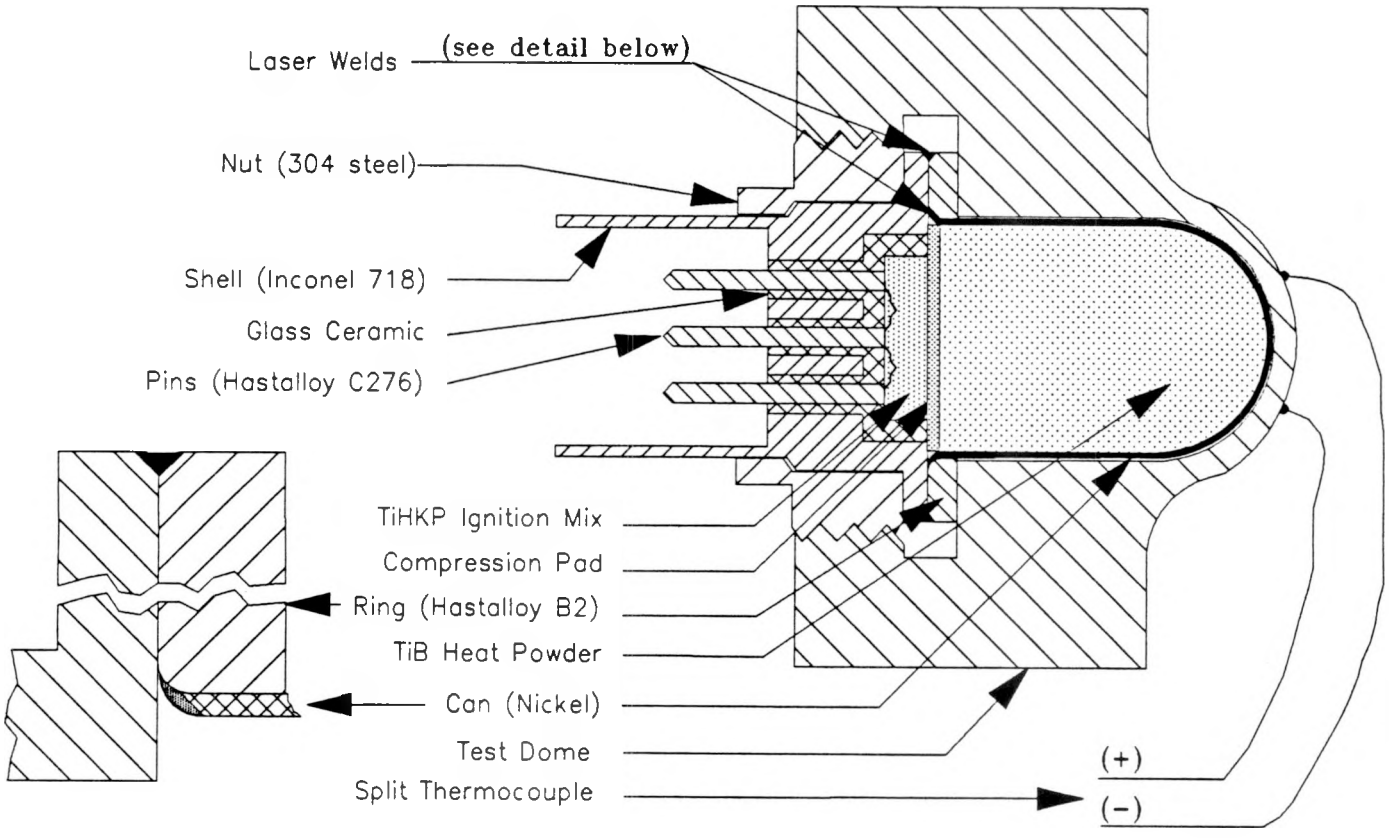


**Figure 1.** Cross section of the Insertable Ignitor installed in a test dome. The diameter of the titanium/boron heat powder column is 0.25 inch and the test dome thickness is 0.036 inch.

The ignition cavity volume is 0.017 $cm^3$, and 35 mg of ignition mix is pressed in the cavity to a dead stop so that the density of the mix is 2.06 $gm/cm^3$. The ignition mix is a blend of 33 wt% titanium subhydride ($TiH_{1.65}$) and 67 wt% $KClO_4$. We commonly refer to this ignition mix as TiHKP, and that acronym will be used throughout this report. The TMD (theoretical maximum density) of TiHKP is 2.83 $gm/cm^3$, thus the porosity is 23%. Other useful properties of TiHKP are; a heat of formation of 1620 cal/gm, an adiabatic flame temperature of 3800°C, and an autoignition temperature of 510°C.

The nickel can, shown in Figure 1, is stamped from 0.005 inch thick soft nickel to form a cylindrical tube with a hemispherical end. The stamped part is cut to a precise length with an EDM process (electro-discharge-machining) and then welded to a Hastelloy-B2 ring to form the can/ring subassembly. The precise nature of the can/ring subassembly is partially responsible for the improved Insertable performance. Final assembly of the Insertable occurs after loading titanium/boron heat powder in the can/ring subassembly. All of the data shown in this report is based on 0.45 gram of heat powder that is loaded in a single pressing. The porosity of the heat powder pressing is 50%. After loading the can/ring subassembly, a silicon rubber compression pad is placed on the consolidated heat powder, and then the loaded header is joined to the loaded can by laser welding the Hastelloy ring to the Inconel flange on the header. The compression pad assures that the TiHKP will not creep away from the bridgewires during the Insertable shelf life. We have observed bridge decoupling when the TiHKP ignition charge is not constrained, consequently, some form of compression is designed into all of our TiHKP hotwire devices.

The performance of the Insertable Ignitors was measured by recording the temperature on the tip of a simulated bulkhead as shown on Figure 1. The internal features of the test dome are held to close tolerances so that there is a maximum 0.002 inch clearance between the outer diameter and length of the Insertable and the inner diameter and depth of the test dome. In order to preserve the insertable features of the device, an interference fit is not allowed. Temperatures were obtained with a split thermocouple in which the plus and minus sides of the thermocouple were spot welded to the test dome, each side being displaced 0.050 inch from the center to give an average reading across the tip of the test dome. The bulkhead is 0.036 inch thick for most of the data that will be shown in this report. In addition to the peak temperature, another parameter that was measured was the time to achieve a temperature rise of 530°C. This temperature was chosen because of an approximate 500°C autoignition temperature of some common pyrotechnics (TiHKP and FEK for example), plus an uncertainty of 30°C in the temperature measurements.

## TITANIUM/BORON HEAT POWDER DEVELOPMENT

### Background.

In order to acheive the goals of precision and flexibility in thermal output, we decided to use a very hot heat powder, and control the output by using inert diluents. A constraint on the heat powder selection was that it not have a liquid phase during the reaction. Liquid phases, from thermites and FEK for example, can interact with the bulkhead wall. This may become important if the Insertable is used in a high pressure application where the strength of the bulkhead becomes a design concern. In the case of copper based thermites, the copper can intrude into the bulkhead grain structure[1].

The FEK heat powders were either too reactive or variable in performance to be of use. The FEK reaction products breached the test dome during a test with an FEK blend that was at a 70-30 wt% ratio. The 70-30 wt% blend of FEK has a calorific yield of 573 cal/gm and an adiabatic flame temperature of 3220°C. The 80-20 wt% FEK blend has a calorific yield of 382 cal/gm and an adiabatic flame temperature of 2500°C. We never observed the breaching phenomenon with the cooler FEK blend, however this heat powder did not give the precision that we were trying to acheive. Thermal records from Insertables that used the FEK heat powders are shown on Figure 2. As evident on the plot for the 80-20 blends of FEK, there is a large variability in both the time to reach a temperature rise of 530°C and in the peak temperature. We believe that a large part of this variability was due to the presence of the mobile liquid phase iron. The random location of the liquid iron would affect the heat capacity of the materials involved causing corresponding hot and cool spots on the dome surface.

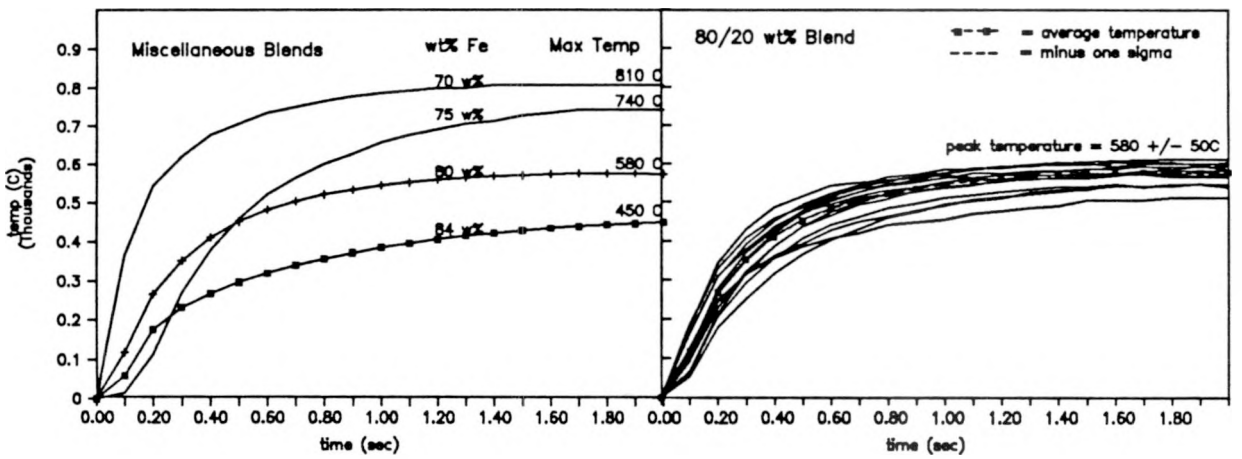


**Figure 2.** Thermal records from test domes and Insertables with iron/potassium perchlorate heat powders. The Insertables were early versions that used 0.002 inch thick nickel cans.

The titanium/boron reaction does not have a mobile liquid phase and is the hottest solid state reaction that we were aware of. Hart[2,3] reports a heat of reaction of 1150 cal/gm for the diboride reaction. Hart also reported the heats of reaction for Ti + 2B blends that were diluted with alumina and titanium diboride, as well as for blends that would form the monoboride and triboride. With the appropiate molar ratios, titanium and boron can form many other products including $Ti_2B_3$ and $Ti_3B_5$.

Munger et al.[1] attempted to use the diboride reaction in their early work, and reported unsatisfactory results. In that work, the blend was prepared by manually stirring the ingredients, and was pressed (to 50% TMD) into a steel liner that was 0.020 inches thick. There was a 0.005 inch thick air gap between the liner and the inside of the test dome. The titanium boron was ignited from a gasless ignition mix. Munger observed a liner temperature of 1300°C, but the dome temperature only reached 250°C, and that occurred on the side of the dome. The results were attributed to poor heat transfer due to the air gap. We now believe that the quality of the blend and the method of titanium/boron ignition contributed to the poor results.

Our first Insertable tests with titanium/boron used a TiHKP ignition charge and a commercial blend of Ti + 2B. We acheived pole temperatures on the order of 950°C, with the peak temperature occuring about two seconds after power was applied to the bridge wire. These results were sufficiently encouraging to suggest that the titanium boron system could be tailored to meet our requirements. To acheive our goals, we investigated the effects of the material purity, blending procedures, titanium to boron ratio, diluent composition and concentration, and the bulkhead thickness. We also measured the temperature distribution on the dome surface and the gas pressure inside simulated Insertables. These topics are discussed separately below.

Reactant Purity

Three grades or lots of titanium and boron were used in development. The physical and chemical analysis of the materials are given in Table I. The lot numbers in Table I are the numbers assigned by EG&G/Mound for quality assurance purposes. All of the titanium was procured from Alpha Ventron Inc. Lot #21803 was used to prepare the TiHKP that is used in the ignition charge of the Insertable. Lot #32837 is a development lot for miscellaneous uses at Mound. Lot #80575 is the highest purity titanium available from Alpha Ventron. It has virtually no hydrogen impurity.

The lot numbers #20644 and #38123 of boron were procured from Kerr McGee. They use a process that reduces boron oxide with magnesium, therefore there is a large concentration of magnesium impurity in these two lots of material. Lot #38118 was procured from Callery Boron Inc. This material is manufactured by decomposing diborane with a chemical vapor deposition process and is the purest boron that is comercially available.

**TABLE I. Titanium and Boron Purity**

| | Titanium | | | Boron | | |
|---|---|---|---|---|---|---|
| Lot # | 21803 | 32837 | 80575 | 20644 | 38123 | 38118 |
| (wt%) | | | | | | |
| Ti or B | 94.5 | 97.5 | 98.5 | 87.4 | 89.7 | 98.4 |
| water | 0.35 | 0.035 | 0.048 | 0.385 | 0.829 | 0.466 |
| Oxygen | 5.27 | 1.01 | 0.73 | | | |
| Mg | 0.70 | | | 6.18 | 4.04 | -nd- |
| Ca | 0.43 | 0.5 | | 0.3 | 0.001 | |
| Al | 0.02 | 0.49 | 0.5 | | 0.02 | |
| Si | 0.06 | | | | 0.11 | 0.57 |
| Fe | 0.06 | 0.03 | | 0.03 | 0.2 | <.001 |
| Ni | 0.01 | 0.08 | | | | |
| Zr | 0.09 | 0.10 | | | | |
| $TiH_x$ (x) | 1.62 | 0.105 | 0.024 | | | |
| dia* | 0.99 | 2.44 | 6.85 | 0.37 | 0.30 | 0.16 |

* average particle size (microns) as measured with a Coulter Counter

Blending Procedure

The blending process used by the commercial vendor and during our early work was roll milling. The constituents were loaded into a one liter velostat jar and then rotated at 60 revolutions per minute (RPM). Velostat rods or rubber stoppers were added to the blending jar to increase the agitation and blending times were on the order of an hour. The blends were prepared in batches of 50 to 150 grams, however this variable had no effect on performance. Also, there was no improvement in performance for blends that were roll milled more than one hour. Table II is comprised of performance data from a representative sampling of the roll milled blends. No diluents were used in the blends shown here. The primary variable in Table II is the purity of the starting materials. The B/Ti ratio shown is calculated from the starting material weights and adjusted for the material purity. The calorimetry data is the average and standard deviation based on three determinations. The Insertable performance data (maximum temperature rise and the time to acheive a temperature rise of 530°C) is based on the number of runs shown in Table II.

There is a trend of increasing heat output with the increasing purity of the starting materials. The problem with roll milling is shown by comparing TB11 with TB12. These blends were prepared in exactly the same manner with the same ingredients to demonstrate reproducibility. The calorimetry results were in reasonable agreement but the performance aspects of the Insertables were not reproducible. This variability is attributed to the inadequate blending acheived by roll milling. The solid state reaction between titanium and boron depends on intimate particulate homogeniety for uniform reation rates. In contrast, TIKP and FEK systems have liquid and gaseous phases to aid in reaction propogation, and roll milling here is acceptable. A small portion of TB7 (879 cal/gm) was ground with a mortar and pestle and the calorific yield increased to 905 cal/gm[4]. That result indicated that a more vigorous blending procedure was required.

**TABLE II. Performance of Roll Milled Titanium/Boron Blends**

| Blend No. | # of runs | Ti assay wt% | B assay wt% | B/Ti ratio | Calorimetry cal/gm | T(max) (delta) (°C) | time to delta 530°C (sec) |
|---|---|---|---|---|---|---|---|
| | | | | | --------average and one sigma---------- | | |
| TB1 | 3 | 94.5 | 87.4 | 1.85 | 840 +/- 28 | 591 +/- 32 | .84 +/- .19 |
| TB7 | 11 | 97.5 | 87.4 | 1.96 | 879 +/- 7 | 741 +/- 28 | .61 +/- .10 |
| TB8 | 5 | 98.5 | 87.4 | 1.94 | 886 +/- 4 | 745 +/- 16 | .59 +/- .04 |
| TB11 | 6 | 98.5 | 89.7 | 1.81 | 956 +/- 9 | 771 +/- 11 | .48 +/- .05 |
| TB12 | 5 | 98.5 | 89.7 | 1.81 | 977 +/- 8 | 833 +/- 9 | .22 +/- .04 |
| COM | 24 | 98.5 | 90.0 | 1.82 | 934 +/- 9 | 783 +/- 25 | .26 +/- .03 |
| TB9 | 3 | 97.5 | 98.4 | 2.01 | 958 +/- 9 | 756 +/- 12 | .31 +/- .03 |
| TB13 | 5 | 98.5 | 98.4 | 1.99 | 1026 +/-10 | 901 +/- 22 | .20 +/- .04 |
| TB15 | | 98.5 | 98.4 | 1.99 | 1004 +/- 8 | | |
| TB16 | 2 | 98.5 | 98.4 | 1.47 | 900 +/- 8 | 935 | .22 |
| TB17 | 2 | 98.5 | 98.4 | 2.38 | 1030 | 950 | .24 |

note: COM is the commercial blend that is referred to in the report. It was procured from Unidynamics/Phoenix Inc.

Our next iteration was to pursue ball milling. The constituents are mixed into a steel jar that contains 50 volume percent of steel balls and 20 volume percent of blend constituents. As with roll milling, the jar is rotated at 60 RPM for 1 hour. The tumbling steel balls provide a vigorous grinding action that is not present with simple roll milling. Several ball milled blends were manufactured with variations in the stoichiometry and the diluents. These blends established reproduceability of the process and are the basis for our current understanding of the system. For safety reasons, the blending is performed behind barricades using mechanical manipulators for several operations. We used a one liter jar for the ball milling and blended 60 grams of heat powder per batch. For production purposes, we wanted to produce batches of 300 grams. Remotely handling the one liter steel jar and the steel balls was difficult, and scaling the process up would have been even more so. An alternative blending procedure using a pin intensifier was implemented.

A pin intensifier is a V-shell blender that is modified so that it has a rotating internal shaft. The V shell rotates at 60 RPM and the shaft rotates at 2000 RPM. Several small pins protrude from the shaft, and as the powder tumbles over the rotating shaft, the pin intensified blending action occurs. Blend times with this apparatus are only two minutes for a 300 gram blend, and the remote operation is straightforward. Table III shows data that was obtained from representative ball milled and pin intensified blends. All of these blends shown in Table III used the purest materials (see Table I). The blend names are TBM or TBP, which stand for titanium/boron milled or pin intensified respectively. We could not differentiate between the two blending processes.

**Table III. Performance of Ball Milled and Pin Intensified Blends**

| Blend # | B/Ti ratio | Diluent type | wt% | Calorimetry cal/gm | # of runs | T(max) (delta) (°C) | time to a delta 530°C (sec) |
|---|---|---|---|---|---|---|---|
| Blends with stoichiometry as the variable. | | | | | | | |
| TBM2 | 1.00 | none | | 677 +/- 6 | 3 | 802 +/- 65 | .25 +/- .03 |
| TBM3 | 1.25 | none | | 810 +/- 11 | 3 | 896 +/- 64 | .19 +/- .02 |
| TBM4 | 1.50 | none | | 906 +/- 9 | 6 | 963 +/- 18 | .15 +/- .02 |
| TBM8 | 1.75 | none | | 999 +/- 5 | 3 | 933 +/- 14 | .16 +/- .02 |
| TBM9 | 2.00 | none | | 1047 +/- 6 | 3 | 904 +/- 19 | .19 +/- .01 |
| TBP25 | 2.00 | none | | 1031+/- 4 | 5 | 917 +/- 27 | .17 +/- .02 |
| Blends with Inert Diluents. (micron sizes are for alumina) | | | | | | | |
| TBM7 | 2.00 | 0.2μ | 50.0 | -nogo- | 3 | -nogo- | -nogo- |
| TBM10 | 2.01 | $TiB_2$ | 40.9 | 452 | 3 | -nogo- | -nogo- |
| TBM6 | 1.99 | 0.2μ | 30.0 | 729 +/- 3 | 6 | 651 +/- 12 | .69 +/- .05 |
| TBM5 | 2.00 | 0.2μ | 29.3 | 719 +/- 8 | 3 | 674 +/- 12 | .61 +/- .07 |
| TBM11 | 2.00 | 0.2μ | 21.6 | 808 +/- 8 | 12 | 763 +/- 22 | .38 +/- .04 |
| TBM12 | 2.00 | 0.2μ | 21.6 | 821 +/- 7 | 22 | 777 +/- 30 | .39 +/- .04 |
| TBM14 | 2.00 | 0.5μ | 21.6 | 830 +/- 3 | | ------not tested------- | |
| TBM15 | 2.00 | 5.0μ | 21.6 | 807 +/- 13 | 11 | 777 +/- 30 | .42 +/- .04 |
| TBM13 | 2.00 | $TiB_2$ | 21.6 | 821 +/- 3 | | ------not tested------- | |
| TBP20 | 2.00 | 5.0μ | 21.0 | 812 +/- 4 | 3 | 775 +/- 36 | .41 +/- .03 |
| TBP21 | 2.00 | 5.0μ | 17.0 | 876 +/- 6 | 3 | 829 +/- 27 | .32 +/- .04 |
| Identical Blends | | | | | | | |
| TBP22 | 2.00 | 0.5μ | 20.0 | 825 +/- 10 | 14 | 776 +/- 27 | .37 +/- .03 |
| TBP23 | 2.00 | 0.5μ | 20.0 | 831 +/- 3 | | ------not tested------- | |
| TBP24 | 2.00 | 0.5μ | 20.0 | 840 +/- 5 | 4 | 766 +/- 11 | .37 +/- .02 |
| TBP26 | 2.00 | 0.5μ | 20.0 | 829 +/- 3 | | ------not tested------- | |
| TBP27 | 2.00 | 0.5μ | 20.0 | 840 +/- 1 | 8 | 774 +/- 17 | .39 +/- .10 |

The top section of Table III shows data from those powders where the variable is the molar ratio of boron to titanium. For example, TBM2 would form the monoboride, TBM4 would form $Ti_2B_3$, TBM8 would form $Ti_3B_4$, and TBM9 would form $TiB_2$. We did not attempt to verify the chemical formulation of the reaction products. The rapid times shown for the 530°C temperature rise for TBM4 and TBM8, and the high peak temperatures obtained is interesting, however, the diboride reaction was utilized for the baseline heat powders.

The middle section of Table III shows the effect of using inert diluents of alumina or titanium diboride to cool the reaction. The particle size of the alumina powders is included. These sizes are the mean particle diameters at the 50% point of the distribution as determined with a Coulter counter. The size of the titanium diboride powder was not determined. The heat powders are arranged in decending order of diluent concentration, and as expected, there is a corresponding increase in calorific output and component performance.

The bottom portion of Table III shows data from five identical blends that used 0.5 micron alumina at a concentration of 20 wt%. Within experimental error, all performance aspects of these blends were identical which satisfied the goal of reproducibility. This goal was also established with the 21.6 wt% diluent blends shown in the middle of Table III, and note here that reproducibility did not depend on the particle size of the alumina diluent. There was no technical basis for chosing alumina over titanium diboride as the diluent in the later work other than color. With alumina, a visual indication of it's distribution is possible since the titanium and boron are black and the alumina is white. The 0.5 micron alumina was selected for the later heat powders because it dispersed more uniformly than either the 5 micron or 0.2 micron material. The 0.5 micron material provides ten times the dispersion relative to the 5 micron material based on the particle size. The 0.2 micron alumina tended to form agglomerates that were not broken up by the pin intensifier. Both of these observations were confirmed by examinimg the blends under low power magnification. Tests were conducted at -40°C, +60°C, and ambient temperature on Insertables with TBP24 and the commercial roll milled blend. Although not shown here, we could not distinguish the runs based on the test temperature when the thermal data was expressed in a delta or temperature rise format.

Note that there is no performance data for TBP23. This blend was used for special purposes including an evaluation on the effect of blending time. Samples of the blend were extracted after blending times of 1, 2, 5, and 10 minutes. These samples were then examined under low power magnification after smearing the material on a glass slide. The white alumina powder was uniformly dispersed on all of the samples. Calorimetry measurements of the 2 minute and 10 minute material was identical within measurement error, therefore the blending time, within the 2 to 10 minute window, is not a critical parameter.

The flexibility in choosing the desired thermal output is shown in the following plots that were derived from the data in Table III. Figure 3 shows the test dome thermal records from Insertables fabricated with representative dilutions. Figure 4 shows the smooth relationship between the diluent concentration and the time to acheive a 530°C temperature rise. Figure 5 shows the effect of concentration on the calorific yield and the maximum dome temperature. The effect of the bulkhead thickness is discussed later in the report.

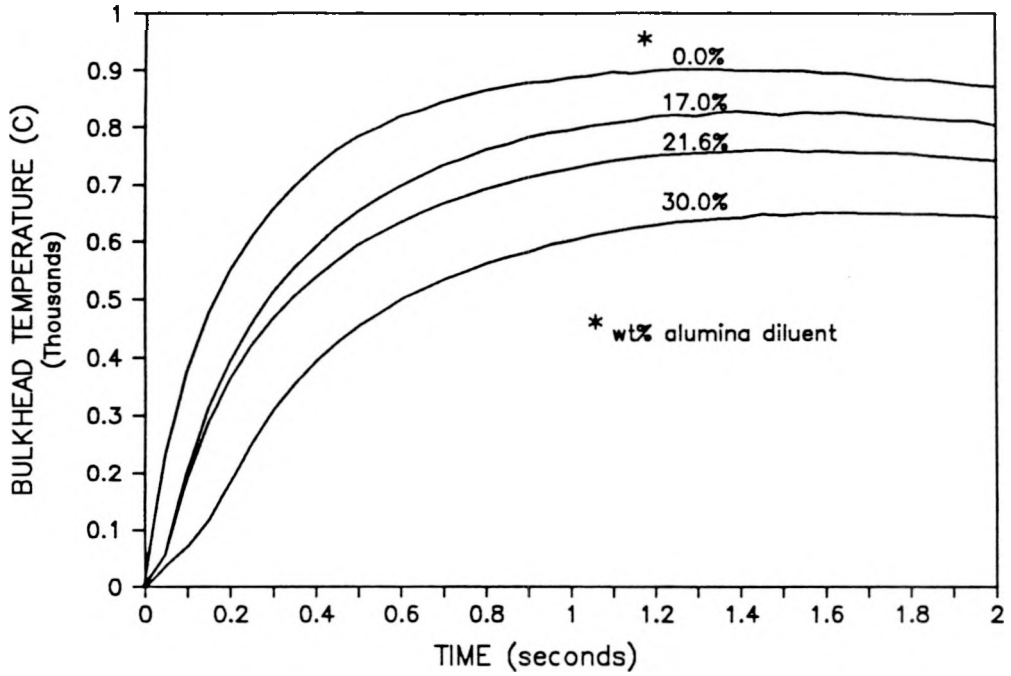


**Figure 3.** Plot of the test dome temperatures versus time for various titanium/boron blends diluted with alumina.

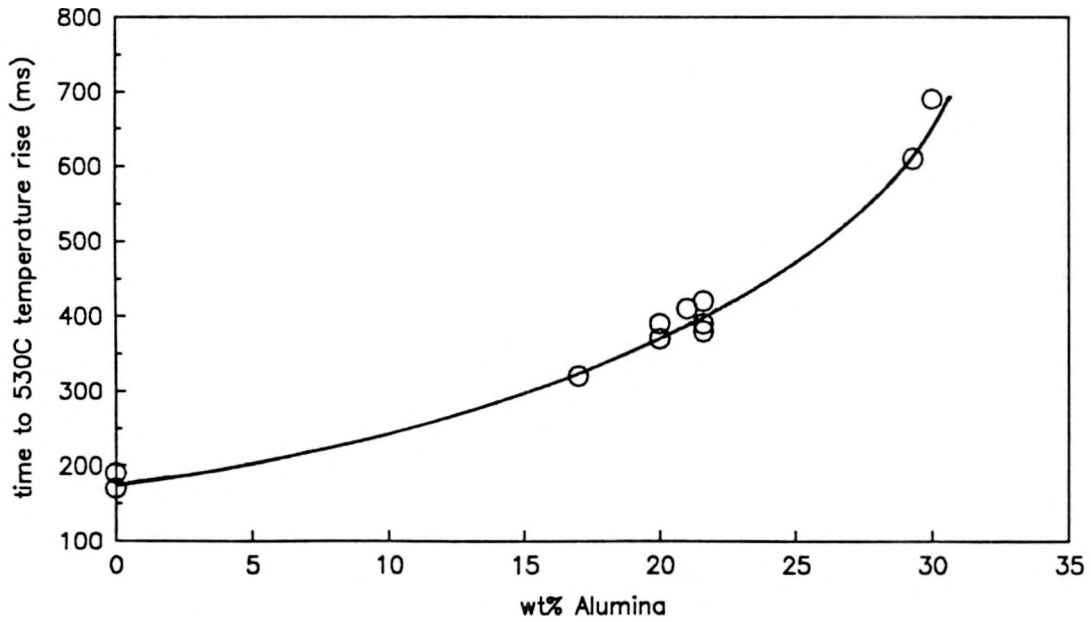


**Figure 4.** Plot of the time for the test dome to have experienced a temperature rise of 530°C versus the alumina concentration.

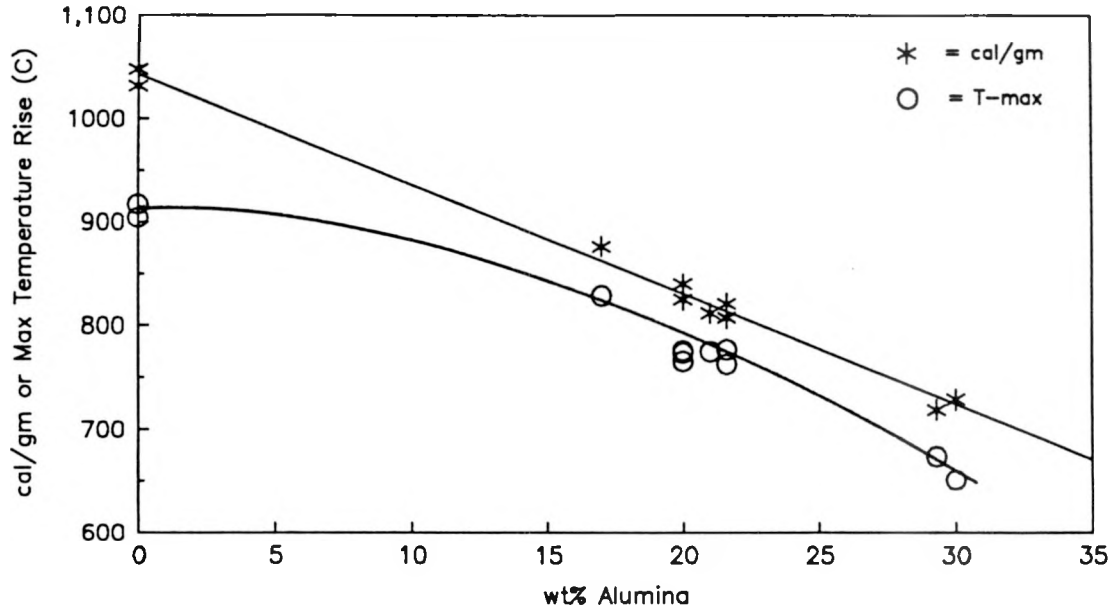


**Figure 5.** Plot of the maximum temperature rise on the test dome and the calorific yield for various dilutions of titanium/boron powders.

## OTHER ASPECTS OF INSERTABLE PERFORMANCE

### Bulkhead Thickness

The tests to address the effect of the bulkhead thickness were conducted early in development and used a commercial blend of titanium/boron. Figure 6 shows the thermal profiles for the different bulkhead thicknesses that were tested. Figure 7 shows the peak temperatures (in a delta format) and the times required to reach a temperature rise of 530°C versus the bulkhead thickness. The values of the thickness on Figure 7 include the 0.005 inch nickel can, Also, the early data point observed by Munger[1] of 1300°C for a 0.020 inch liner is included on Figure 7. The lines drawn through the data points on Figure 7 are power fits to the data and fit the function:

$y = ax^b$ where;

for temperature, a = 84.85 and b = -0.699
and for time, a = $1.5 \times 10^6$ and b = 2.669

It was encouraging to observe that the data did fit a power loss function which is expected for this kind of a heat transfer process.

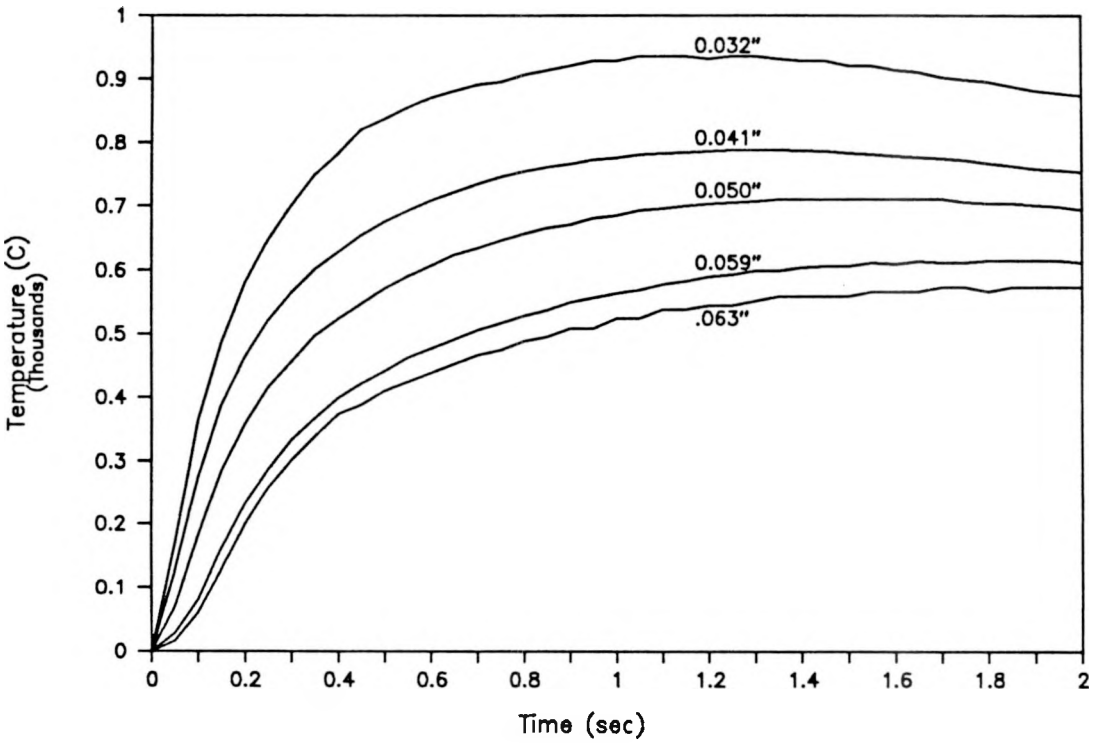


**Figure 6.** Plot of the test dome temperature rise as a function of time for different bulkhead thicknesses. The thickness includes the 0.005 inch nickel can.

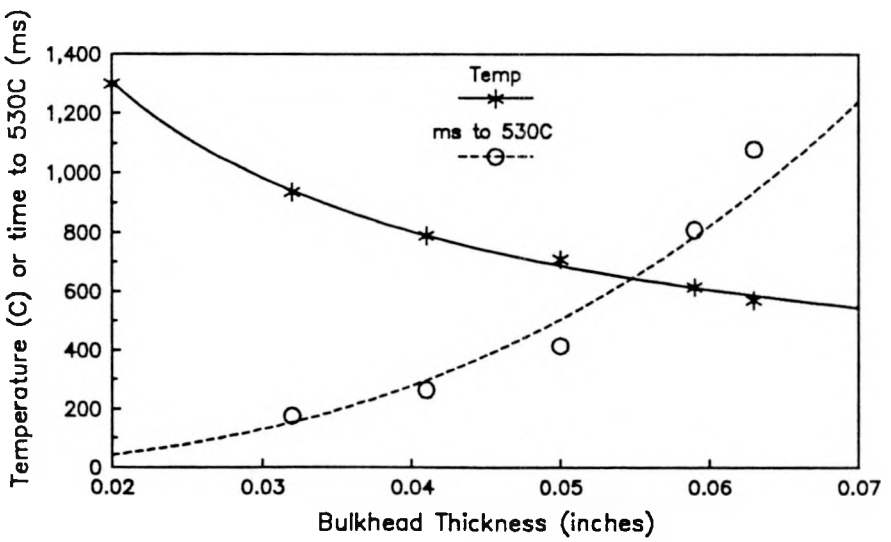


**Figure 7** Plot of the time to reach a temperature rise of 530°C and the maximum temperature rise as a function of the bulkhead thickness. This plot was generated from data on Figure 6.

Thermal Distribution

Real-time thermography[5] was used to measure the radial distribution of temperature on the test domes. These measurements were also done early in development and used Insertables that were loaded with TB15 heat powder. The detector viewed the top of the Insertable during test and the data collected is a map of the dome temperature versus time. A video monitor is required to view the entire thermal profile, however the circumferential distribution was quite good. A plot of a typical cross section of the thermography data is shown on Figure 8. As shown, there are no extreme hot spots and the distribution is symmetrical about the center. Also, the temperature in the region of interest (the center 0.100 inch diameter region) is fairly uniform. The largest variation is at 1.0 seconds after ignition and is on the order of 50°C.

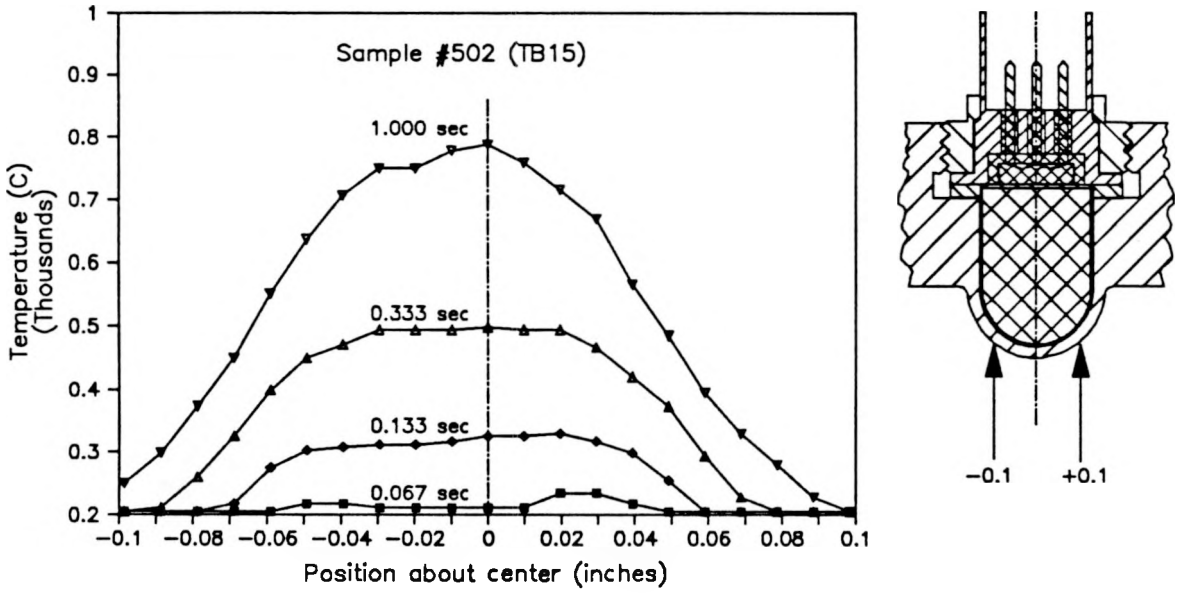


**Figure 8.** Plot of a cross section of real time thermography data from the test dome surface on a run with an Insertable using TB15 heat powder. The important feature shown by this plot is the uniformity of the heat zone on the tip of the test dome.

Internal Pressure

The pressure build up inside an Insertable was measured with special headers and cylindrical cavities fabricated so that a pressure gage could be installed at the end of the heat powder column. The results and a sketch of the test unit is shown on Figure 9. When the cavity length was 0.3 inches long, the powder column simulated that in the Insertable. Two runs were made with TBP22 heat powder; one at the 0.3 inch length and one with a column length of 0.15 inch. On both runs, there is an initial surge of gas pressure at 1 millisecond followed by a steady decline in pressure until 10 milliseconds into the runs. The initial surge and decay is due to the arrival and cooling of the decomposition gases from the TiHIKP ignition charge. Both runs then showed a slow pressure rise between 10 and 20 ms, and then a rapid increase in pressure at 20 ms. Apparently, there is some initial exothermic reaction occuring in the titanium/boron followed by a rapid bulk ignition at 20 ms. The shorter sample showed no further activity after 20 ms indicating completion of the titanium/boron reaction. The longer sample showed a slow increase in pressure between 20 and 40 ms at which time it is presumed that all of the titanium and boron was consumed.

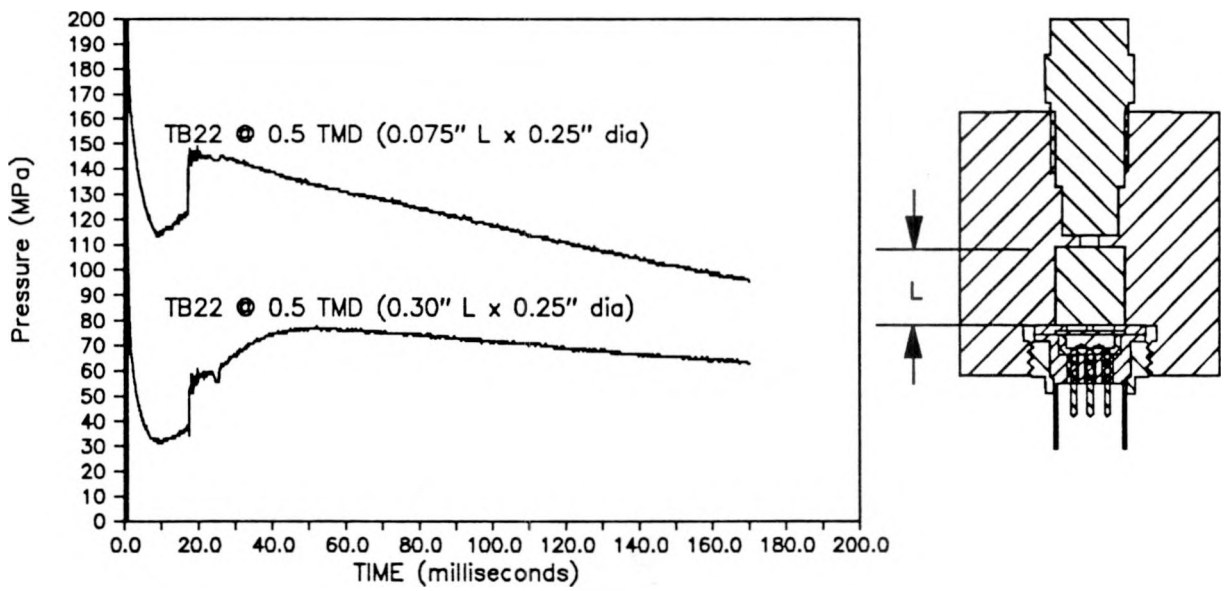


**Figure 9.** Plot of the internal pressure in simulated Insertables as a function of time.

The slow exothermic reaction between 10 and 20 ms indicates that the titanium/boron reaction is more complicated than originally suspected. From a heat transfer viewpoint however, all of the material has reacted within 40 milliseconds. The temperature profiles on the Insertables show no temperature increase on the first data point (at 50 ms), therefore the temperature profiles show little or no contribution from the titanium/boron burn rate, but are instead purely heat transfer from an effectively instantaneous heat source. Confirmation of the bulk ignition with the gas producing TiHKP ignition charge resolved the questions related to the poor performance observed by Munger[1] early in the development of the Insertable. When titanium boron is ignited from a non-gas producing heat source, it has a burn rate of about 80 cm/sec.[6] With that slow burn rate, Munger's early results are not surprising. The high pressures exerted by the TiHKP gases are also beneficial in that they cause movement of the thin nickel can and close small air gaps inside the test dome. Three tests were conducted with Insertables using the TBP22 heat powder and loaded can/ring subassemblies that were 0.005 inch shorter than normal. The normal air gap between the Insertable and the test dome is 0.000 to 0.002 inch, therefore it was between 0.005 and 0.007 inch on these tests. The thermal profiles from these tests could not be distinguished from those with the normal Insertable dimensions.

Safety

Safety is an important consideration in our work, and because of that, we wanted to know what to expect if there was an accidental fire during the blending, storage, or transport of the titanium/boron heat powder. The remainder of TBP23 powder was used to evaluate the safety issue. Typically, a blend is divided into 50 gram sublots and storaged in steel containers. Up to 3 of these containers are transported in a metal dessicator. Two burn tests were conducted by purposely igniting the powder from 1 or 3 of the steel containers, corresponding to a 50 gram and 150 gram burn test. In both cases, a small amount of gas and unburned powder was vented at the lid of the dessicator and this was probably due to the heating of ambient air and water vapor in the dessicator. As expected, the dessicator did get quite hot, however, the relative nonviolence of the tests demonstrated another positive attribute of the solid state pyrotechnic reaction.

## SUMMARY

This report has described the use of diluted titanium/boron mixtures as a variable heat source in an insertable ignitor. The factors affecting the reproducibility of the heat output are the homogeneity of the heat powder, ignition from a hot gas producing pyrotechnic, and a precision assembly to contain the heat powder. The Insertable that has been described is intended for use in through-bulkhead applications. For steel hemispherical bulkheads that are 0.036 inch thick, a hot spot with a diameter of 0.05 inch can be produced with a temperature range of 680°C to 950°C, and a precision of +/- 20°C. The data presented shows that the inert diluent can be up to 30 wt% of the heat powder, and the heat powder output is a smooth function of the diluent concentration. Further, the effective output can be extended by changing the bulkhead thickness.

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