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TITANIUM HYDRIDE - POTASSIUM PERCHLORATE:
A SPARK INSENSITIVE PYROTECHNIC MATERIAL (U)

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ABSTRACT (U)

This report is the result of a study of the comparison of titanium hydride-potassium perchlorate and titanium-potassium perchlorate as pyrotechnic mixtures for actuators and squibs. The handling characteristics of the powders and the performance when used in actuators are described. The nearly ideal properties of the hydride mixture are evident.

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- c. Design changes (deliberate or inadvertent) can occur during production. Again this can lead to a hazardous situation since the precautions and procedures might not be adequate.
- d. Manufacturing defects can occur which circumvent the engineering techniques used for desensitization.
- e. The units are handled prior to and during installation.
- f. Installed components are removed on occasion for stockpile sampling tests and opened for postmortem examinations.
- g. Other agencies frequently handle and use Sandia components (often not in the intended application). Often this is not done in strict accordance with the detailed safe procedures.

In summary, if a component contains a sensitive material it must be regarded as inherently hazardous independent of engineering design and procedures.

Consequently, we have been concentrating our efforts on materials and techniques which are safer, particularly with regard to electrostatic charges generated by the human body. In particular we have examined pyrotechnic powders which have previously been accepted by others as spark insensitive (probably examined only in an actuator or squib configuration) and found that some lots of material are spark sensitive when examined as loose powder, for example Al-CuO and B-CaCrO₄.

We also have examined a mixture of titanium hydride-potassium perchlorate (TiH₂-KClO₄) and found it to be spark insensitive. Additional tests of a preliminary nature showed that this material should be investigated further as an actuator and squib material. Since we had already studied some of the properties of Ti-KClO₄, we believed that a thorough investigation of the two powders conducted in parallel would be worthwhile.

Titanium powder mixed with potassium perchlorate has been used by many workers as an actuator and squib material. The properties of the mixture and titanium powder alone are well documented (for example, see Reference 17).

Titanium hydride, a much lesser known material, is a grey powder of specific gravity 3.76 grams per cubic centimeter.² Titanium hydride is not a solid solution of hydrogen in titanium because the metal structure is hexagonal close-packed while the hydride has a face-centered cubic fluorite structure.³

A composite phase diagram of the titanium-hydrogen system has been prepared from pressure-composition-temperature measurements taken from several sources.⁴

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Titanium hydride may be prepared by the direct union of hydrogen gas and titanium metal. The reaction is exothermic and is carried out at 673 to 873 K (400 to 600°C).^{5, 6}

Trace impurities in titanium such as oxygen and nitrogen have a marked effect on the rate of attainment of equilibrium in a titanium-hydrogen system. Impurities in the hydrogen used in the production of titanium metal powder (by hydriding and dehydriding) cause the formation of metal that is considerably harder than metal produced with highly purified gas,⁷ which further shows the significance of impurities.

The hydride is remarkably stable. For example, it may be heated in 25 percent hydrochloric acid at 373 K (100°C) for 2 hours without significant decomposition.⁸ Titanium hydride is also slightly less prone to spontaneous ignition when heated in air than is titanium metal.⁹ The hydride probably does not react readily with the halogens, nitrogen, ammonia, or hydrocarbon gases.¹⁰ Reactivity between the hydride and metals is more dependent on the nature of the alloying than on corrosion mechanisms. Since some hydrogen can be liberated, the problem of hydrogen embrittlement with certain metals must be carefully considered.¹¹

Procedures have been developed for the quantitative analysis of various impurities in TiH₂ as well as the determination of the Ti and H content.^{12, 13}

The thermal decomposition of TiH₂ starts at 523 to 653 K (350 to 380°C).¹⁴ The coefficient of thermal expansion of TiH₂ has been reported to be 10.6×10^{-6} .¹⁶

Titanium hydride has been little used as a pyrotechnic material. Ellern, in his book on pyrotechnics,¹⁷ states that because TiH₂ is more inert than the metal, its lower ignition sensitivity and slower burning rate limit its usefulness.

A gas producing composition has been reported which consisted of a Zr-KClO₄-Viton B ignition mixture (hot wire sensitive) and a main charge of TiH₂-KClO₄-Viton B.¹⁸ On the basis of our measurements on the above ignition powder, an actuator or squib prepared as described above would be very spark sensitive.

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II. Experimental Procedure and Results

The two pyrotechnic mixtures used in this study were prepared as follows. The titanium-potassium perchlorate mixture contained 33 percent (by weight) titanium and 67 percent potassium perchlorate. The proportions were chosen, based upon the reaction:



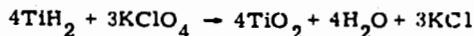
The mixture contained a 29 percent excess of potassium perchlorate over the stoichiometric requirement. These proportions were found to be an optimum in the course of a study conducted by Unidynamics, Phoenix, Inc., Phoenix, Arizona for Sandia Laboratories.

The titanium powder was -325 mesh, Grade Z, (Lot No. J-3896A-2) manufactured by Metal Hydrides Corp., Beverly, Mass. (name since changed to Ventron Corp.).

The potassium perchlorate was -325 mesh and was supplied by Mason & Hanger-Silas Mason Co., Inc., Amarillo, Texas.

The details of the procedure for the preparation of the mixture are described in Sandia Laboratories Drawing Number SS287895.*

The titanium hydride-potassium perchlorate mixture contained 26.5 percent (by weight) titanium hydride and 73.5 percent potassium perchlorate. The proportions were chosen, based upon the reaction:



The mixture contained a 29 percent excess of potassium perchlorate over the stoichiometric requirement. This excess was chosen only because the same excess was found best for Ti-KClO₄, as noted above. This may not be a valid extrapolation, however, since commonly used titanium powder may contain as high as 13 percent of titanium hydride (calculated as TiH₂) which could explain the need for excess oxygen.

*The mixture used in this study was designated Lot SC-TP-1 and was prepared by R. J. Buxton, 2516 and T. M. Massis, 2516.

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Spark Ignition Threshold -- The spark ignition threshold of the loose powder was measured by discharging a 600 pf capacitor from an electrode through a sample of loose powder (approximately 200 mg sample) to a ground plane. A sketch of the test fixture is shown in Figure 1. No resistance was added to the discharge path. Only one discharge was made through each sample.

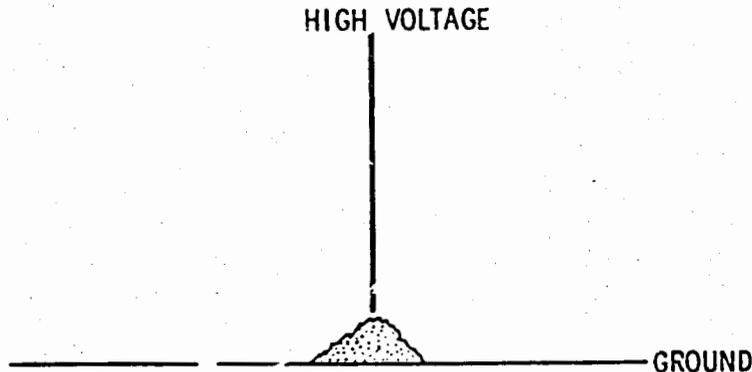


Figure 1. Test fixture for spark ignition of loose powder

The voltage was varied until one ignition in 10 samples tested was obtained or the limits of the test equipment were reached. The energy stored in the capacitor at that voltage level was designated as the spark ignition threshold. The data are summarized below.

TABLE III

Summary of Spark Ignition Tests on Loose Powder

Ignition threshold	Ti-KClO ₄ <7.5 mJ	TiH ₂ -KClO ₄ >180 mJ
--------------------	---------------------------------	--

Flame Ignition -- A train of loose powder, approximately 3 mm wide, 3 mm high, and 50 mm long (0.12 x 0.12 x 1.97 inches) was laid out on an asbestos board. One end of the train was ignited by a small flame of a propane torch. If the train failed to propagate, it was ignited again. This was repeated until the train was consumed.

When a train of Ti-KClO₄ was ignited, it burned in a single brilliant flash. A train of TiH₂-KClO₄ was slow to ignite, and when it did ignite it failed to propagate. It required 14 successive ignitions by the flame before being consumed.

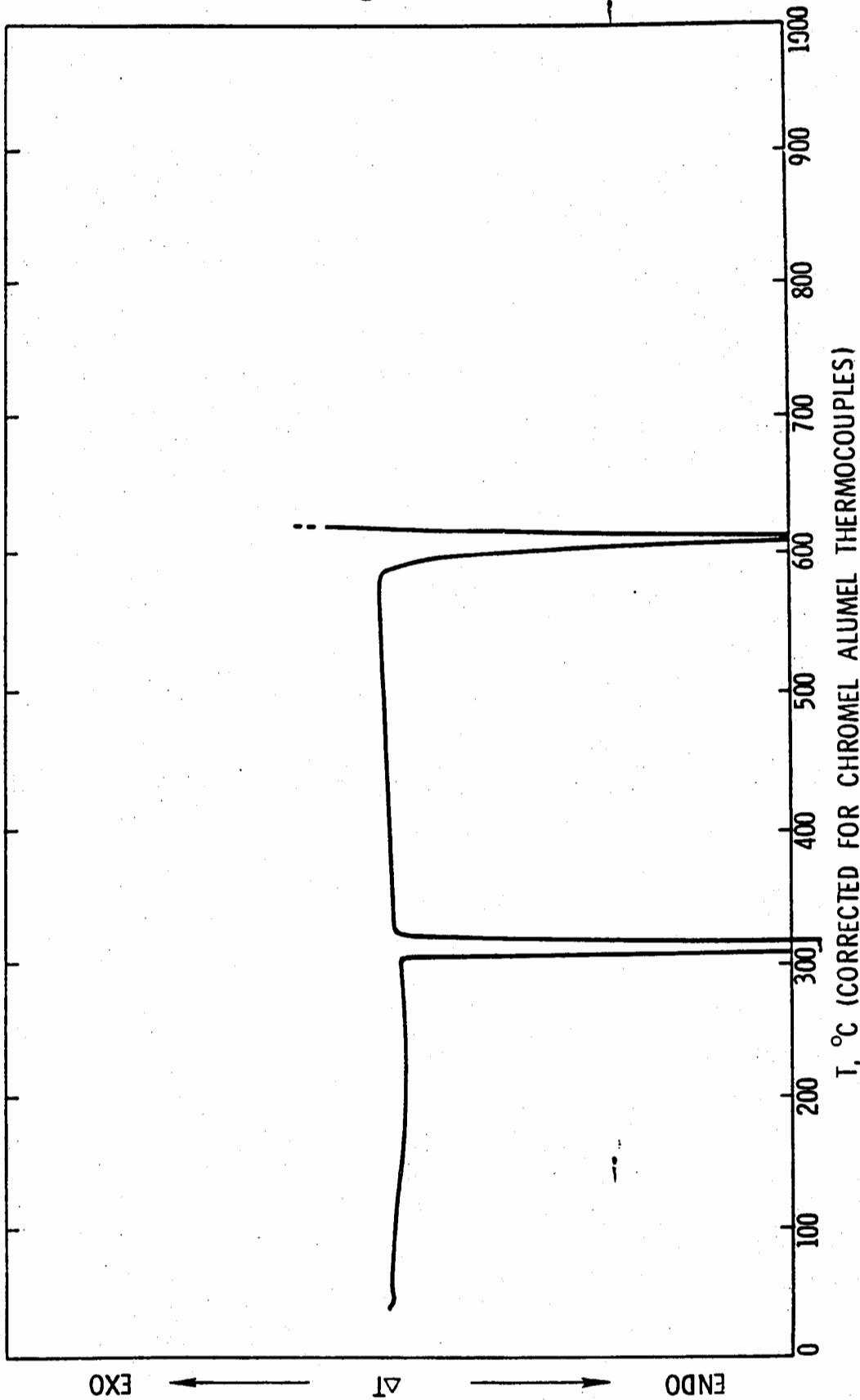


Figure 2. Differential thermal analysis of $KClO_4$

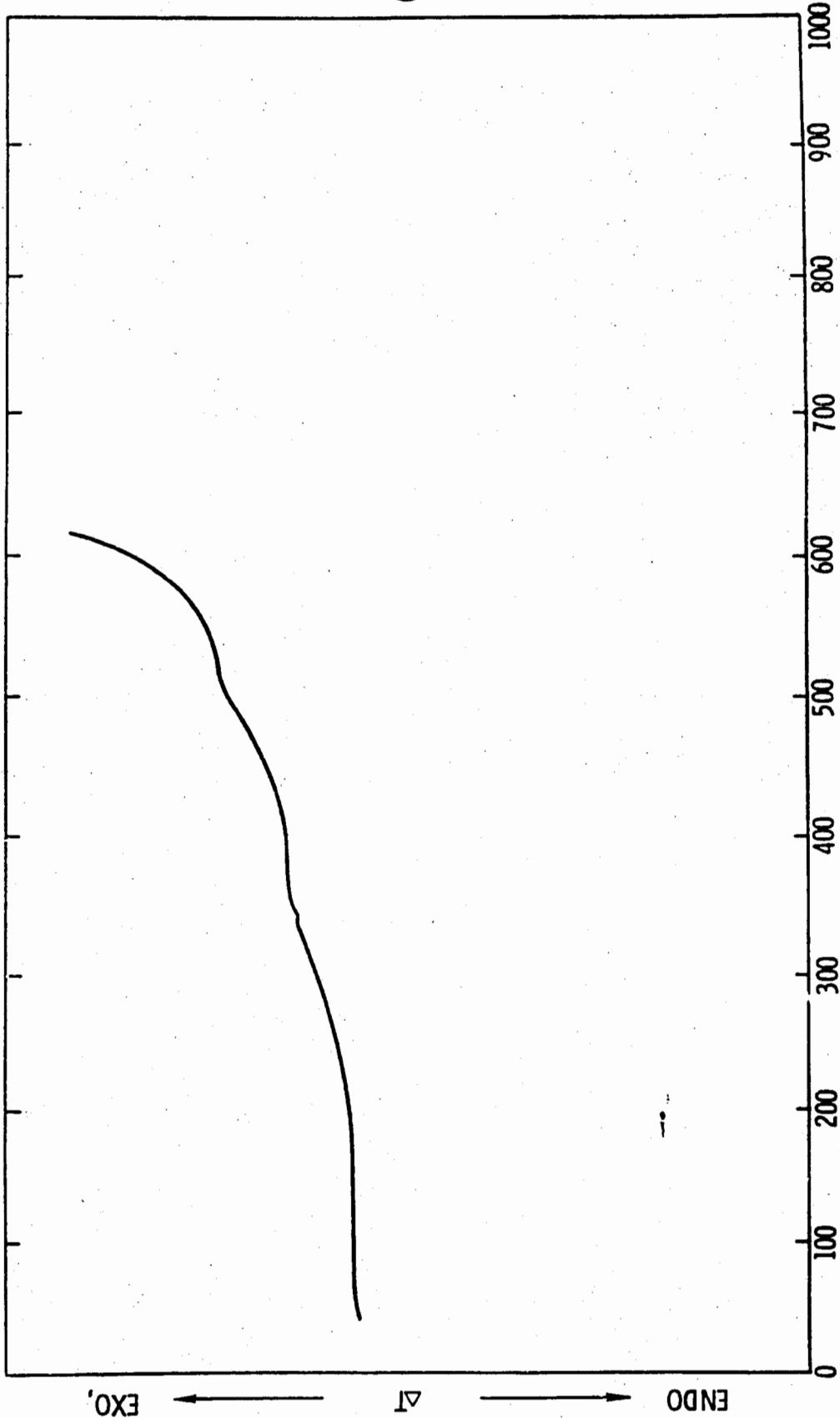


Figure 3. Differential thermal analysis of Ti

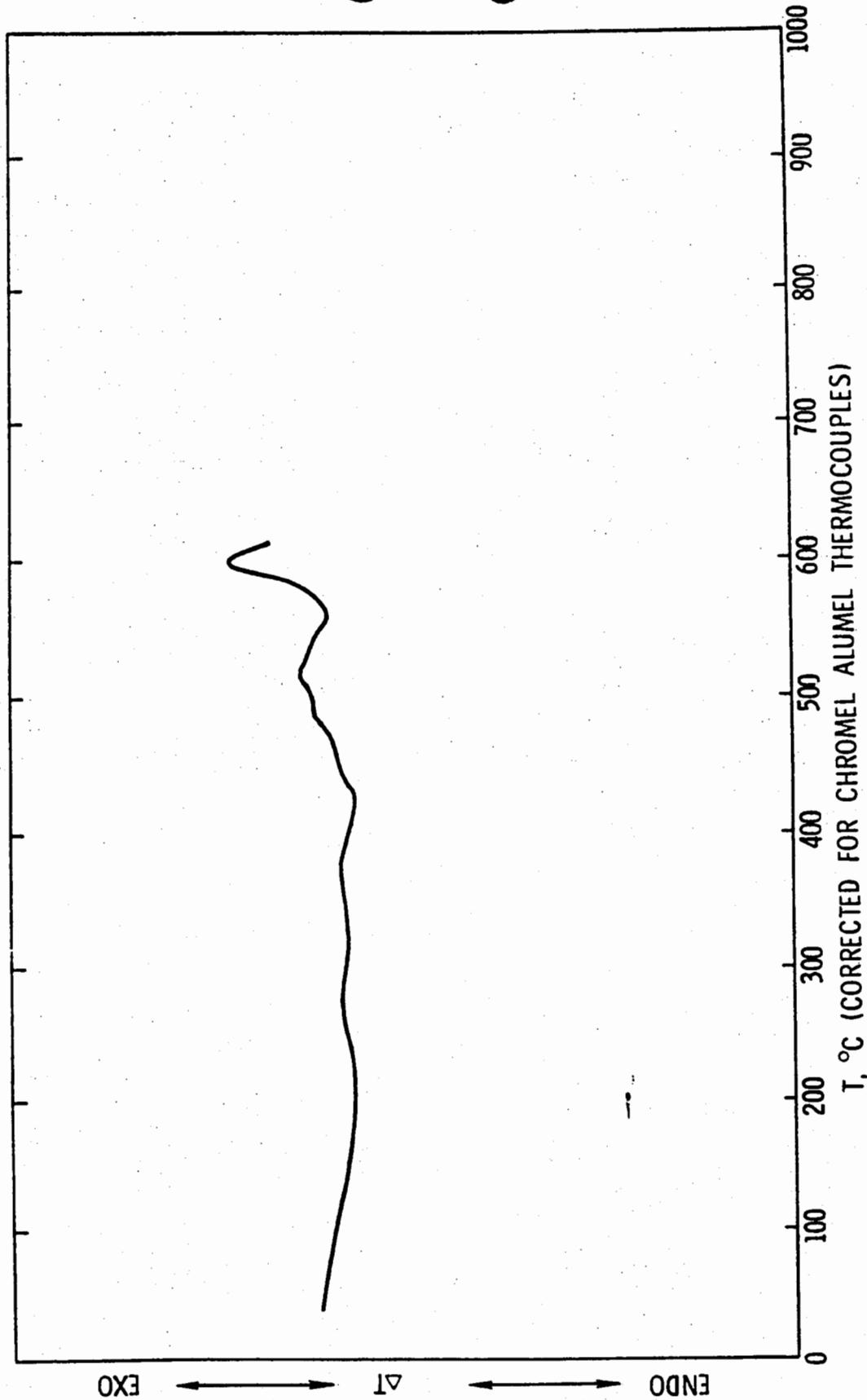


Figure 4. Differential thermal analysis of TiH_2

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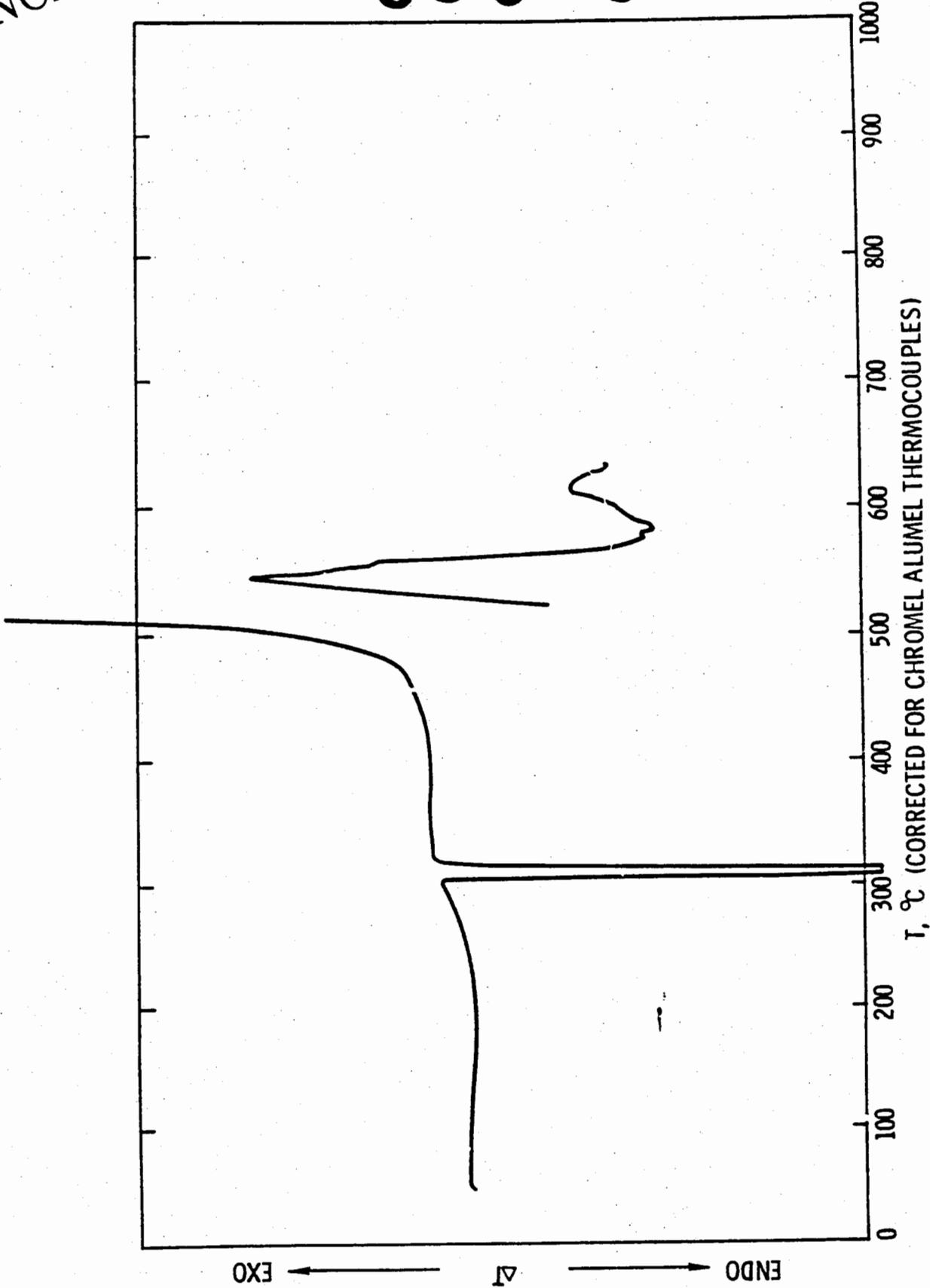


Figure 5. Differential thermal analysis of Ti-KClO₄

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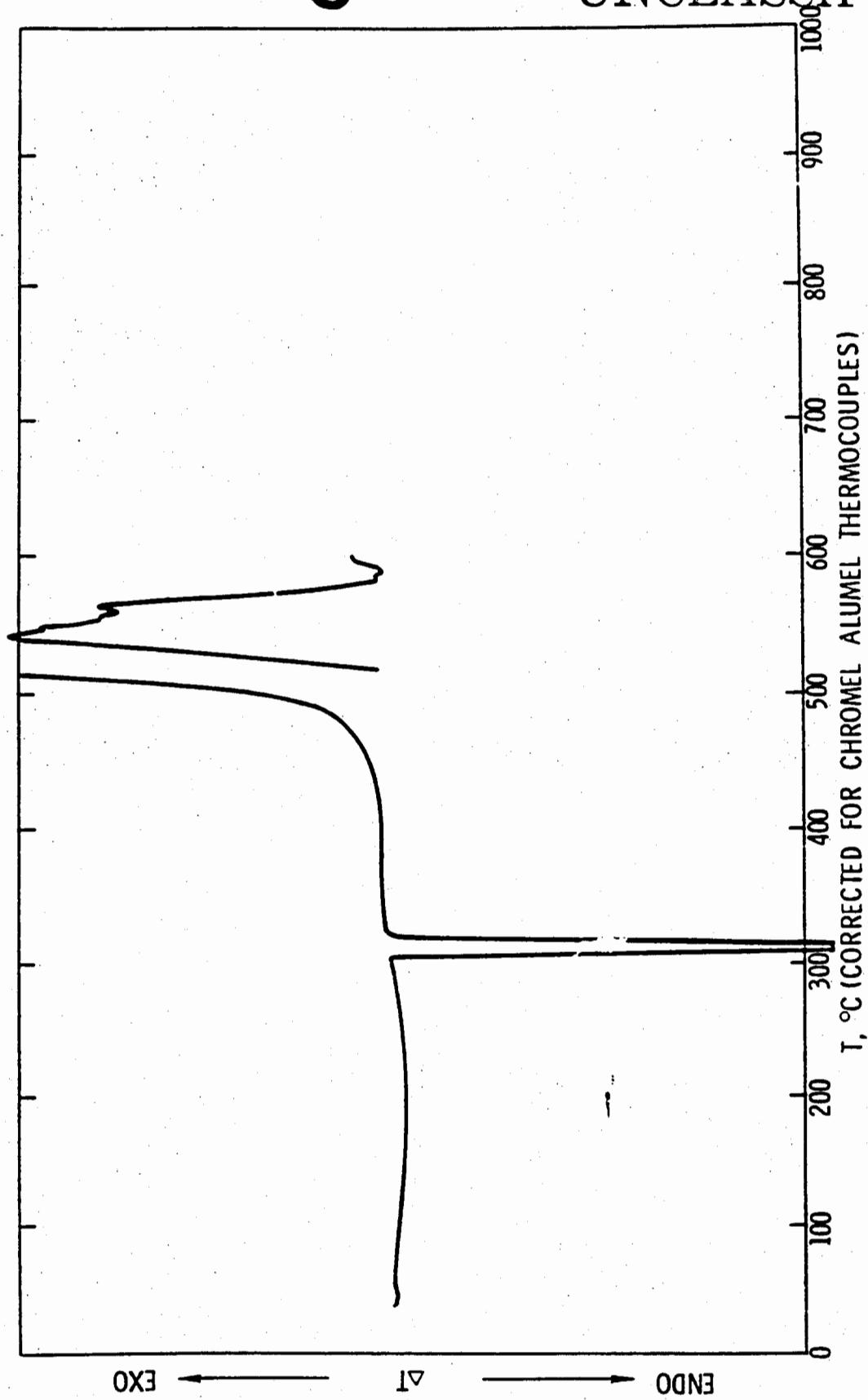


Figure 6. Differential thermal analysis of TiH₂-KClO₄

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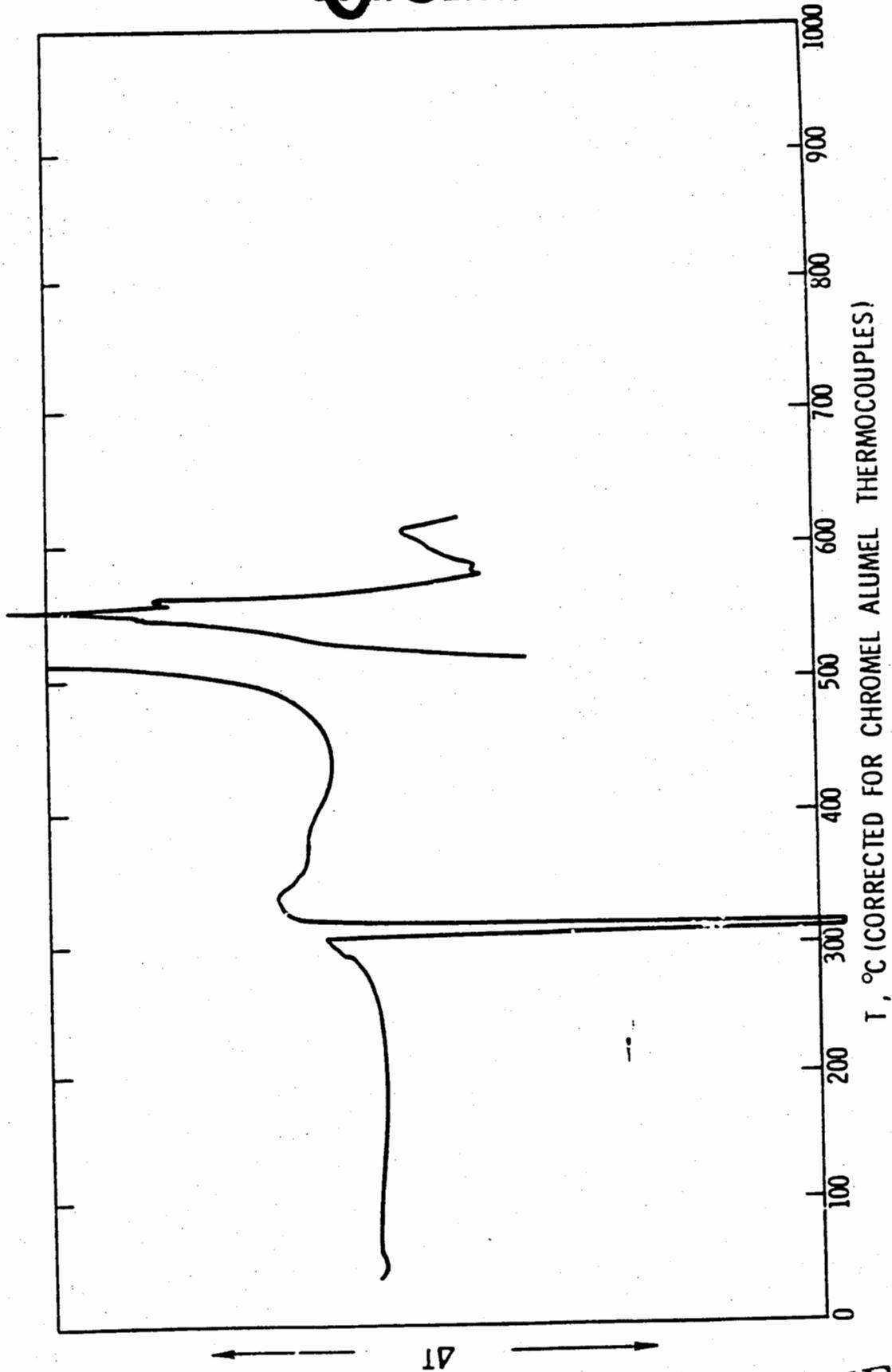


Figure 7. Differential thermal analysis of $\text{ThI}_2\text{-KC10}_4$ after storage at 373K (100°C) for 30 days

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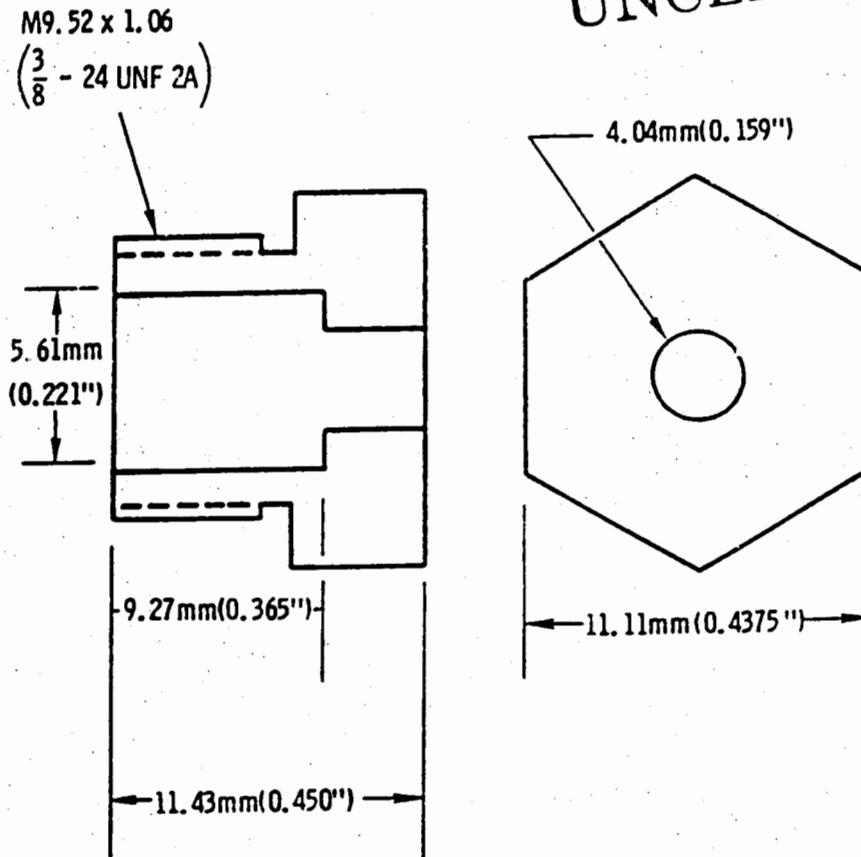


Figure 8. Actuator housing

The header for the actuator was made from glass and Kovar. The connecting pins were spaced 2.41 mm (0.095 inch) center to center. A 0.051 mm (0.002 inch) round, straightened and cleaned Evanohm[®] wire [655.8 ohms per meter (199.9 ohms per foot)] was resistance welded to the connecting pins. The effective bridgewire length was 1.40 mm (0.055 inch) and the resistance was 1.00 ± 0.10 ohm.

The bridged header was pressed into the actuator body. The assembled actuator is shown in Figure 9. Powder was pressed against the bridgewire at 703 kg/cm^2 (10,000 psi) which filled the remainder of the cavity. Some of the constants for the actuators are listed in Table 4.

[®]Evanohm is a trademark of the Wilbur B. Driver Co., Newark, N.J., for an alloy of the composition 74.5 percent Ni, 20 percent Cr, 2.75 percent Cu and 2.75 percent Al. The wire has a resistance of 800 ohms/circular mil foot, a temperature coefficient of $\pm 3(10)^{-6}$, exhibits high resistance to corrosion and has high tensile strength.

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Figure 9. Actuator housing and header with bridgewire. The assembled actuator is shown on the right.

TABLE IV

Some Actuator Constants

	<u>Ti-KClO₄</u>	<u>TiH₂-KClO₄</u>
weight (mg)	175	110
Cavity diameter (mm - inches)	5.61 - 0.221	5.61 - 0.221
Cavity length (mm - inches)	3.79 - 0.149	1.98 - 0.078
Cavity volume (cm ³ - cubic inches)	0.0937 - 0.00572	0.0491 - 0.00300

When TiH₂-KClO₄ was loaded into actuators with the larger powder cavity, the actuator body usually failed at the thread area. For this reason, the studies with this powder were made using the actuator with the smaller powder cavity. All actuators loaded with Ti-KClO₄ used the actuator body with the larger powder cavity.

When actuators containing TiH₂-KClO₄ were fired without confinement at the open end of the actuator, the powder usually failed to propagate properly. The actuators fired by bridgewire ignition were assembled using a 7.95 mm (0.313 inch) diameter brass disc [0.41 mm (0.016 inch) thick] firmly held against the powder for confinement. (A few actuators were fired using copper discs, which may have had the added advantage of more tightly sealing the actuator to prevent pressure loss upon firing.)

Bulk Density of Actuator Load -- The bulk density of the powder in the loaded actuator was determined from the weight of actuators before and after loading, and the volume of the actuator cavity. The actuators were loaded with a ram pressure of 703 kg/cm² (10,000 psi). The average density of the actuator loads were as follows:

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TABLE V

Bulk Density of Powder in Actuators

Ti-KClO ₄	1.93 g/cm ³
TiH ₂ -KClO ₄	2.23 g/cm ³

Spark Initiation Threshold -- The spark initiation threshold of the actuators was measured by discharging a charged 600 pf capacitor from the bridgewire of the actuator to the actuator body. Only one discharge was made through each actuator.

Two different tests were performed: a) the capacitor was charged to 20 kV and then discharged through the actuator with a 500 ohm resistor placed in the discharge circuit; the number of ignitions in 10 units tested was recorded. b) the capacitor was charged to a specific voltage and then discharged through the actuator with no resistance added to the discharge circuit. the voltage was varied until one initiation was obtained in 10 units tested at one voltage level, or until 10 units were tested at the maximum voltage of the tester. The energy stored in the capacitor at that voltage level was designated as the spark initiation threshold. The test data is summarized below.

TABLE VI

Summary of Spark Initiation Tests on Actuators

	Actuator Type	
	Ti-KClO ₄	TiH ₂ -KClO ₄
No. of initiations @ 600 pf-20 kV - 500 ohms	0	0
Initiation threshold (600 pf-0 ohms)	>370 mJ	270 mJ

Spark initiation tests were also made with a different type of actuator that contained two bridgewires connected in series. The inside diameter of the actuator was 5.0 mm (0.201 inch) and contained 162 mg of TiH₂-KClO₄ pressed at 703 kg/cm² (10,000 psi). The internal arc path (from bridgewire to case) was 1.0 mm (0.040 inches). The actuators were tested while assembled into the Mini-Flipper (see section II-B-6). A 600 pf capacitor was charged to 35 kV and discharged through the actuator, from pins to case, with a 500 ohm resistor in the discharge circuit. A layer of oil, approximately 3 mm (0.120 inch) deep, covered the top of the actuator to prevent external arcing from leads to case. There were no initiations in 10 units tested. Based on current models and on our experience, there is strong evidence that these actuators would not be initiated by a discharge from the human body.

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Autoignition Temperature -- The autoignition temperature of experimental actuators was determined by assembling the actuator into the Mini-Flipper¹⁹ test device and heating the assembly in a vertical-tube electric furnace. A thermocouple and recorder were used to monitor the internal temperature of the assembly. The assembly was heated at a rate of 13.3K (13.3°C) per minute by controlling the rate at which it was lowered into the preheated furnace. When the autoignition temperature was reached, the record showed a strong exotherm caused by ignition of the powder.

A brief description of the operation of the Mini-Flipper is given below in "Actuator Output," Page 23.

The autoignition temperatures of the two types of actuators are listed below.

TABLE VII

Autoignition Temperature of Actuators

Ti-KClO ₄	748K (475°C)
TiH ₂ -KClO ₄	793K (520°C)

No-Fire Current -- The no-fire test was conducted by assembling an actuator into a Mini-Flipper test device and passing a one ampere DC current through the bridgewire for a five minute period. To pass this test, the actuator must not fire. Tests were conducted at both ambient temperature and 347K (74°C or 160°F). Actuators loaded with Ti-KClO₄ or TiH₂-KClO₄ passed tests at both temperatures.

Minimum Current for Ignition -- The minimum current for ignition of the actuators was determined by passing a constant current through the bridgewire of the actuator and determining if the powder ignited within a fraction of a second (units that did not fire were not used in subsequent tests). The current level was lowered until a minimum level was reached. The lowest current level that produced ignitions in four out of five units tested is listed below.

TABLE VIII

Minimum Current for Actuator Ignition

Ti-KClO ₄	1.7 A
TiH ₂ -KClO ₄	1.3 A

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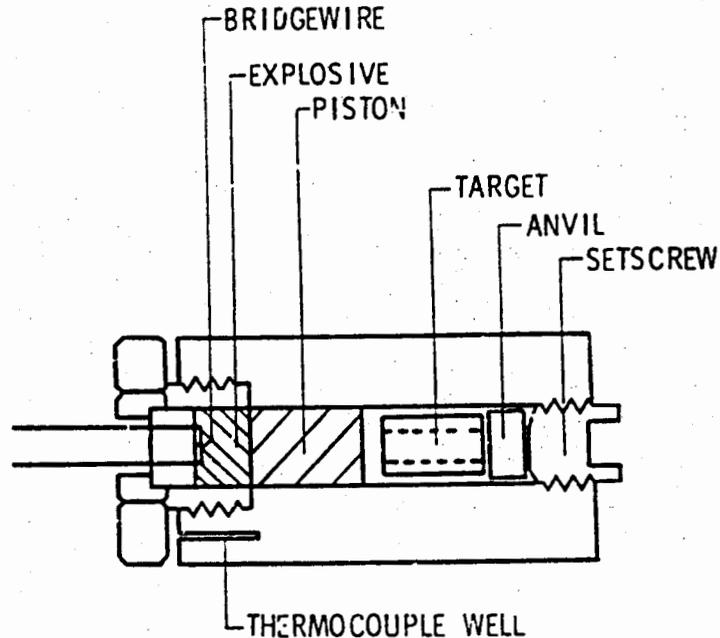


Figure 12. Cross section of Mini-Flipper

A graph illustrating the relationship between target deformation and the quantity of $Ti-KClO_4$ loaded into an actuator is shown in Figure 13 (the data for the preparation of the graph was taken with actuators with powder cavities of varying volume). The figure also shows similar data for TiH_2-KClO_4 .

Average values of target deformation for the powder loads given in Table IV are shown below.

TABLE XI

Average Values of Actuator Output

	<u>Target Deformation in Millimeters (Inches)</u>
$Ti-KClO_4$	3.07 (0.121)
TiH_2-KClO_4	1.50 (0.059)

Resistance-After-Fire -- Resistance-after-fire (RAF) is the resistance measured across the two bridgewire leads of the actuator, beginning immediately after the actuator has been fired. In this study, RAF was measured for a total time of one minute, beginning at the start of current flow in the bridgewire. Two oscilloscopes and a high-impedance input strip-chart recorder were used to measure RAF over three different time intervals. One oscilloscope was used to record RAF during the first 20 ms and another oscilloscope for the first second. The recorder measured RAF for the full minute. A RAF record for the first 20 ms for an actuator is shown in Figure 14.

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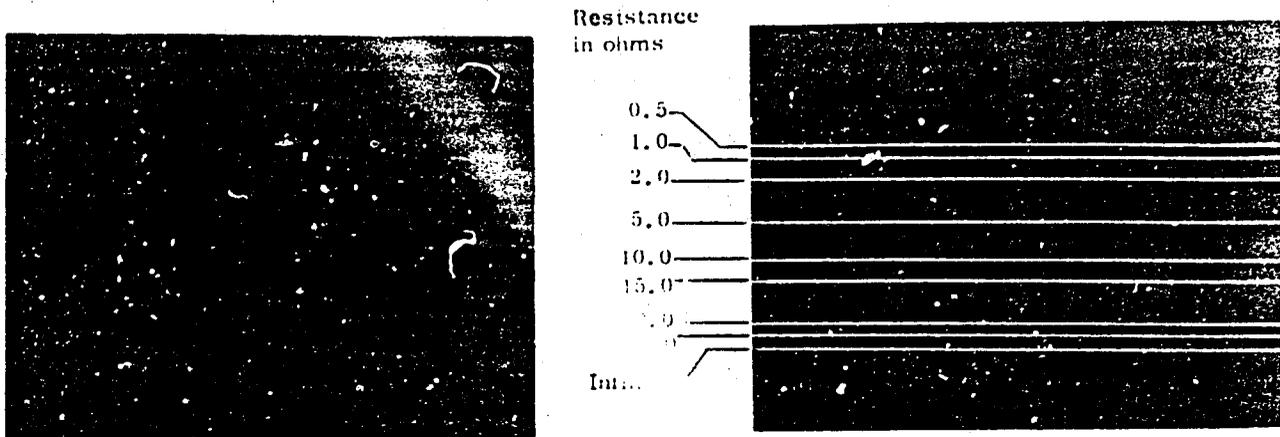


Figure 14. Resistance-after-fire (RAF) record of an actuator containing TiH_2-KClO_4 . (The oscillogram covers the first 20 milliseconds of the RAF record. The height of the trace above the base line is a measure of resistance. The flat portion of the record during the first 4-5 ms is a measure of bridge resistance-one ohm. The photo to the right is the resistance calibration record. The photograph of calibration time marks is not shown here).

The actuators were fired from a 3.5 ampere direct current source. Twenty actuators of each type were tested. The minimum resistance observed for each group is given in Table XII.

TABLE XII
Minimum Resistance-After-Fire

$Ti-KClO_4$	0.01 ohms
TiH_2-KClO_4	2.0 ohms

Storage at Elevated Temperature -- One approach to the study of the accelerated aging of a pyrotechnic powder is to hold the powder at elevated temperatures and then test for signs of degradation.

Loaded actuators were assembled into Mini-Flippers and the assemblies were heated in a temperature test chamber at $373K \pm 1K$ ($100^\circ C \pm 1^\circ C$) for 24 hours (the assemblies were not hermetically sealed). The assemblies were then fired at ambient temperature using a 3.5 ampere direct current source. Actuators containing $Ti-KClO_4$ or TiH_2-KClO_4 fired properly and yielded a satisfactory output.

Powder removed from actuators containing TiH_2-KClO_4 was tested for spark sensitivity as loose powder. The threshold for ignition was found to be greater than 480 mJ. Thus the heating had not measurably increased the spark sensitivity.

Thermal Output -- The thermal output of the powder in actuators was measured by firing the actuator by an electrical pulse while the actuator was assembled in a Mini-Flipper. Before ignition, the assembly was placed inside a Parr Adiabatic Calorimeter pressurized with argon. Temperature was measured by a quartz oscillator thermometer.* The data obtained, based upon a small number of measurements, is given in Table XIII.

TABLE XIII

Thermal Output of Actuators

	ρ /g of Powder
Ti-KClO ₄	1530 - 1700
TiH ₂ -KClO ₄	1410 - 1750

Leads to Case Resistance -- The actuator internal resistance was measured by applying a constant DC voltage between the actuator leads (leads joined together) and the case. The voltage was increased in 50-volt increments, and maintained at each voltage for 15 seconds. Current flow was monitored by a 0-100 milliamper meter. During the test, the actuator was installed in a Mini-Flipper to maintain confinement of the powder.

When the above test was performed with TiH₂-KClO₄, two actuators ignited immediately upon application of 200 volts and two ignited immediately upon application of 250 volts. Four actuators loaded with Ti-KClO₄ fired upon application of 10 volts.

Experiments on High-Density Columns

Resistivity -- The resistivity (the resistance of a one cm cube measured across two opposite faces) of high density columns of powder may be determined by employing the relationship:

$$\rho = A \left(\frac{R}{l} \right)$$

where ρ is the resistivity, A is the cross sectional area of a column, R is the resistance of the column measured between the two ends, and l is the length of the column.

The resistance of several different column lengths was measured using the technique sketched in Figure 15. The ohm meter used was one with a high impedance input. The column diameters were 5.61 mm (0.221 inch); column lengths were up to 10 mm (0.39 inch).

* Bomb calorimetry measurements made by T. M. Massis, 2516.

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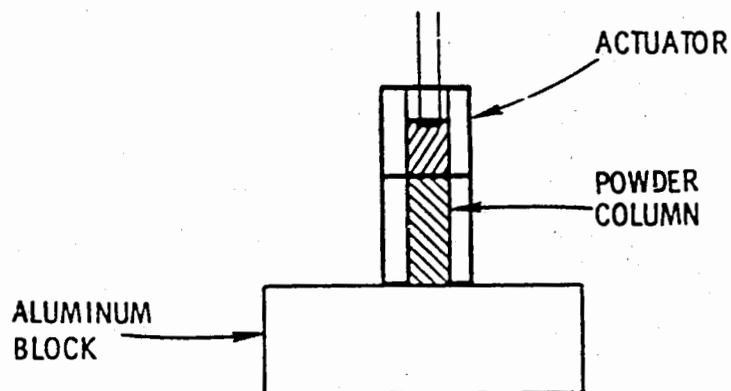


Figure 18. Apparatus for dent measurements of high density columns

TABLE XVI

Hot-Wire Initiation of High Density Columns

Powder	Column Density (g/cm^3)	Dent in Aluminum (mm-inches)	Type of Propagation Through Column
Ti-KClO ₄	1.93	0.79* - 0.031*	burning
TiH ₂ -KClO ₄	2.23	1.40* - 0.055*	burning
NLS	2.40	0.33 - 0.013	detonation

*These values are not the depth of the usual dents observed in explosive diagnostic studies, but are the depth of annular cavities that were eroded by high pressure-high temperature gases escaping from the confined sleeve. A photograph of a cavity is shown in Figure 19; a usual type dent is shown in Figure 20.

b) Shock Wave Initiation -- A column of high density powder (prepared as described in "Dent Tests," page 30) was placed on end, on an aluminum block (Brinell 95-100; 500 kg weight) or on a mild steel block (Brinell 153-156; 3,000 kg weight). A PETN exploding wire detonator containing a high density tetryl output pellet [7.6 mm (0.300 inch) diameter] was placed against the opposite end of the column. The assembly was held together using pressure sensitive tape. The assembly was similar to that shown in Figure 18. The detonator was initiated with a high voltage capacitor discharge firing system. After firing, the depth of the dent in the aluminum or steel block was measured. For comparison purposes, tests were also made with normal lead styphnate (NLS) and PETN. Measurements also were made with an inert column (Ti-KCl) to measure the degree of transmission of the shock wave from the tetryl pellet through the confined high density column.

A data summary is given in Table XVII.

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III. Discussion

Titanium hydride-potassium perchlorate as an actuator or squib loading powder is similar to Ti-KClO_4 in performance. The outstanding difference is the fact that $\text{TiH}_2\text{-KClO}_4$ as loose powder is very insensitive to initiation by static electricity, while Ti-KClO_4 can be initiated by a few millijoules. Both mixtures have a very high autoignition temperature. Another difference is that $\text{TiH}_2\text{-KClO}_4$ has less output energy than Ti-KClO_4 (about 58 percent of the output of Ti-KClO_4 for actuators containing 110 mg of powder).

The combination of spark insensitivity and high autoignition temperature could make $\text{TiH}_2\text{-KClO}_4$ a very useful actuator material. If this material has a disadvantage when compared to other materials it is that it must be well confined in order to propagate properly. The confinement can be attained by the addition of a suitable closure disc at the output end of the actuator. It actually may be possible to make use of this disadvantage in designing a new type of safing system for the actuator, that is, the actuator could, (1) be rendered safe or disabled by removing confinement, or (2) be armed by adding confinement to a normally unconfined unit.

Another possible disadvantage is that the actuator can be initiated by 200 volts continuously applied between bridgewire and case. This could probably be eliminated by the insertion of an insulating sleeve in the actuator cavity.

Both Ti-KClO_4 and $\text{TiH}_2\text{-KClO}_4$ are powders that are easily loaded into the pressing die and press smoothly without binding or galling the pressing fixture.

Both Ti-KClO_4 and $\text{TiH}_2\text{-KClO}_4$ appear to be stable materials at temperatures above ambient as judged from the modest experiment involving storage at 373 K (100°C) for 30 days and the DTA measurements. It has been reported that TiH_2 begins decomposing at 623 to 653 K (350 to 380°C).^{14, 15}

The minimum resistance-after-fire (RAF) of an actuator containing $\text{TiH}_2\text{-KClO}_4$ appears to be considerably better than an actuator containing Ti-KClO_4 judging from the data presented in this report. This may seem surprising when it is considered that the reaction products are probably the same for both actuators (in the case of $\text{TiH}_2\text{-KClO}_4$, water also is formed which might cause RAF to be lower). However, the value of RAF obtained when an actuator is fired depends not only upon reaction products, pin spacing, header materials, etc., but also upon chance. It will be necessary to measure a large number of actuators before a lower limit for a value of RAF can be stated with confidence. The values of RAF reported here are maximum values of the lower limits.

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The values of resistivity in this report are of interest since they are not usually determined for actuator materials. The technique devised gave very exact values of resistivity for each instantaneous measurement. However, as constant pressure was maintained on the column, the value of resistance displayed by the ohm meter slowly changed (usually toward a larger value) and sometimes suddenly shifted to a lower value. When the pressure was released and immediately reapplied the resistance value was usually higher.

The decrease in resistance could be explained by the fact that friction between the column and the wall of the die as well as internal friction between grains of powder was being overcome. This resulted in a column of slightly higher density. The increases in resistance might be explained by chemical changes produced at particle boundaries by the current applied to the column by the ohm meter, even though the current was only a few milliamperes. The values of resistivity reported are the average of many readings.

The values of resistivity were an early indication that Ti-KClO_4 filled actuators would have low leads-to-case resistance and that $\text{TiH}_2\text{-KClO}_4$ actuators would be marginal. A common requirement for actuators in weapon systems is that the powder resistance must not be less than 10,000 ohms when 500 volts DC is applied between bridgewire and actuator case. The tests conducted in "Leads to Case Resistance," Page 27, showed that actuators filled with either powder could not meet this requirement.

We believe that the technique developed for the measurement of the average velocity of a propagation front through a high density column of powder gave values that are valid to at least three significant figures. However, a spread of velocity data was obtained when the measurement was made several times (see Table XV). As a model, one might visualize a propagation front originating at the bridgewire when a column is ignited and then progressing uniformly along the column until the column is consumed. Such a model would be similar to the accepted model for a movement of a deflagration front along a column of propellant. Perhaps a more realistic model might be that a propagation front originating at the bridgewire generates high temperature-high pressure gas which seeks an outlet through fissures and local low density areas in the column as well as lower flow resistance areas at the column-brass cylinder interface. Such jets would ignite unburned powder as they travel forward thereby aiding their progress by the local generation of even higher pressures. These jets might reach the end of the column before all of the powder is consumed, and the measurement of propagation velocity then really would be a measurement of the progress of jets through and along the side of the column. This progress could be a random and nonuniform event and therefore yield the varying velocity data observed. The fact that high pressure-high temperature gas is generated by the burning of Ti-KClO_4 and $\text{TiH}_2\text{-KClO}_4$ is evident in Figure 19 as well as in other experiments not reported here.

The aluminum and steel block dent tests described in "Dent Tests," Page 30, were conducted to determine under what conditions the actuator powders could be caused to detonate. The data show

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that neither Ti-KClO_4 nor $\text{TiH}_2\text{-KClO}_4$ in highly confined high density columns detonated when initiated by a hot wire. However, when a column of Ti-KClO_4 was initiated by a shock wave, the dent produced in an aluminum block indicated that the column did detonate. However, because the dent produced under the same test conditions with $\text{TiH}_2\text{-KClO}_4$ was not markedly deeper than the dent caused by the pressures transmitted by an inert powder (Ti-KCl), one should not conclude that $\text{TiH}_2\text{-KClO}_4$ detonated, nor conclude that it will not detonate.

Because normal lead styphnate (NLS) is a common actuator material and because there is controversy among those who work with actuators whether or not NLS detonates when initiated by a hot wire, this material was also included. It is known that NLS will detonate under proper conditions since a detonation velocity of 4.90 mm/ μs ($d = 2.6 \text{ g/cm}^3$) has been reported.²¹

The dents produced in the tests described here show that NLS can detonate under these conditions when initiated by either a hot wire or a detonation wave.

PETN was included in the test series since it is a standard reference explosive.

In conclusion, the data obtained from this study show that Ti-KClO_4 and $\text{TiH}_2\text{-KClO}_4$ are very similar actuator and squib powders in performance but with the outstanding difference that $\text{TiH}_2\text{-KClO}_4$ is remarkably less sensitive to spark initiation, and based on current models and on our experience, the test data are strong evidence that it would not be initiated by static electricity from the human body. It is recommended that $\text{TiH}_2\text{-KClO}_4$ be investigated further, (1) to determine the optimum ratio of titanium to hydrogen in the titanium hydride to be used, (2) to determine the optimum ratio of hydride to potassium perchlorate, (3) to determine optimum particle size of TiH_2 and KClO_4 , and (4) to establish firmly its almost ideal properties for an actuator and squib material. As mentioned earlier, if $\text{TiH}_2\text{-KClO}_4$ is to be used in a development program, attention must be given to the potential problem of hydrogen embrittlement.

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