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MODIFICATIONS TO THE FAST VARIABLE CONFINEMENT COOK-OFF TEST (VCCT) AT PICATINNY ARSENAL

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U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND ARMAMENTS CENTER

Munitions Engineering and Technology Center

Picatinny Arsenal, New Jersey

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14. ABSTRACT
The response of an energetic material when heated in confinement is critical safety knowledge for explosives and munitions developers. Cook-off experiments are required for energetic material qualification, hazard classification, and Insensitive Munitions (IM) assessment. The variable confinement cook-off test (VCCT) is a sub-scale test used to assess an explosive's confined response to heating. There are standard procedures in place to perform VCCT in a slow or fast cook-off configuration, with heating rates ranging from 3.3 °C/hr for the slow VCCT to 2 to 3 °C/sec for the fast VCCT. Due to obsolescence of the mica band heaters typically used for VCCT, a new approach to the fast VCCT was needed. This report details revised fast VCCT procedures at the U.S. Army Combat Capabilities Development Command (DEVCOM) Armaments Center (AC) Explosive Development Facility, Picatinny Arsenal, NJ, and provides test data for a common combined effects explosive fill, PAX-30.

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INTRODUCTION

The response of an energetic material when heated in confinement is critical safety knowledge for explosives and munitions developers. Cook-off experiments are required for energetic material qualification, hazard classification, and Insensitive Munitions (IM) assessment. In many cases, these experiments are performed at the system level with technologies incorporated to reduce reaction violence and/or increase reaction temperature. Since the results of these thermal experiments are highly dependent upon the heating rate selected, the energetics community has typically evaluated two threats: (1) fast cook-offs, which simulate a munition directly in a fire, and (2) slow cook-offs, which simulate a munition in close proximity to a fire or other heat source. Such cook-off tests are typically resource-intensive, so sub-scale experiments are used during formulation development to predict full-scale response.

The first major documented thrust into the area of sub-scale cook-off tests occurred at the Naval Air Weapons Station China Lake, CA, formerly the Naval Weapons Center, by Pakulak, Anderson, and Cragin in the early 1980s (refs. 1 and 2). They composed comprehensive reports that detailed thermal tests ranging in scale from milligrams of explosive powder to munition-scale, fuel-fire cook-off experiments and introduced the small-scale cook-off bomb (SCB) and super small-scale cook-off bomb (SSCB) tests. Nichrome ribbon heaters powered with 115 VAC were used to heat the SCB and SCBB vessels at a rate of 2 to 3 °C/sec. These experiments were designed to represent fast cook-off events. Reaction temperature and violence, based on the damage to the test fixture, were reported.

Alexander, Gibson, and Baudler, experimentalists at the Naval Surface Warfare Center Indian Head Division (NSWC IHD), MD, developed the variable confinement cook-off test (VCCT) based on modifications to the SSCB (ref. 3). The VCCT consists of various thickness steel confinement sleeves secured between two thick steel witness plates and requires 50 to 60 g of explosives per trial. The mild steel confinement wall thicknesses range from 0.015 to 0.120 in. Slow cook-off tests are performed at a heating rate of 3.3 °C/hr using two 125-W mica band heaters. Fast cook-off tests require the use of nichrome wire to reach the desired target temperature of 1,000 °F within 1 min.

The first VCCTs at Picatinny Arsenal were performed at the U.S. Army Combat Capabilities Development Command (DEVCOM) Armaments Center (AC) Explosive Development Facility (EDF), formerly the U.S. Army Armament Research, Development and Engineering Center (ARDEC) EDF, Picatinny Arsenal, NJ, in the early 2000s. A detailed description of local test methods and a comprehensive summary of fast and slow VCCT results from 2012 to 2019 are described in reference 4. The Picatinny Arsenal methods are comparable to Alexander, Gibson, and Baudler for slow VCCTs, but substantial modifications were made to the approach in the initial transition of fast VCCTs. The EDF’s subsequent shift from mica band heaters to flexible silicone rubber fiberglass (SRFG) heaters in 2015 was shown to be adequate for slow VCCTs but further reduced the already inadequate heating rate in fast VCCTs. In order to provide improved thermal response data for new energetic materials, a new approach to conducting fast VCCTs was necessary.

The purpose of this report is to detail redesigned procedures for properly integrating fast VCCTs at the DEVCOM AC EDF. Specific modifications to the VCCT fixtures are discussed, both successful and unsuccessful, and fast VCCT results for the high-explosive composition PAX-30 are presented. The proposed experimental setup and procedures are more aligned with other Department of Defense (DoD) explosives qualification laboratories and will allow better comparison of energetic materials between the services.

LEGACY PICATINNY ARSENAL FAST VARIABLE CONFINEMENT COOK-OFF TEST PROCEDURES

The preparation and assembly of the explosive components and metal parts for fast VCCT remained the same at Picatinny Arsenal for several years as documented in reference 4. Given the rapid heating rate of fast VCCT, the improvements presented to seal the test fixtures for energetic materials containing low melting-point materials were unnecessary. A diagram of the fast VCCT configuration developed by Alexander, Gibson, and Baudler, from which the Picatinny Arsenal methods were derived, is shown in figure 1.

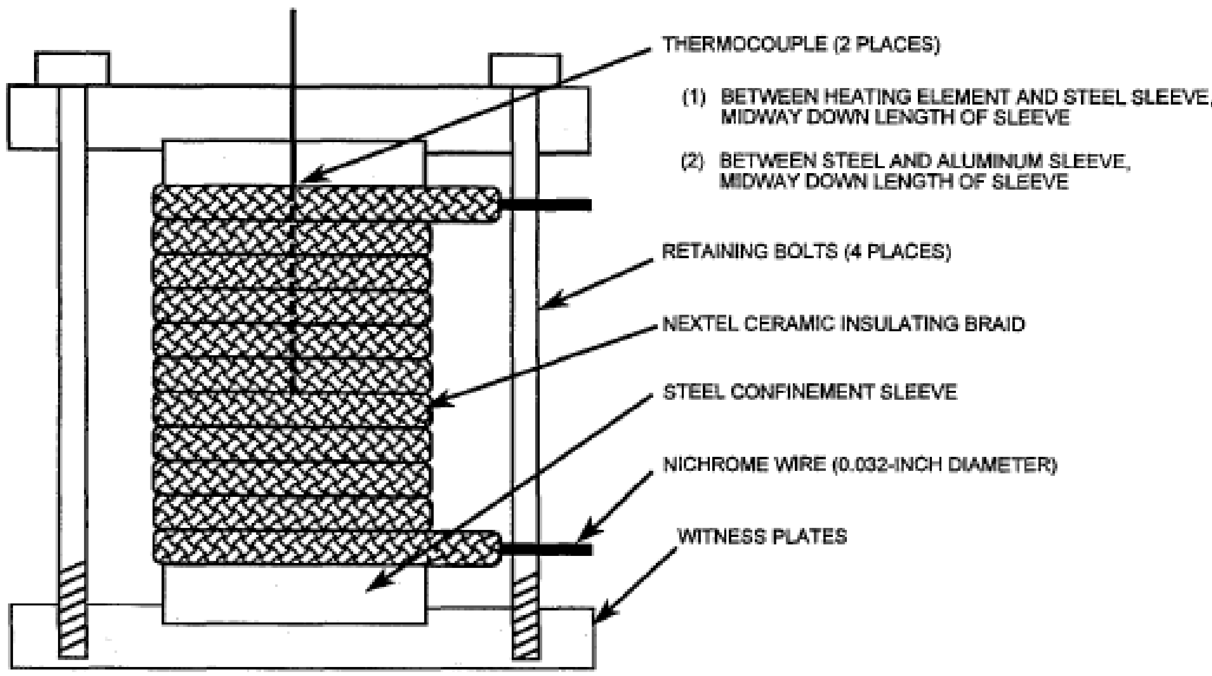

Figure 1
Diagram of fast VCCT setup (from ref. 3)

Until 2015, two 125-W, 1-in. diameter mica heating bands electrically connected in parallel were used for all VCCT trials at Picatinny Arsenal. The heating bands were individually secured in place around the steel sleeve with integral tightening bolts. Fast VCCT experiments were performed by simply toggling 115 VAC on/off via a relay, enabling the mica band heaters to heat the test fixtures as quickly as possible. This heating rate did not meet the 1,000 °F in a minute objective but yielded reasonably comparable data for experiments performed at Picatinny Arsenal with the 125-W mica band heaters. The temperature ramp rate was highly nonlinear. Time to ~400 °F, where many of the propellant samples reacted, was typically on the order of 3 to 5 min. Time to ~500 °F varied significantly from 7 to 13 min. The fast cook-off heating profile for an experiment on a thermally stable pyrotechnic powder is shown in figure 2. Thermocouple data for fast VCCTs is typically recorded at a rate of 1 to 12 samples per second.

In 2015, the EDF's supplier for mica band heaters was acquired by another manufacturing company and an abrupt change to the dimensions of the bands prevented their use for VCCT. After researching alternatives, operators at the EDF selected 10-W/in^2 Omega SRFG heaters, 2 x 5 in. (100 W total). This geometry permitted at least one full wrap around the confinement sleeve with a similarly effective heating area. The flexible SRFG heaters were affixed to the confinement sleeves with a combination of aluminum tape and twisted bare copper wire. The SRFG heaters were capable of maintaining the slow VCCT heating rate (3.3 °C/hr) but performed poorly in the fast VCCT configuration, taking approximately 30 min to reach 450 °F, as seen in figure 3. Note that the thermocouple in this specific fast VCCT was located on the exterior of the confinement sleeve, compared to the mica heating band configuration where the thermocouple was located on the interior of the confinement sleeve.

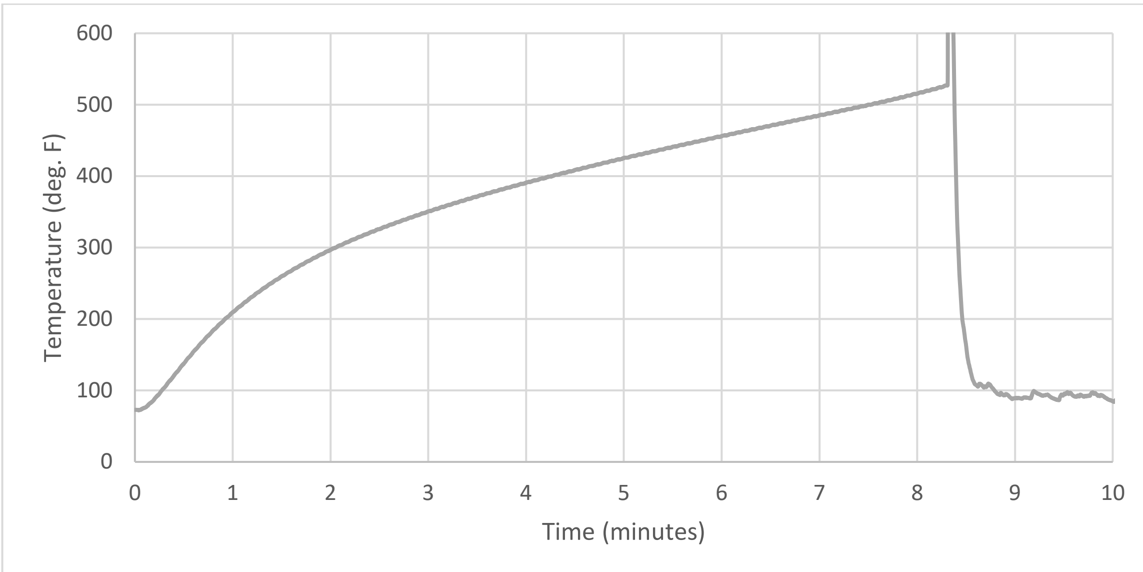

Figure 2
Fast VCCT heating profile with mica band heaters

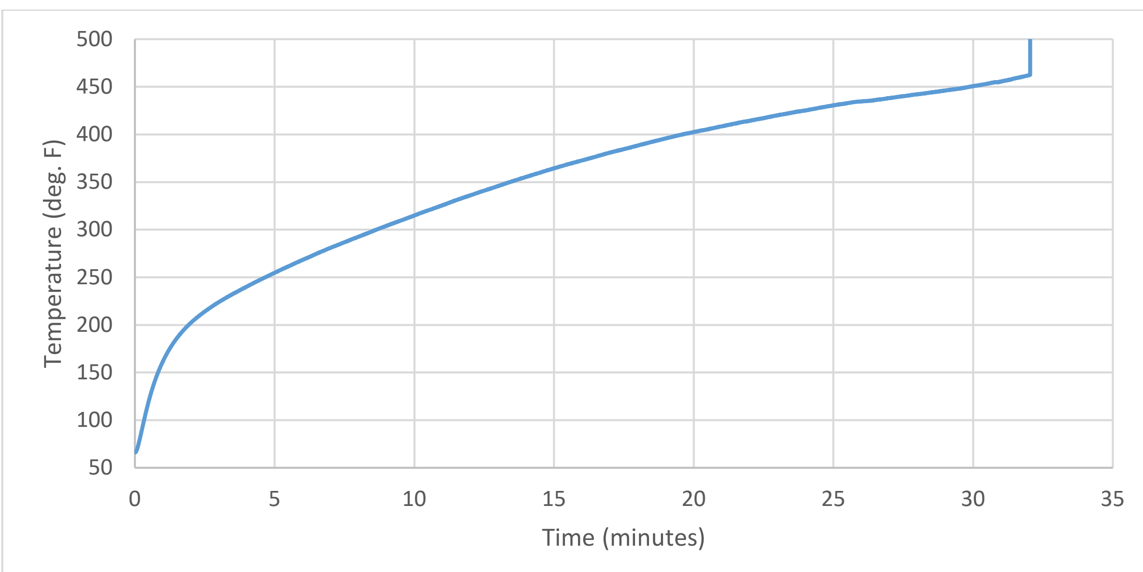

Figure 3
Fast VCCT heating profile with SRFG heater

PROPOSED PICATINNY ARSENAL FAST VARIABLE CONFINEMENT COOK-OFF TEST PROCEDURES

The original Picatinny Arsenal fast VCCT approach with mica heating bands did not approach the requirements of Standardization Agreement (STANAG) 4240, “Fast Heating Munition Test Procedures,” which calls for a flame temperature of 1,000 °F within 30 sec and an average flame temperature of 1,500 °F for the duration of the experiment (ref. 5). Given the limited wattage of the SRFG heaters, their use in fast VCCT was not viable. The authors reviewed the original work of Alexander, Gibson, and Baudler (ref. 3) and the updated work by Cart-Obregón and Gibson (ref. 6) and then implemented a nichrome wire configuration similar to that utilized in those technical reports. Through an iterative procedure, starting with an inert test sample, the assembly technique, power source, and thermocouple insulation approaches were down-selected and implemented.

Test Charge Assembly

Initially, the majority of the VCCT assembly procedure remained the same. Nichrome wire in a ceramic insulating braid, as shown in figure 1 and described in reference 3, was tightly wrapped around the steel confinement sleeve and temporarily fastened with electrical tape. Approximately 12 in. of excess nichrome wire was allowed on each end to connect to the power source. Once the VCCT end plates were installed and the bolts torqued to specification, the electrical tape was removed from the confinement sleeve and the free ends of the nichrome wire were wrapped around the retaining bolts several times to ensure that the heating braid was taut and secured. The free ends were then stripped and prepared for connection to the power source. A photograph of an assembled charge is shown in figure 4.

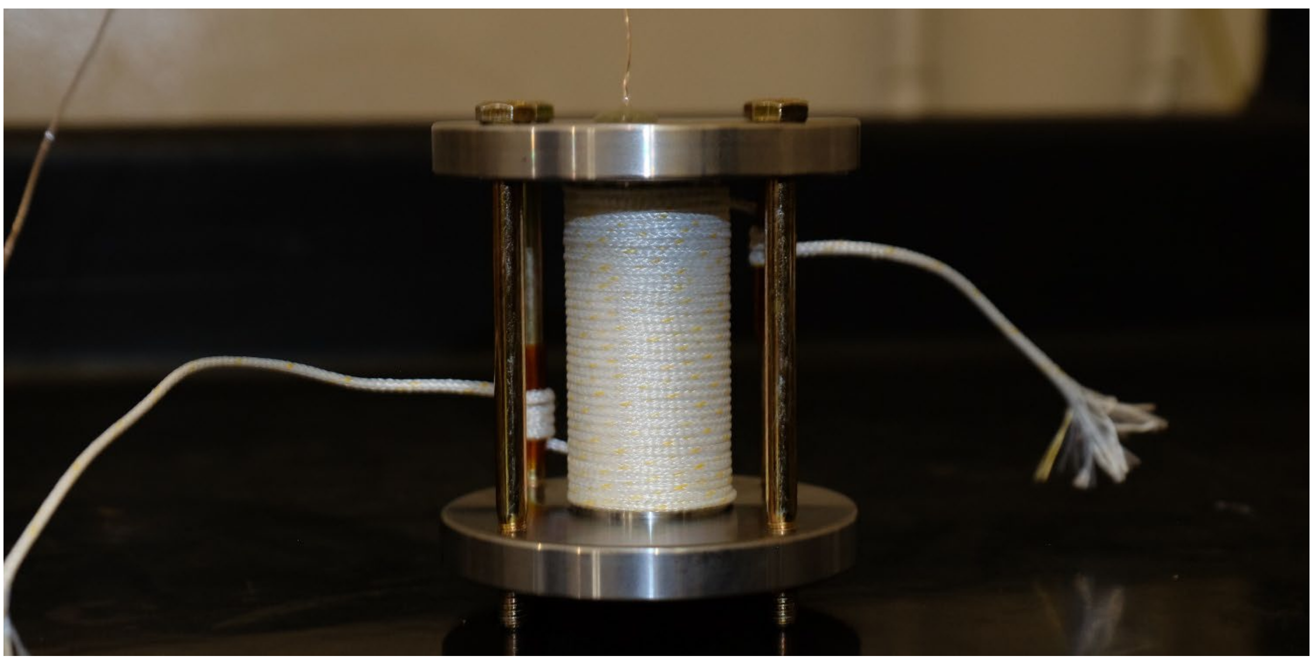

Figure 4
Assembled fast VCCT fixture

The first inert trials showed that the Type K thermocouples were being influenced by the 115 VAC used to heat the nichrome wire. The ceramic insulating braid was successful in isolating the voltage at the onset of heating, but stray voltage affected the thermocouple within seconds, leading to erroneous readings. Two approaches were investigated to mitigate this issue: (1) addition of electrical insulation between the steel confinement sleeve and bolts and the nichrome wire, and (2)

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isolation of the exposed thermocouple end. For the first approach, various insulating tapes, including vinyl and polyimide, were wrapped around all external points where the ceramic braid made contact. In normal assembly of VCCT fixtures at Picatinny Arsenal, operators use small sheets of crushed aluminum foil to secure the thermocouple in the aluminum sleeve channel. To implement the second approach, isolating the thermocouple from the metal components, thin pieces of Kapton® polyimide and Teflon® polytetrafluoroethylene (PTFE) tapes were wrapped around the exposed end of the thermocouple and carefully secured into the aluminum sleeve channel.

Test Chamber Preparation and Execution

The test chamber configuration was similar to legacy fast VCCT experiments. The assembled charge was placed inside the firing pot, an 18-in. diameter steel tube with ¾-in. thick walls, to prevent potential fragmentation from damaging the test chamber walls. The thermocouple was connected to a laptop, which recorded the temperature throughout the experiment. The nichrome wire was connected directly to an interlocked 115 VAC outlet; all test chamber and surrounding access points had to be closed and a key switch activated before the outlet could be energized. No additional thermal insulation was added to the VCCT fixture or inside of the firing pot.

After the test item was wired in the test chamber and all interlocked doors and ports secured, temperature data recording was initiated on a LabVIEW laptop at a rate of 12 sec^{-1}. After confirming proper thermocouple measurements, the interlocked outlet connected to the nichrome wire was energized. Data recording continued until an audible reaction was heard, at which time the outlet was de-energized. For any trials with energetic materials, a minimum 30-min waiting period was observed prior to entering the test chamber and assessing the reaction violence.

RESULTS

Four fast VCCT trials on the combined effects of highly explosive PAX-30 are presented herein. The first three trials (T-45, T-90, and T-120 confinements) were conducted with varying configurations of external insulating tapes on the steel confinement sleeve and bolts. After approximately 20 to 30 sec of heating, the tapes combusted and a voltage path to the thermocouple end was available, resulting in erroneous temperature values. As seen in figure 5, the tapes delayed the effects of voltage on the thermocouple but not long enough to complete an explosive test. The final trial (T-120 confinement) did not contain any external insulating tape on the steel fixtures but instead included two thermocouples and integrated polyimide tape around the exposed thermocouple ends. This configuration was successful in isolating the thermocouple until reaction. The temperature/time plot is shown in figure 6.

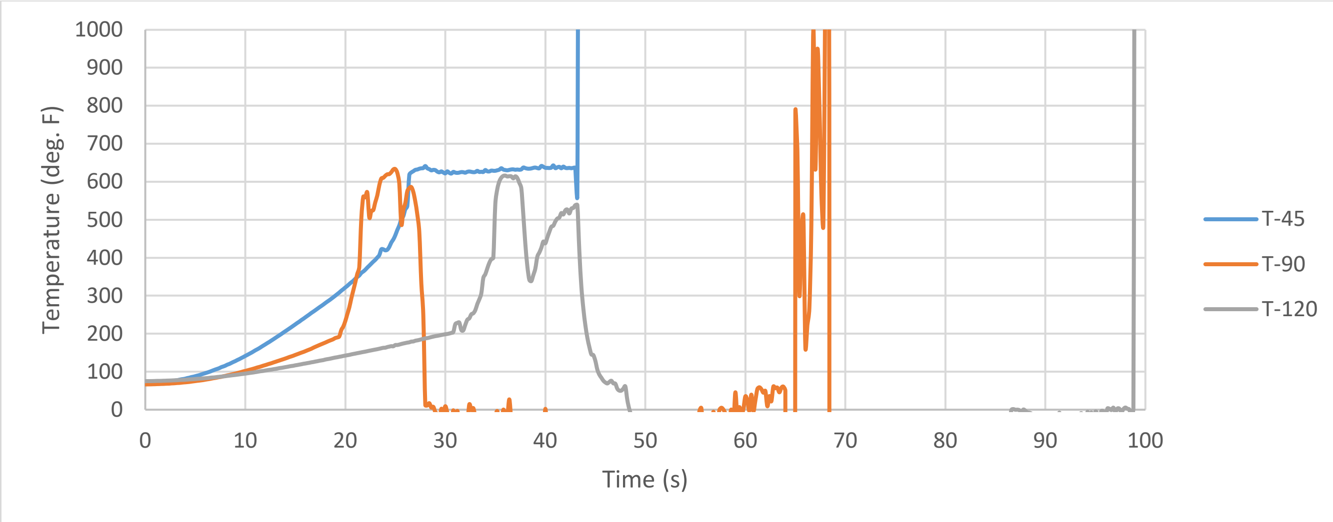

Figure 5
PAX-30 trials with external insulating tapes

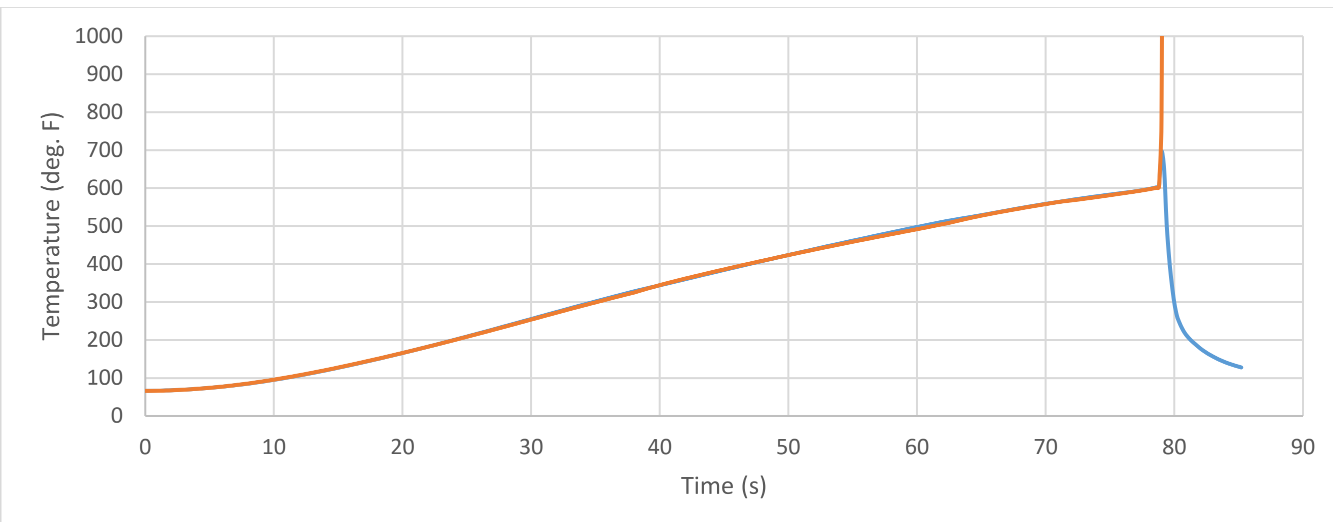

Figure 6
PAX-30 trial (T-120 repeat) with internal insulating tapes

PAX-30 did not react violently in any of the fast VCCT experiments. All trials resulted in burn reactions, the lowest level of reactivity defined for the test. The aluminum sleeves and steel confinement sleeves were split open, no bolts were sheared, and there was no evidence of bulging or damage to the end plates. The reaction time was found by locating the point at which the thermocouple reported as an open line. The reaction temperature could not be determined for the first three trials due to inadequate isolation of the thermocouple from the power source. The PAX-30 fast VCCT results are shown in table 1 and a photograph of the post-test fixtures is included as figure 7.

Table 1
PAX-30 fast VCCT results

Trial no.	Confinement	Reaction time (sec)	Reaction temperature (°F)	Reaction violence
1	T-45	43.4	unknown	burn
2	T-90	64.2	unknown	burn
3	T-120	99.0	unknown	burn
4	T-120	79.0	602.4	burn

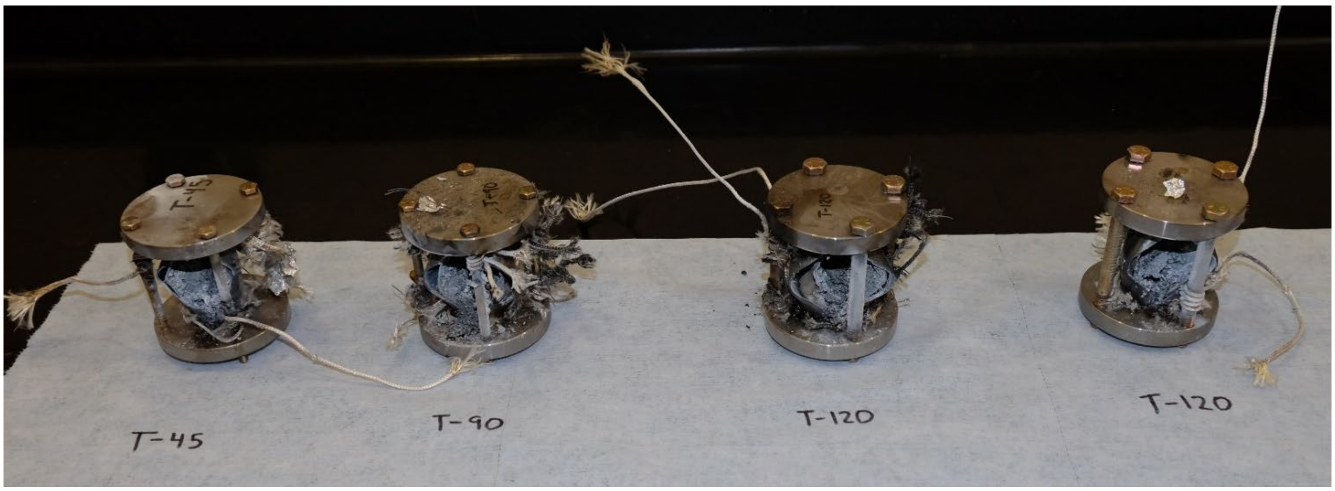

Figure 7
Post-test photograph of PAX-30 fast VCCT fixtures

DISCUSSION

Initially, the use of direct current (DC) power supplies was considered to heat the nichrome wire. Two 30 V 30 A power supplies were placed in series and connected to an inert fast VCCT fixture. The resulting temperature plot is shown in figure 8. This heating rate was insufficient, reaching only 400 °F in approximately 2 min, and the trial was halted at approximately 2.5 min. These results led to the subsequent trials using 115 VAC building power.

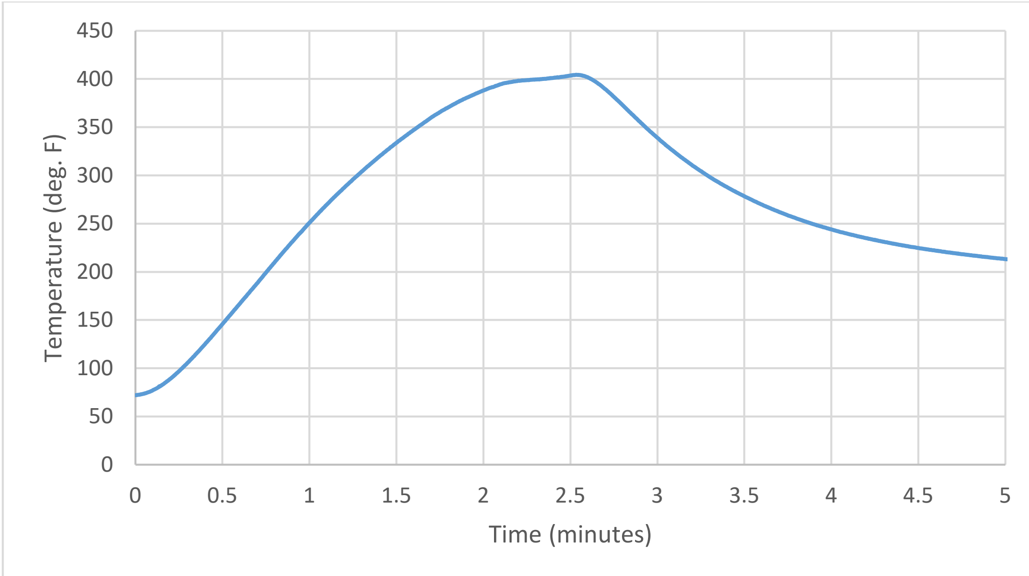

Figure 8
Heating rate with DC power supplies

Of the various approaches to isolate the thermocouple from stray voltage, surrounding the exposed end of the thermocouple with polyimide was the most successful and is expected to be the standardized approach at Picatinny Arsenal. The insulators selected for use on the confinement sleeve and the retaining bolts were not survivable at high temperatures. An inert trial with the thin polyimide tape on the thermocouple showed consistent internal temperature recording up to 1,000 °F before breakdown. Future fast VCCT fixtures will be constructed using two isolated internal thermocouples, one in each channel of the aluminum sleeve, as was done for the final T-120 experiment with PAX-30.

Reactions were seen in PAX-30 within 2 min of heating. Given the limited sample size, the heating rate appears to be similar to or higher than the 2 to 3 °C/sec that Pakulak et al. targeted in the SCB and SSCB fast cook-offs and comparable to the NSWC IHD fast VCCT. This nichrome wire approach will be used for future fast VCCTs at Picatinny Arsenal and should improve the ability to compare results with other DoD laboratories. Tests on a variety of high explosives, including pressed, melt-pour, and cast-cure formulations, are needed to establish baseline time to reaction, reaction temperature, and reaction violence results for this new procedure.

CONCLUSIONS

A redesign of the fast variable confinement cook-off test (VCCT) protocol at the U.S. Army Combat Capabilities Command (DEVCOM) Armaments Center (AC) Explosive Development Facility (EDF), Picatinny Arsenal, NJ, was necessary due to obsolescence of the legacy mica band heaters. The selected replacement, flexible silicone rubber fiberglass (SRFG) heaters, proved effective for slow cook-off experiments but did not have the power output to achieve fast cook-off heating rates. The authors reviewed technical reports from two U.S. Navy facilities and adopted a nichrome wire heating method. After several inert trials and various configurations to maintain quality thermocouple data recording, a final configuration using polyimide tape to isolate the thermocouple ends was implemented. Four fast VCCT experiments were conducted on PAX-30, a combined effects high explosive. The results showed a promising heating rate. Future fast VCCTs at Picatinny Arsenal's EDF will be conducted following the procedures established herein.

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