Advancing the Propane Fast Cookoff Burner and Testing

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Abstract

Propane burners have already been shown to produce the temperature and heat flux requirements to replicate the thermal environment of a liquid-pool-fire fast cookoff test. Ordnance items tested for fast cookoff in both propane burners and liquid pool fires have shown to have comparable reactions in the test. Further design work was done on the propane burner to allow it to be used to test larger ordnance items. The fuel delivery system to the larger burner was optimized and calibration showed that it produced a uniform flame that met the thermal requirements. It was then used to test a 500 lb bomb which was also tested in a liquid pool fire. The results of the testing are compared and demonstrate the ability to test large ordnance items in the propane burners. Additional testing was performed on an ammunition can containing a large number of energetic items. This test demonstrated that the multiple reactions that occur in such a test do not damage the burner or cause the test to change. Within the variation expected from fast cookoff testing the results from this test were very similar to the results from an identical test that was performed in a liquid pool fire. These test results continue to show that propane burners are safer, less expensive, and more environmentally friendly compared to the liquid pool fire for conducting fast cookoff tests.

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Expansion of Large Burner

The propane burner located at China Lake, CA was increased from 3.1 m by 6.1 m (10 ft by 20 ft) to 4.6 m by 6.1 m (15 ft by 20ft). The smaller burner had met the temperature and heat flux requirements for a 4.3 m by 1.2 m by 1.8 m (14 ft by 4 ft by 6 ft) volume in the flame hearth [1]. However, the burner was increased in size to have greater flame coverage and the burner design was changed to have evenly spaced burner pipes throughout the entire length of the burner. The burner was then calibrated using a thermocouple grid and heat flux gauges. The burner with the thermocouple grid is shown in Figure 1.

Figure 1. 4.6 m by 6.1 m Propane Burner Built at China Lake

During the testing with the thermocouple grid, there was higher than desired wind and no consistent temperature volume was measured. Also, in operation, the burner did not qualitatively produce as high a flame as the 3.1 m by 6.1 m burner. The surface area of the burner was increased by 50% going from 3.1 m by 6.1 m to 4.6 m by 6.1 m. It was hypothesized that the current fuel delivery system was inadequate and not enough fuel was reaching the burner. The burner was reduced to a 4.6 m by 4.6 m burner, which only increased surface area by 12.5% compared to the 3.1 m by 6.1 m burner. Heat flux measurements were taken within the 4.6 m by 4.6 m burner. Two test stands were inserted and used to measure the heat flux. The measurement locations on the stand were 45.7 cm, 91.4 cm, 137 cm, 183 cm (18 in, 36 in, 54 in, and 72 in) above the ground. One of the test stands was placed at the center of the burner and the other test stand was placed 1.22 m from the center of the burner. Two tests were performed with this configuration. The first test had high winds and the heat fluxes were below the required value of 80 kW/m^2. The second test had little wind and the heat fluxes measured were above the required value. The quantitative results of these two tests are shown in Table 1.

Table 1. Heat Flux Results from 4.6 m by 4.6 m Burner

	Heat Flux Center of Burner (kW/m^2)		Heat Flux 4' from Center of Burner (kW/m^2)	
Height Above Ground	Test #1	Test #2	Test #1	Test #2
182 cm	63	96	30	89
137 cm	106	115	38	109
91.4 cm	118	135	54	135
45.7 cm	115	147	97	154

The heat fluxes from test #2 were sufficient to meet the STANAG requirements. However, the flames were not always consistent and a full 4.6 m by 6.1 m burner was desired. A new burner setup was designed. The size of the burner was returned to 4.6 m by 6.1 m. As shown in Figure 1, the previous burners at China Lake had the entrance of propane into the burner on the same side for all of the pipes. This is different than the Dahlgren design, which had entrance of the propane into the burner alternating sides up the length of the burner. The new China Lake design adopted the alternating entrance of the propane into the burner. Also the modified 4.6 m by 6.1 m burner was made of 3.1 m pipes. This meant that the center 1.5 m is where the alternating pipes overlapped. The inner-pipe spacing is 15 cm in this region. The 1.5 m on both sides of the center region had 30.5 cm spacing for the pipes. The change was done to inject the majority of the propane in the center of the burner and provide for a more stable flame. There were convenience benefits from this design change as well. The 3.1 m pipes were the largest that could fit in the water drilling facility. The propane-injecting orifices for the 4.6 m pipes had to be drilled by hand, which was tedious and time consuming. Also the 30.5 cm spacing at the ends of the propane burner will allow for A-frame placement during testing. The modified 4.6 m by 6.1 m burner is shown in Figure 2.

For both the Dahlgren and China Lake burner setups, the vapor pressure of the liquid propane in the tank provides the pressure difference to flow the propane through the burner. The testing with inconsistent measured temperatures in the flame was completed in the winter. Although the winters in the China Lake desert are relatively mild, early morning temperatures in November are often around -1 ^{0}C (30 F) compared to early morning temperatures in July at 27 ^{0}C (80 F). This difference in temperature equates to about double the vapor pressure at the higher temperature. To remove the temperature dependence and variance of the propane vapor pressure, a heating blanket was placed on the propane tank. A commercially available Powerblanket ©, model GCW1KS Rev C was placed around the propane tank. The temperature of the propane tank was set to be maintained at 32 ^{0}C (90 F). After the burner design and setup changes were completed the flame consistency and volume were improved as shown in Figure 3.

Figure 2. Modified 4.6 m by 6.1 m Burner

Figure 3. Qualitative Flame Structure for Modified 4.6 m by 6.1 m Propane Burner

Quantitative measurements of the flame structure were also performed on the modified 4.6 m by 6.1 m propane burner. The temperature grid was composed of 17 temperature measurement locations in a horizontal plane. There were 4 vertical locations of the horizontal planes for a total of 68 temperature measurements. The heat flux measurements consisted of 2 test stands that had 4 heat flux gauges at different vertical locations for 8 heat flux measurements per test. The heat flux test stands were placed at nine different locations. The temperature and heat flux measurement setup is shown in Figure 4 and Figure 5.

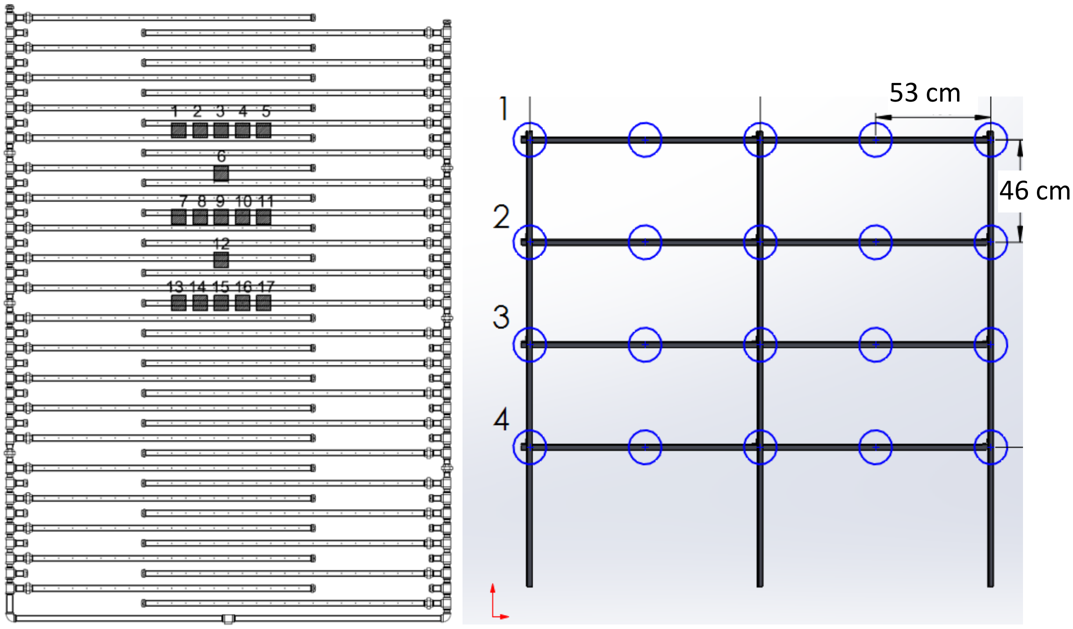

Figure 4. Temperature Grid Setup for Modified 4.6 m by 6.1 m Propane Burner

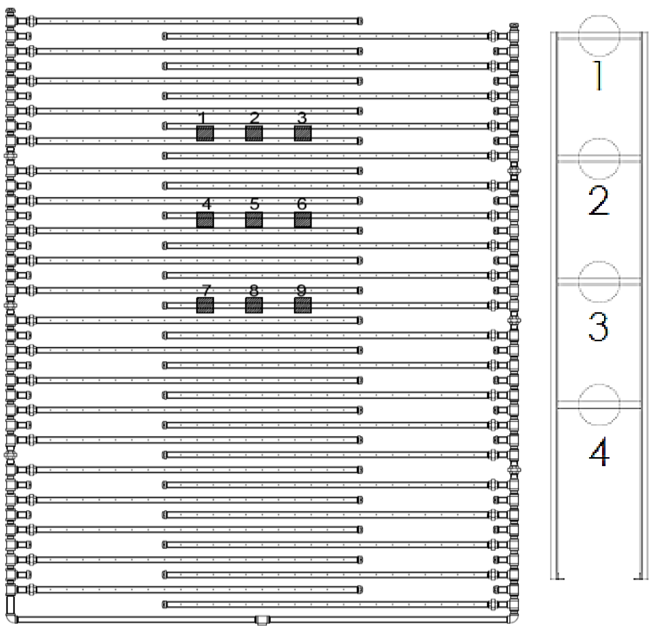

Figure 5. Heat Flux Measurement Setup for Modified 4.6 m by 6.1 m Propane Burner

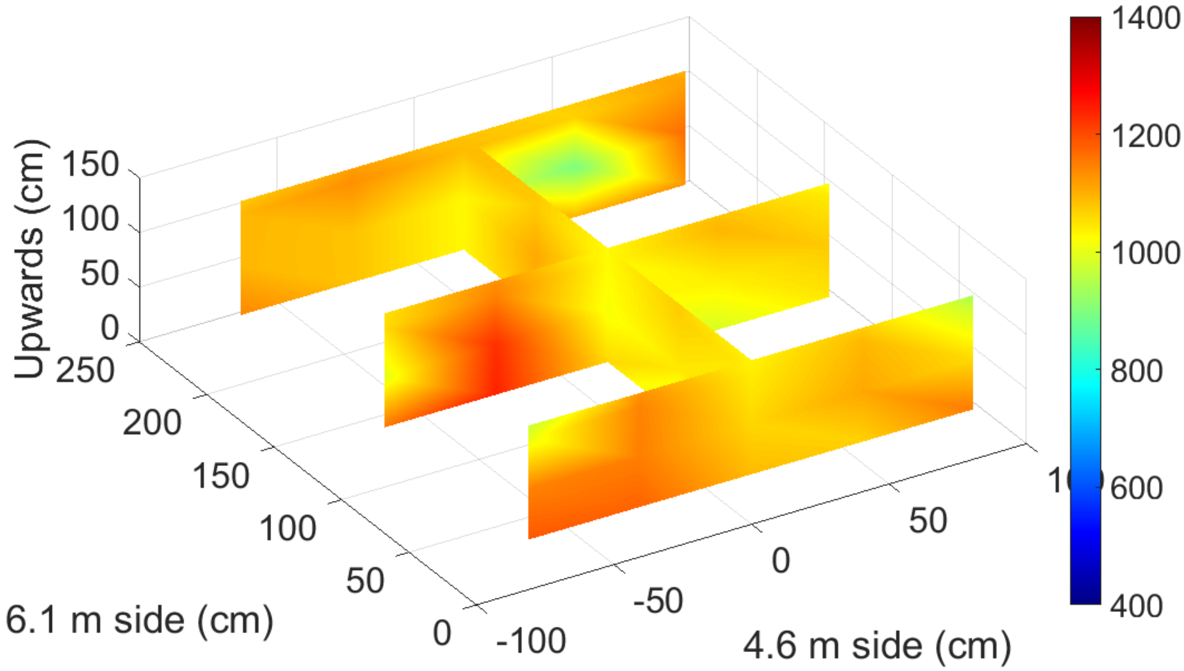

Figure 6. Temperature Contours (^{0}C) from Temperature Measurements of Modified 4.6 m by 6.1 m Propane Burner

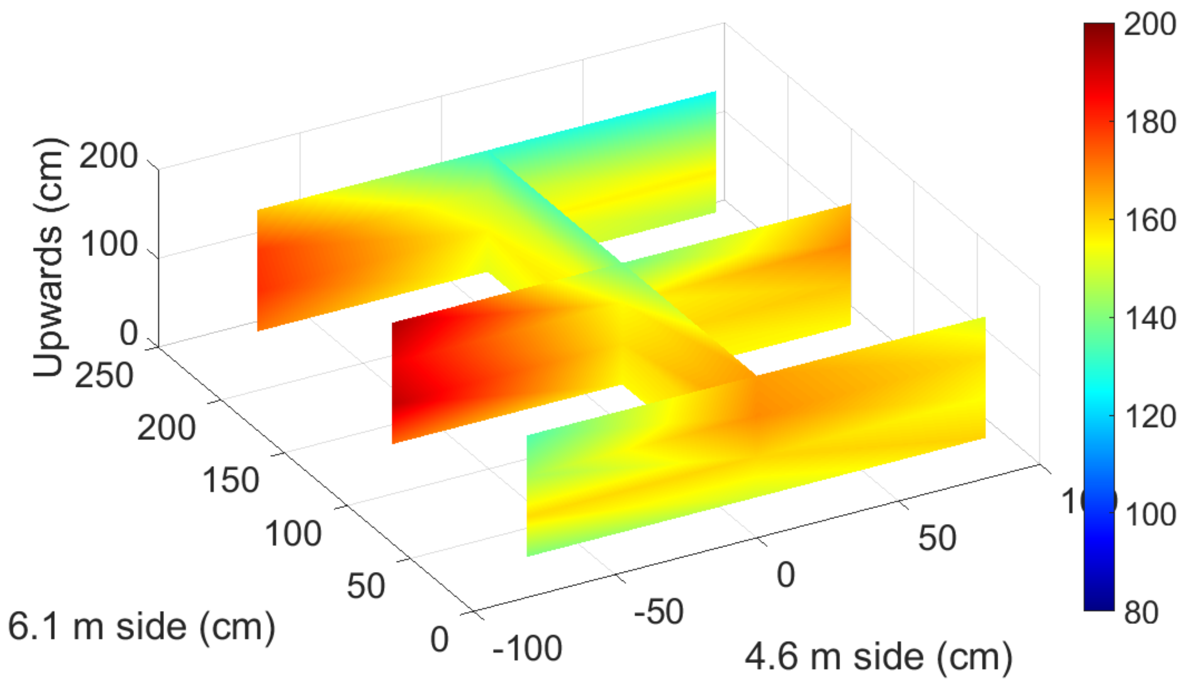

Figure 7. Heat Flux Contours (kW/m^2) from Heat Flux Measurements of Modified 4.6 m by 6.1 m Propane Burner

Figure 6 and Figure 7 show contours that were generated from the temperature and heat flux measurements. The STANAG requirement is that the temperatures are greater than 800 ^{0}C and the heat fluxes are greater than 80 kW/m^2. Both of these conditions were met. Another requirement of the STANAG is that the standard deviation of the average temperatures at each location be less than 10% of the overall average temperature. The measured standard deviation was 7% of the overall average temperature, which fulfilled the requirement and indicated a uniform flame. The results show that the China Lake burner produced a volume 4.3 m by 1.5 m by 1.8 m that meets the STANAG requirements and can be used for fast cookoff (FCO) testing.

Continued Ordnance Testing

At Dahlgren, Virginia, a FCO test with the 3.7 m by 3.7 m (12 ft by 12 ft) propane burner was performed on an ammunition can containing 110 medium ammunition cartridges. This test was performed for two reasons. First, data exist from an identical test performed in the liquid pool fire and this test will help show whether energetic items perform similarly between the two types of FCO tests. Second, there has been concern within the community that items that contain multiple energetics would not perform well in the propane burner. The concern is that after the initial reaction scatters energetic items within the burner, that subsequent reactions of items in contact with the burner tubes will cause extensive damage and alter the fire created by the burner.

The ammunition can is shown in Figure 8. In this test, the rounds tested were training and practice (TP) rounds and therefore contained live propellant but inert (no HE) projectiles. It was decided that testing of multiple high explosive items should be avoided until it had been demonstrated that the burner could handle multiple lower order explosions. Each cartridge contained 50 grams of propellant for a total NEW of 12.25 lbs.

Figure 8. Ammo Can Containing 110 Medium Ammunition Rounds. Shown at Right, Ammo Can on Test Stand Prior to Propane FCO Test in 3.7 m by 3.7 m Burner.

The test was performed on a day with nearly perfect weather conditions and no wind. The item was fully engulfed in the flame for 14m 40s at which point the firing director decided that no further reactions were likely and the burner was shut off. The first reaction occurred at 2m 30s and the final reaction was heard at 9m 10s. Throughout the interim period, a large number of explosions could be heard and debris could be seen leaving the burner area. At no point did the flame appearance change or give any indication that damage had occurred to any of the burner tubes. Posttest inspection did show some minor damage to a few burner tubes indicating where rounds had exploded while in contact with the tubes, but none of these created new holes or impacted the gas flow in any way.

As an additional test of the propane burner, the FCO test of the medium ammunition cartridges was performed as if it were to be presented to the munitions reactions evaluations board (MREB) of the US Navy. Therefore, all fragments from the test were collected and all those that travelled further than 50 feet were catalogued, weighed, and there final location (distance and angle) were documented. A photograph of the fragments recovered is shown in Figure 9 as they are sorted into three categories; those that remained within the burner, those that left the burner but traveled less than 50 feet, and those that traveled further than 50 feet.

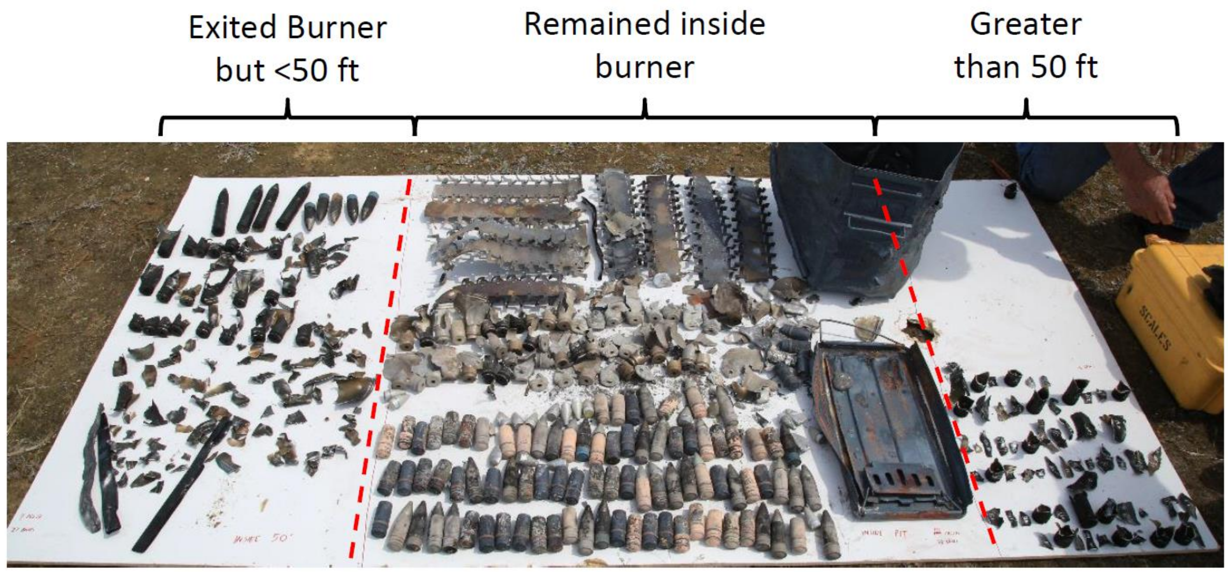

Figure 9. Fragments Recovered from Multiple Medium Ammunition in FCO test in 3.7 m by 3.7 m Propane Burner.

64 fragments were thrown a distance greater than 50 feet. The debris map and resulting energy plot for these 64 fragments is shown in Figure 10. Note that the in the plot at right the distribution of fragment weights is bimodal. The lighter fragments (at left) are all pieces of the cartridge case closer to the neck where the material is thin. The heavier fragments are all pieces of the cartridge case at the base. The base is heavier material and remains largely intact and therefore all these fragments have approximately the same weight. Also note that none of the fragments had an energy that exceeded the 20 Joule criteria, although one was very close. If this item had gone to the MREB, it would almost certainly have been scored a type V based on this energy plot.

When the same medium ammunition container was tested in the liquid pool fire, it received a type IV reaction evaluation. While this differs from the type V that it received in the propane burner, the reactions were actually very similar. This is apparent when the fragment energy plots from the two tests are viewed side by side as shown in Figure 11. Note that in the liquid pool fire test plot shown at right that the fragment weight dispersion is very similar and that the only real difference is that one of the fragments barely exceeded the 20 J criteria. Under the new criteria, this could have been scored a Type V reaction. So while the two tests received different scores, the reaction of the item was nearly identical. This is another indication that within the typical variation of a FCO the propane burner accurately simulates the liquid pool fire FCO test.

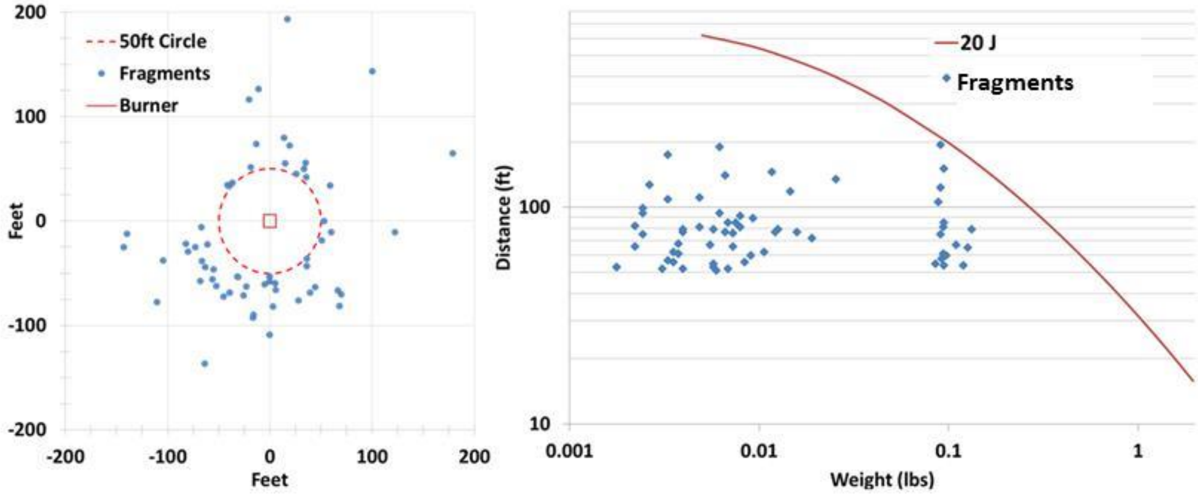

Figure 10. Debris map and energy of the 64 fragments that traveled greater than 50 feet. None exceed the 20 J criteria but one is very close.

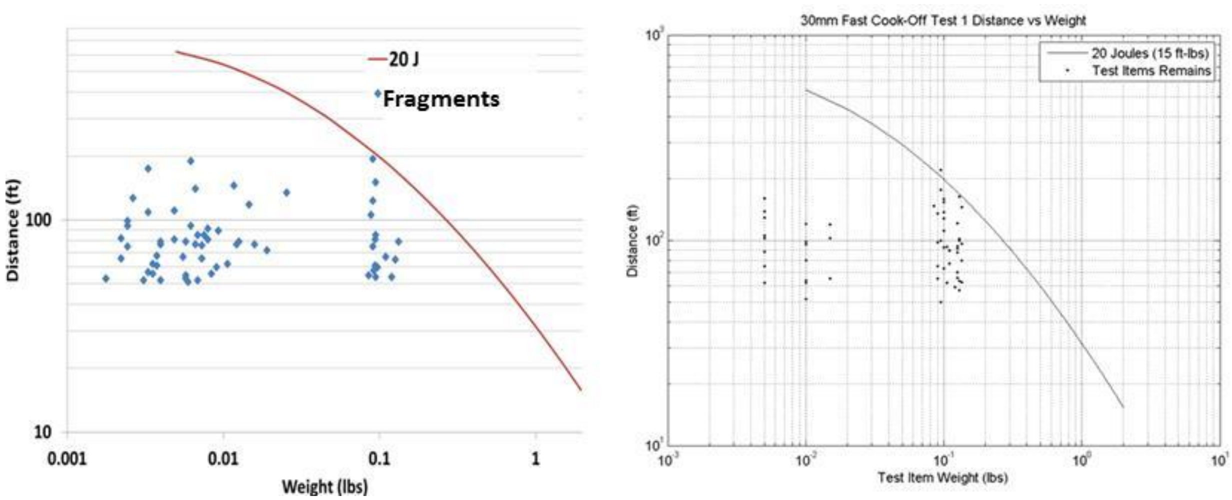

Figure 11. Fragment energy plots from propane FCO test (left) and liquid pool FCO test (right)

An additional task undertaken during this fiscal year was the development of a technical data package (TDP) including detailed drawings of the 3.7 m by 3.7 m square burner used at Dahlgren. As the burner transitions from a developmental project to an established test platform, the TDP will help other test centers who want to build their own propane burner. As shown in Figure 12, the drawings created contain not only the assembly and machine drawings needed to build the burner itself, but also the details related to the plumbing and controls of the burner. The complete TDP is available upon request.

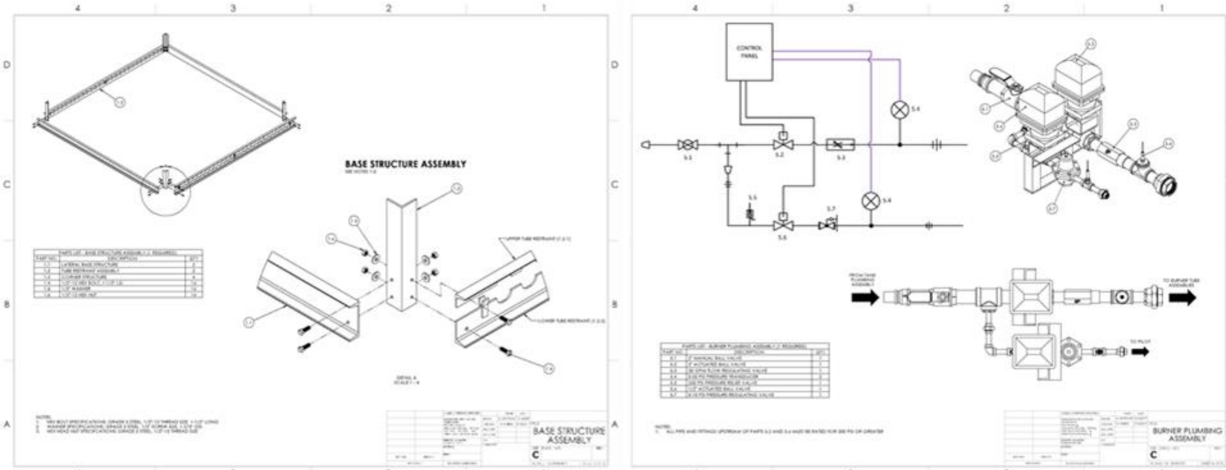

Figure 12. Sample of TDP Drawings Showing Assembly Type Drawings (left) and Valve Schematic and Assembly (right)

A 227 kg (500 lb) class bomb was tested at China Lake in the traditional FCO liquid fuel fire and in the modified 4.6 m by 6.1 m propane burner. The bomb had an installed fuze, nose plug, and tail kit. For one test, the bomb was suspended on an A-frame in the middle of a pool of 11360 liters of F-24 fuel. The other test suspended the bomb on an A-frame centered over the modified 4.6 m by 6.1 m propane burner The objective of these tests were to test a large ordnance item in the propane burner and have a direct comparison of reaction with a liquid fuel fire. The bomb had 87 kg of energetic material. The expected result of the test was a Type V reaction.

Figure 13. FCO Test Setup and Post Test for Liquid Fuel Fire

In the pool fire, the asset was tested in the tactical configuration. The asset had a reaction occur in the aft end 11 minutes and 26 minutes into the test. The asset began venting from about 12 minutes and 42 seconds to 18 minutes into the test. A piece of the tail kit that was mapped was found beyond the 50 foot distance arc, but no items were beyond the 20 J level. Data was captured on all channels by the ground mounted piezoelectric blast pressure gages but no significant blast pressure was observed. Temperature data was recorded for the duration of the test and the temperatures met the STANAG requirements.

The same class and configuration of bomb was later tested in the modified 4.6 m by 6.1 m propane burner. The burner was ignited with the bomb suspended on the A-frame. A large engulfing flame was produced. At approximately 1:20 into the test the propane flow was cut and the flames disappeared. After determining that the fuze was not armed in the bomb, an investigation was conducted. A relay had corroded and shorted the electricity to the propane valve, which failed shut. The relay was replaced and the test was retried the next day. The burner ignited again without issues and burned the entire test without difficulty. The flames were large and luminous and completely engulfed the item and test stand for the entirety of the test. There was a loud noise and short vent that occurred at 6 minutes and 39 seconds. The item began to vent from the aft and top of the item at 7 minutes and 50 seconds. The item stopped venting about 11 minutes and 45 seconds after the start of the test. The propane was shut-off after about 17:45 minutes after the test started. The test used 3600 liters of liquid propane. At the time of the writing of this paper, the photography and video of the test are still being processed along with the mapping of the fragments.

Some important lessons were learned from this first large ordnance FCO test with the propane burner. First, having the propane shut off mid-test is one of the worst things that can happen. This is not an issue with the pool fuel fire test as once it starts it will burn to completion of the pool of fuel. This occurrence left a partially thermally damaged item on the test stand. Fortunately, the time at temperature was short and the fuze was not armed and the test was completed the next day. Contingency plans need to be in place for the occurrence of a stoppage of propane during the FCO test. Also, care needs to take place to prevent this occurrence. Future FCO tests with the modified 4.6 m by 6.1 m propane burner will have a checkout procedure for all electrical relays before the test occurs. Second, the propane burner could provide an adequate thermal environment for the FCO test even with the large A-frame and ordnance item. Third, it was very convenient to not have to plan for fuel delivery. As the test was postponed one day there was no need to worry about fuel that had been delivered to the fuel pit. Also, there was some concern for excessive wind conditions those two days. There was no need to worry about whether to pump the fuel into the pit. The operators just waited in the control room until the wind was at a sufficiently low level and then started the test. Finally, within the normal variability of FCO, the initial comparison of the liquid fuel fire FCO test and the propane burner FCO test showed same reaction violence.

Conclusions

Propane FCO burners are being developed and demonstrated at Dahlgren, VA and China Lake, CA. These two sites represent vastly different climates and their successfully demonstration at these locations is an indication that the technology would be applicable almost anywhere. As additional testing is completed, the applicability of the technology is further demonstrated and now virtually all of the subject matter experts are in agreement that the propane burner is a suitable test platform for performing FCO testing.

References

[1] E. Washburn, R. Falen, J. Prevost, D. Hubble, and J. Yagla. “Calibration of a Propane Fast Heating Burner Used to Test Large Ordnance Items,” Proceedings of the Insensitive Munitions and Energetic Materials Technology Symposium, Nashville, Tennessee, August 2016.