Cost of Propane Fast Cook-Off Testing

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ABSTRACT

The cost of fast cook-off testing with propane has been obtained by careful tracking of expenses over a significant number of tests. These costs are compared to liquid fuel fire testing. The costs consist of nonrecurring costs, the costs directly attributable to a given test, and recurring costs of damage repair, maintenance, and environmental compliance. The nonrecurring costs are design, siting, materials, chamber fabrication, fuel distribution systems, fabrication, and calibration. The costs attributable to a given test are mainly planning, construction of test stands, instrumentation, field crews, fuel, data analysis, and reporting. Recurring costs of damage repair, maintenance of the cook-off facility including fuel equipment, and environmental compliance are itemized.

These costs have been compared to the corresponding costs of liquid fuel fire testing. The cost of testing with propane is shown to be significantly less than with liquid fuels. The total cost of the propane fast cook-off test was found to be $25,886, compared to $36,791 for the liquid fuel test. The paper explains the development of the cost model and cost of each item, and how the costs were obtained.

INTRODUCTION

A cost assessment was performed to compare the total operating costs associated with performing fast cook-off testing. Both the propane fast cook-off (FCO) burner and the traditional jet fuel pool fire were analyzed (Figure 1 and Figure 2).

Figure 1. US Navy FCO 3.7 m by 3.7 m propane burner located in Dahlgren, Virginia

The total operating cost of the propane burner is based on data from the burners that were developed and operated at Dahlgren (2.4 m by 2.4 m and 3.7 m by 3.7 m square burners). Annualized recurring cost data are more limited, as the Dahlgren burners are the only ones that have been operational long enough to obtain data. The regulatory compliance costs are very site-specific, as regulations vary from state to state in the U.S., and by country internationally. The per-test costs vary according to the test site's labor rates and safety rules, but the hours of work required should be accurate anywhere.

Figure 2. The liquid fuel pool fire at Dahlgren

Costs are compared to liquid fuel fire testing. Standard test cost estimating templates are used by test ranges. The cost of conducting liquid fuel fire tests and propane fire tests can be accurately obtained with the templates. However, cost is only one element of the decision as to what type of burner to use or build. Liquid fuel burners have a large environmental liability, which can make them impractical no matter what the cost. Propane burners have a very small environmental impact and should be able to be used almost anywhere.

COST MODEL

The cost assessment was performed by breaking the costs down into three categories:

(1) Nonrecurring costs of engineering, manufacturing, construction, and calibration

(2) Per-test cost of daily operations

(3) Annualized recurring costs of maintenance and regulatory compliance

Nonrecurring Costs. The nonrecurring costs are the one-time costs associated with obtaining a burner. The nonrecurring costs include the engineering costs to design the burner, the manufacturing and construction cost to fabricate and build the burner, and the costs associated with calibrating and certifying the burner. The majority of the nonrecurring cost is the labor required to fabricate and assemble the facility. Dahlgren's labor rate of $149 per hour was used throughout the cost assessment whenever labor hours were involved.

Per-test Cost. The per-test costs include all recurring costs that are repeated for each additional test performed. The per-test costs include the requirements and documentation, all pre-test preparations and fabrication, the labor involved in test execution, all post-test activities (i.e., clean up), material surcharges (i.e., fuel), and non-labor costs (i.e., test stand material). Significant savings in the per-test costs are due to the lower cost of propane per gallon, as well as the need for less total fuel per test. Additionally, there are savings from not requiring a commercial driver to deliver the fuel truck on the day of the test. Instead, the propane tank is filled as a routine operation when all other tanks are filled at the test site and the delivery fee is factored into the fuel cost. Finally, per-test savings are realized with the propane burner by requiring fewer weather-call man hours. The weather call is factored into the cost of the test because historically, a certain percentage of tests are cancelled due to high wind. It is anticipated that the shorter time required to set-up for a propane test (no delay for fuel to be pumped) will decrease the likelihood of a weather-related cancellation.

Annualized Recurring Costs. Finally, the annualized recurring costs include all recurring costs that are not specifically tied to test execution. These recurring costs would include regular maintenance to the system and the costs associated with maintaining regulatory and safety compliance. It is assumed here that the truck used to transport jet fuel is owned by the test site, while propane will be delivered by a truck owned by the propane supply company. There are significant costs associated with maintaining fuel delivery capability as will be presented in the following section.

NONRECURRING COSTS

Engineering Costs. Drawings of the 3.7 m by 3.7 m burner at Dahlgren are provided in Figure 3 and Figure 4. This burner has been carefully developed and calibrated and is made from readily available materials that are inexpensive and easy to assemble. The parts list with suppliers is shown in Table 1. The engineering has been done and is not a cost item should this burner be selected by a test facility.

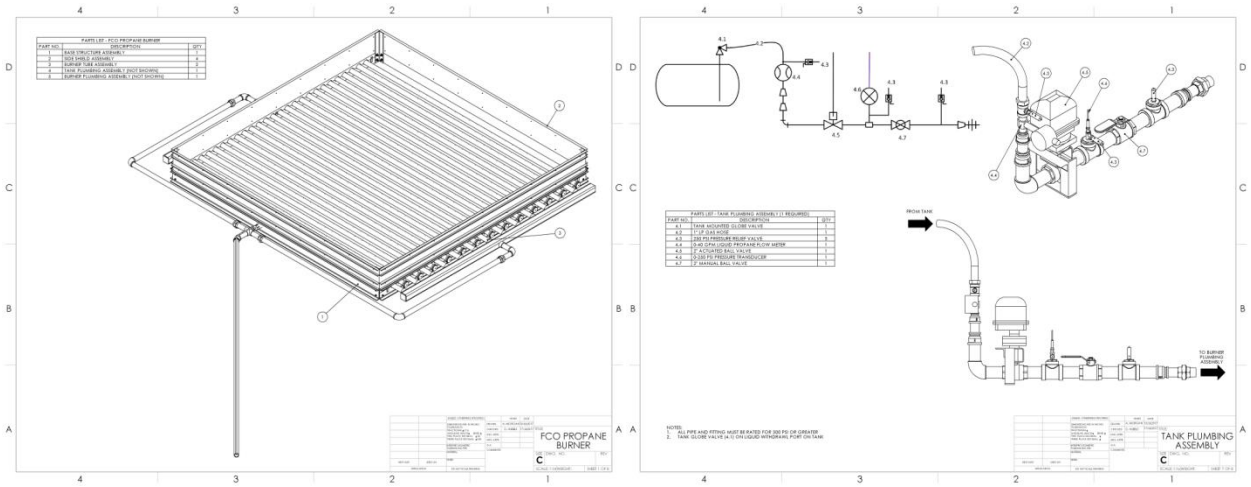

Figure 3. Dahlgren propane burner and propane burner tank piping assembly

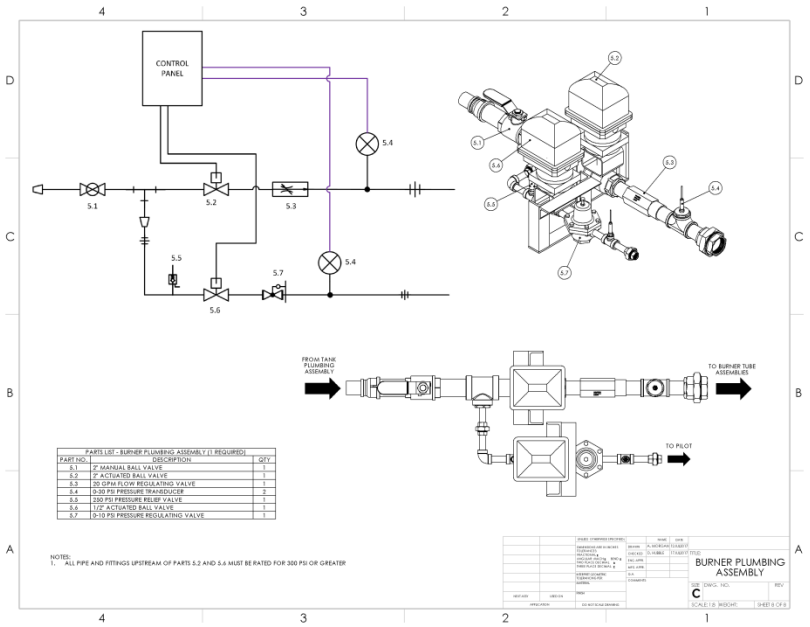

Figure 4. Dahlgren burner piping assembly

Table 1. Material costs and labor for constructing a propane burner

Electrical Panel at Tank

Part	Quantity	Source	Item ID #	CY 17 price	Total
Mil Spec Connector receptacle 3 pole female QuickConnect	1	McMaster Carr	6134T31	$18	$18
Mil Spec Connector receptacle 6 pole female QuickConnect	1	McMaster Carr	6134T33	$14	$14
Mil Spec Connector receptacle 10 pole female QuickConnect	1	McMaster Carr	6134T34	$25	$25
Mil Spec Connector receptacle 15 pole male QuickConnect	1	McMaster Carr	6134T25	$22	$22
Category 5E Keystone Style Coupler	1	McMaster Carr	3243T2	$11	$11
1 ft. 5E cord	1	McMaster Carr	9953K21	$3	$3
Terminal Block 2 circuits	3	McMaster Carr	7527K42	$2	$6
Terminal Block 10 circuits	1	McMaster Carr	7527K51	$5	$5
IEC 320-C14 with switch	1	Digikey	CCM1915-ND	$9	$9
110V AC to 10V DC tranformer	1	Omega	PST-10	$200	$200
110V AC to 24V DC tranformer	1	McMaster Carr	7009K35	$116	$116
Ignition transformer 1092-F	1	Grainger	23M557	$103	$103
Enclosure	1	McMaster Carr	8261K31	$100	$100
Ethernet Daq	1	National Instruments	9184	$100	$100
Digital relay module	1	National Instruments	9481	$232	$232
+-10V voltage module	1	National Instruments	9215	$540	$540
+-500mV module	1	National Instruments	9238	$1,100	$1,100
Relay socket	1	McMaster Carr	7266K17	$13	$13
Relay	1	McMaster Carr	7266K65	$16	$16
Labor CY17	50			$149	$7,450
				Sum:	**$10,083**

Electrical Panel at Burner

Part	Quantity	Source	Item ID #	Price	Total
110V AC to 10V DC tranformer	1	Omega	PST-10	$200	$200
Enclosure	1	McMaster Carr	8261K31	$100	$100
Relay socket	3	McMaster Carr	7266K17	$13	$39
Relay	3	McMaster Carr	7266K65	$16	$48
Terminal Block 10 circuits	2	McMaster Carr	7527K51	$5	$10
IEC 320-C14 with switch	1	digikey	CCM1915-ND	$9	$9
Mil Spec Connector receptacle 10 pole female QuickConnect	1	McMaster Carr	6134T31	$25	$25
Mil Spec Connector receptacle 3 pole male QuickConnect	1	McMaster Carr	6134T21	$12	$12
Mil Spec Connector receptacle 15 pole male QuickConnect	1	McMaster Carr	6134T25	$22	$22
Labor	50			$149	$7,450
				Total Elctrical	**$17,533**

Burner

Part	Quantity	Source	Item ID #	Price	Total
2" sch 40 gal pipe	30	Discount Steel		$75	$2,250
6" X 8.2lb Channel 12' Long	4	Discount Steel		$103	$412
2" union	30	Plumbing Supply		$20	$600
2" Tee	25	Plumbing Supply		$15	$375
2 " ellbow	2	Plumbing Supply		$11	$22
2 " caps	30	Plumbing Supply		$5	$150
2" nipple (5" length)	60	Plumbing Supply		$7	$420
Windscreens	22	various		$4	$88
labor	80			$149	$11,920
				Total burner:	**$16,237**

Pipe-system from tank to burner

Part	Quantity	Source	Item ID #	Price	Total
30psi pressure gage	2	Omega	MMG030V1P4D01	$420	$840
250 psi pressure gage	1	Omega	MMG250V1P4D01	$420	$420
2" Regulator	0	Flomec	8580	$1,530	$0
Propane hose 10', 1"	1	McMaster	45835K653	$158	$158
2" to 1" reducer (300 psi)	4	McMaster	4627K196	$37	$147
1" to 1/2" reducer (300 psi)	2	McMaster	4627K143	$14	$29
2" Tee (300 psi)	4	McMaster	4627K258	$44	$174
2"X6" Nipple (300 psi)	10	McMaster	4550K289	$12	$120
1 1/2" to 1/2" reducer (300 psi)	2	McMaster	4627K193	$31	$61
1 1/2" nipple (300 psi)	2	McMaster	7727K313	$5	$10
1/2" nipple (300 psi)	5	McMaster	4550K197	$3	$15
1/2" to 1/4" reducing tee (300 psi)	3	McMaster	4627K322	$14	$42
2" to 1 1/2" reducing tee (300 psi)	2	McMaster	4627K332	$60	$120
2" Ball valve	2	McMaster	47865K28	$64	$127
2, 2" ball vales and 1/2" ball valve with three actuators	1	Indelac Controls, Inc		$10,619	$10,619
labor	120			$149	$17,880
				Total pipe:	**$30,762**
				Total Cost:	**$64,532**

Manufacturing and Construction Costs. The manufacturing and construction costs are provided in Table 1 above. The burner at Dahlgren sits on a 2.5 cm thick steel plate that is covered with hand-placed bricks without mortar. Options at other sites would be an existing concrete slab, a fabricated slab, or tamped crushed rock. If a bare steel plate is used, the heat from the fire will cause it to warp during the test and not return to its original shape. Some tests spill molten aluminum onto the bricks, which is easily cleaned. The plate and bricks were already available at the test site and are not included in the cost. The burner at Dahlgren uses a 1900 liter propane tank. It is on a skid for easy transport to and from the range. There is a quick-disconnect coupler for connecting the tank to the equipment in the shelter. It is rented from a propane supplier and not considered to be a part of constructing the system.

Fuel Delivery and Control System. There are several options for controlling a gas burner. The first and least expensive is manual control. Dahlgren burners were operated manually while under development. Manual operation consists of opening valves to start the gas flow, operating a switch to start the igniter, and turning the valves off after the test. The operations have to be performed in a shelter when energetic materials are being tested. The fuel supply tank also has to be sheltered. The shelters for the Dahlgren burner and equipment are shown in Figure 5.

Figure 5. Shelter for the fuel delivery and pressure regulation system equipment and shelters for propane tank and fuel

With a manually operated system, the shelters need to be close enough to the burner to allow reasonably short runs of pipe or hose, but still provide safety for the operators. Pipe runs on the order of 9.1 m worked fine and were used for all of the development testing (probably 100 or more tests). With the passive evaporation burner design, only liquid flows through most of the

pipe and the pressure drops are small. The Dahlgren liquid and gas fuel fast cook-off tests are only part of the testing going on at the range. Other tests such as bullet impact, fragmentation arenas, and rocket motor restrained firings are conducted there as well. There are central, collocated shelters for test control and data acquisition. Pipe runs from these shelters would be on the order 305 m, making manual operation impractical. Therefore, a personal computer (PC)-based electrical system, based on an existing system being used to control a propane burner for treating explosive debris, was developed. Figure 6 shows the PC-based system at Dahlgren. Simulated dial gauges are shown for the tank pressure, the burner pressure, and the pilot ignition flame. The valves are controlled by touch screen rectangular buttons. The status of each valve is indicated by the color of the simulated lamp next to each button.

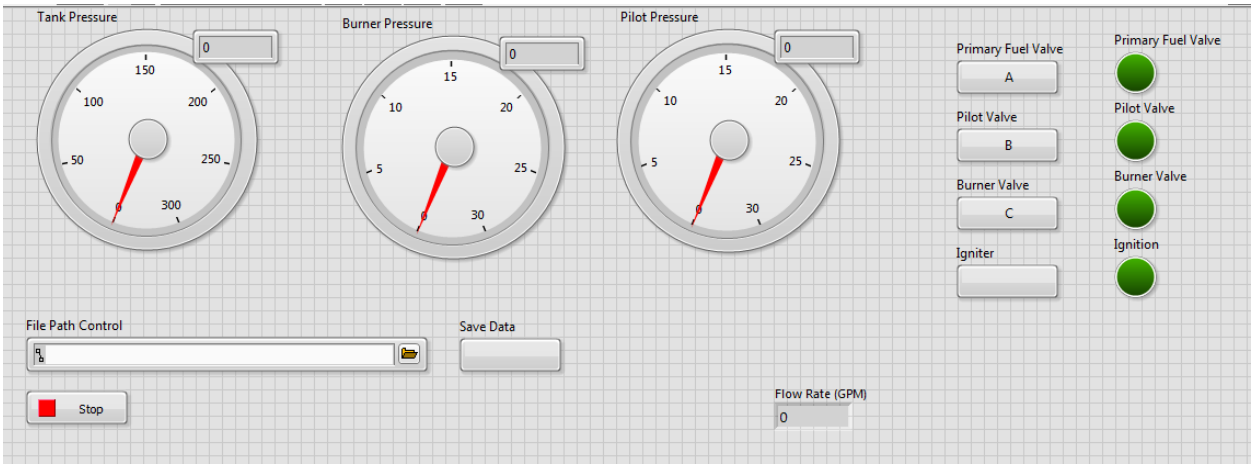

Figure 6. This is a screen shot of the LabView display for the PC-based burner control system at Dahlgren

The Dahlgren burner PC uses LabView software. PCs and the software are available at most large test centers and laboratories, and are not included in the cost estimate. The computer uses a network connection to remotely control the test from a test control shelter. Network connections can have problems with reliability and latency. Should a more reliable control system be desired, a PLC should be used instead of a PC on a network. A PLC is an industrial digital computer which has been ruggedized and adapted for the control of manufacturing processes, such as assembly lines or any activity that requires high-reliability control, ease of programming, and process fault diagnosis.

The cost of materials for constructing a propane burner is $20,300. The labor cost (at $149 per hour) at Dahlgren was $44,700. The cost of a fully operational burner is $65,000 with PC control, or $65,300 with dedicated PLC control. The system costs are shown in Table 1 above.

CALIBRATION COST

The cost of burner calibration, as required in References 1 and 2, depends on the skills and equipment available at the test center. Calibration testing requires collection of forty-eight (48) channels of thermocouple and heat flux data during a number of tests. Figure 7 shows possible equipment for calibrating a burner with thermocouples placed at forty positions in the burner. Many test centers have personnel and equipment suitable for the testing. Dahlgren personnel have calibrated burners in Virginia, California, the Netherlands, and Sweden. Using Dahlgren personnel to perform the calibration for the test site, the calibration cost is $29,764 as shown in Table 2.

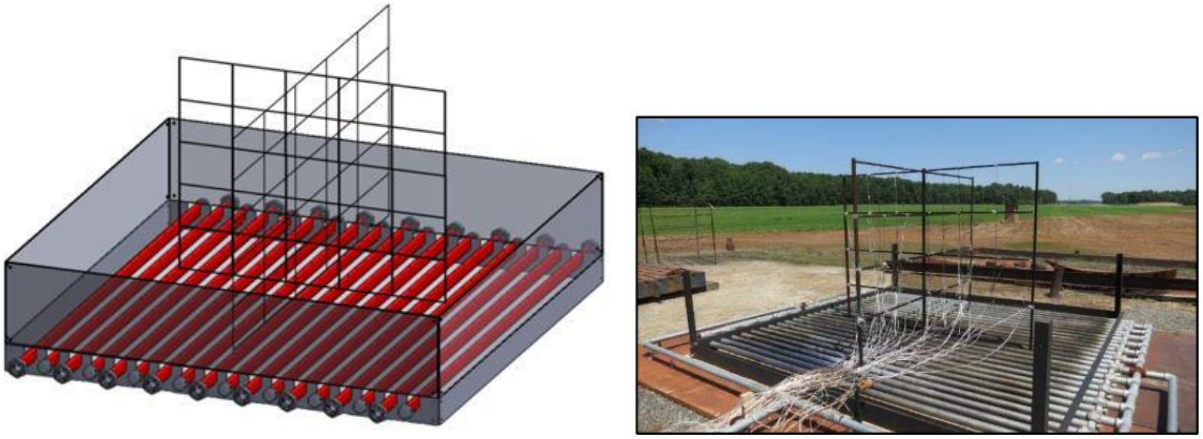

Figure 7. Burner calibration arrangement and test

Table 2. Calibration testing cost worksheet

	Calibration Testing Cost Worksheet				
Item		No. persons	Duration (hrs)	rate	total
Checkout and pack		1	40	150	6000
Conduct tests		2	40	150	12000
Return, clean equipment		1	20	150	3000
Analyze & report		1	40	150	6000
				Labor	**27000**
Materials					
Materials				**Materials**	**1000**
Travel:	Unit cost		Days	Total	
Per diem	67	2	6	804	
Hotel	100	2	6	600	
Car rental	60		6	360	
Transportation	xxx	2			
				Travel	**1764**
				Total calibration	**29764**

PER-TEST COST OF BURNER OPERATIONS

There are two basic types of fast cook-off tests performed at Dahlgren. The first are tests conducted on items with energetic materials in compliance with STANAG 4240. These tests are scored for reaction type by a national authority. The tests may require preapproval by the authority, instrumentation to measure blast overpressure, video, or high-speed photography to monitor the fire, fragments, debris, and six thermocouples located near the top, bottom, ends, and sides of the test item. The final positions of the fragments and debris that are projected out of the pit are mapped, and the fragments are collected, weighed, and photographed. The data are compiled into a report and video clips for the reviewing officials.

The second type of test is performed for engineering purposes. These are sometimes performed during the research and development of new munitions. These tests are used to see

what might happen if a test of an item were conducted for score, to develop and improve mitigation systems for items under development, fire research to characterize fast cook-off fires, and materials research to study new materials and improve existing materials. These tests are usually less complete in regards to the instrumentation in STANAG 4240 tests, but may have more instrumentation in and around the test item. Sometimes, the test items are inert. These tests are so diverse that only the costs for the basic facility and operation are provided.

The liquid fire costs are well characterized and form the basis for estimating the costs of conducting tests with the propane burner. A standard template is used to plan a STANAG 4240 liquid fuel test and calculate the cost, as shown in Table 3. The table is organized into sections for producing and organizing documents, test site preparations, conducting the test, analyzing and reporting the data, instrumentation expenses, and materials and surcharges. The elements of the table in the context of the liquid fuel fire and propane burner are discussed below.

Requirements and Documentation. The first block of data is for meeting with the customer, learning his requirements, learning about the test item, handling the test item, any special safety requirements, preparing the test plan, preparing other safety documents such as the threat hazard analysis, and designing the test stand. This requires 29 man hours at a cost of $4,321 and is the same for both the liquid pool test and the propane test.

Pre-test Preparations. This section covers fabrication of the test fixtures, installing them into the burner, and setting up the thermocouples, blast overpressure gauges, and video cameras. For a liquid pool fire, the pan is inspected and any required repairs are made and fuel is delivered to the test site. For a propane test, the fuel tank is brought out and connected to the burner supply lines. The burner tube ports are cleaned, fittings are checked for leaks, propane is flowed through the system, and depending on how much time has lapsed since the previous test, a short checkout burn may also be conducted. For the liquid pool test, this requires 50 man hours for a cost of $7,450.

Test Execution. The test requires calm or very low wind speeds, as the test item must be engulfed in the flame until it reacts, and the fire is very susceptible to wind. The wind is usually at its lowest speed in the early hours of the morning before sunrise, and then builds as the sun rises. Therefore an early start is required. The instrumentation team makes final checks of the blast overpressure gauges, videos, and thermocouples. The test engineer and the test director monitor the wind speed and decide whether or not to conduct the test. The test item is brought out to the test site and put on the test stand. Thermocouples are installed 5.1 cm from the front, back, left, and right sides of the test item. The new STANAG 4240 will require thermocouples also at the top and bottom. The only persons allowed to touch the test item on Dahlgren ranges are ones who have special qualifications and certifications for handling explosive items. Two ordnance handlers are required. There must also be a certified firing director and a certified lookout (safety observer) present. For tests in a liquid fuel fire, the ordnance handlers also install thermite grenades in the corner of the pit (required to ignite the liquid fuel). For liquid fuel fires, fuel must be transferred from a pumper truck into the pit. Once the fuel transfer is complete, gasoline is poured in the corners as an accelerator to achieve the required rise rate of temperature on the test item. The test personnel retire to a shelter, and once instrumentation is confirmed to be ready, the test is conducted. After the test item reacts and the fire is completely out, a minimum hold time (minimum of 30 minutes) is started and all personnel must remain in the shelter. After the hold time has elapsed, the firing director and ordnance handlers go to the pit and confirm it will be safe for the others to come out to begin the post-test operations. This requires 63 man hours for a total cost of $9,387.

Post-test Activities. Fragments and debris from the test are catalogued as to range and bearing from the test stand, description, and mass. The items are arranged by type and then photographed. Instrumentation and video data are played back to confirm the test setup and correct any obvious errors. The videos are edited into clips from each view and compiled into a single DVD. Electronic data are reduced to plots with engineering units and put onto a DVD. These materials are used by the test engineer to prepare a final report, and shared with the customer at the test site. Finally, there is test debris to clean up and possible repairs for the burner. The clean costs are often significant. Post-test costs are assumed to be the same for both the propane and liquid pool test. These activities require 36 hours for a cost of $5,364.

Materials and Surcharges. There are fixed charges for fuel, technical writers, and the range control console operators that are billed to the test. Fuel makes up the bulk of the material cost of a liquid pool fire. Total costs for this section are $9,275.

Non-labor Costs. The cost of expendable items such as the firing leads, thermocouples, and test stand are billed to the test. The total is $995 per liquid pool test.

Total Liquid Fuel Fire Cost. The total cost of the example liquid fuel fire test in Table 3 is $36,791.

Propane Fire Costs. The pre-test requirements and documentation costs for the two types of fires are the same. The post-test activities are the same. However, there are significant differences in the pre-test preparation, test execution, and materials.

Changes in Pre-test Preparations. Part of the cost of the liquid fuel fire test is inspecting and repairing the water-tight pit that holds the fuel. The pit is required to be water tight to ensure that fuel does not escape onto the ground. The propane burner does not require this inspection, which saves $745 per test. A fuel delivery cost of $1,192 is also avoided resulting in a total pre-test savings of $1,937.

Changes in Test Execution. The weather call is not so critical, as the test can be conducted very quickly once the test item in in place on the stand. This will save on average 6 man hours ($894) per test due to fewer test cancellations. Further, the test can be aborted at any time. An hour or more may elapse between the start of fuel delivery and closing the firing key on the liquid fuel test, with no abort possible once fuel is introduced to the pan. Also, the labor required to pour the fuel and wire and place the thermite grenades is eliminated. Together, this results in a savings of an additional 10 man hours ($1,490) per test, for a total of $2,384.

Changes in Materials and Surcharges. For the liquid fuel fire, the test requires a quantity of fuel that will burn for 150% of the expected reaction time. Fuel quantities in the range of 2,000 to 3,000 gallons are normal, with 2,000 gallons used in this analysis. With the gas fuel fire, the fuel can be shut off at any time, which saves a lot of fuel. Liquid JP-5 fuel costs $3.50 per gallon. This leads to a normal fuel expense of $7,000. A typical propane fast cook-off test can be performed using a single 500-gallon fuel tank. The current price delivered for the last test that was conducted was $0.99/gallon. One full tank would cost $500. This results in a fuel savings of $6,500.

Total Cost and Savings. The total cost of the example propane fast cook-off test depicted in Table 3 is $25,886 compared to $36,791 for a total per-test savings of $10,905.

Table 3. Cost of burner operations

Requirements & Documentation	People	hr/Day	Days	Labor Hours	Labor Cost($)	Propane	Savings
Customer interface & Requirements	1	4	1	4	$ 596.00	$ 596.00	$ -
Preparation of test plan(s)	1	4	1	4	$ 596.00	$ 596.00	$ -
Preparation of safety documents	1	8	1	8	$ 1,192.00	$ 1,192.00	$ -
Schedule coordination	1	4	1	4	$ 596.00	$ 596.00	$ -
Fixture design & procuremnt	1	2	1	2	$ 298.00	$ 298.00	$ -
Planning meeting(s) support	2	2	1	4	$ 596.00	$ 596.00	$ -
Review Test Plan	2	1	1	2	$ 298.00	$ 298.00	$ -
Review Test Plan	1	1	1	1	$ 149.00	$ 149.00	$ -
Subtotal				29	**$ 4,321.00**	$ 4,321.00	$ -
Pre-Test Preparations							
	People	hr/Day	Days	Labor Hours	Labor Cost($)		
On-site technical direction (range coordination)	1	4	1	4	$ 596.00	$ 596.00	$ -
Fabrication of fixtures/targets (range crew)	2	4	1	8	$ 1,192.00	$ 1,192.00	$ -
Pan Checkout and Setup	2	5	1	10	$ 1,490.00	$ 745.00	$ 745.00
Build up Thermocouples (4)	1	4	1	4	$ 596.00	$ 596.00	$ -
Set up gauges, cameras, and TCs	2	8	1	16	$ 2,384.00	$ 2,384.00	$ -
Fuel Delivery	1	8	1	8	$ 1,192.00	$ -	$ 1,192.00
Subtotal				50	**$ 7,450.00**	$ 5,513.00	$ 1,937.00
Test Execution							
	People	hr/Day	Days	Labor Hours	Labor Cost($)		
On-site technical direction	1	5	1	5	$ 745.00	$ 745.00	$ -
Weather Call	1	2	1	2	$ 298.00	$ 298.00	$ -
Lookout / firing director	2	4	1	8	$ 1,192.00	$ 1,192.00	$ -
Weather Call	7	2	1	14	$ 2,086.00	$ 1,192.00	$ 894.00
Test Setup (leaving during test)	5	2	1	10	$ 1,490.00	$ 596.00	$ 894.00
Ordnance Support during test	2	2	1	4	$ 596.00	$ 596.00	$ -
Weather Call	2	2	1	4	$ 596.00	$ 596.00	$ -
Instrumentation Setup	4	2	1	8	$ 1,192.00	$ 1,192.00	$ -
Instrumentation Support during test	2	2	1	4	$ 596.00	$ 596.00	$ -
Public works support	1	4	1	4	$ 596.00	$ -	$ 596.00
Subtotal				63	**$ 9,387.00**	$ 7,003.00	$ 2,384.00
Post Execution Activities							
	People	hr/Day	Days	Labor Hours	Labor Cost ($)		
Test Engineering							$ -
On-site technical direction	1	3	1	3	$ 447.00	$ 447.00	$ -
Quick-Look Report(s)	1	4	1	4	$ 596.00	$ 596.00	$ -
Engineer meeting with I.E.	1	2	1	2	$ 298.00	$ 298.00	$ -
Site/ mount cleanup (range personnel)	3	2	1	6	$ 894.00	$ 894.00	$ -
Equipment breakdown/storage	2	2	1	4	$ 596.00	$ 596.00	$ -
Film/video editing	1	4	1	4	$ 596.00	$ 596.00	$ -
CD/DVD reproduction (labor)	1	1	1	1	$ 149.00	$ 149.00	$ -
Data Analysis	1	6	1	6	$ 894.00	$ 894.00	$ -
I.E. Meeting with Test Engineer	1	2	1	2	$ 298.00	$ 298.00	$ -
Post-test ammo expenditure documentation	2	1	1	2	$ 298.00	$ 298.00	$ -
Test Engineer generates deliverables for I.E.	1	2	1	2	$ 298.00	$ 298.00	$ -
Subtotal				36	**$ 5,364.00**	$ 5,364.00	$ -
Materials and Surcharges							
Item			Unit Cost($	Qty	Cost ($)		
JP-5 fuel			3.5	2000	$ 7,000.00	$ 500.00	$ 6,500.00
Tech Writer (per document- TP, OPS, RHA)			605	3	$ 1,815.00	$ 1,815.00	$ -
Range Control (per range day)			460	1	$ 460.00	$ 460.00	$ -
					$ 9,275.00	$ 2,775.00	$ 6,500.00
Burdened Non-Labor Costs							
Item			Unit Cost ($)	Qty	Cost ($)		
Firing lead			60	1	$ 84.00	$ -	$ 84.00
Thermocouples (4)			100	4	$ 560.00	$ 560.00	$ -
Table Materials			250	1	$ 350.00	$ 350.00	$ -
					$ 994.00	$ 910.00	$ 84.00
			Total		**Liquid**	**Propane**	**Savings**
					$ 36,791.00	$ 25,886.00	$ 10,905.00

Annualized Recurring Costs. The recurring costs of maintenance and regulatory compliance for the liquid fuel fast cook-off and the propane gas fuel fire are presented here and in Table 4. The annualized recurring cost for liquid fuel fire testing is $45,382. The annualized recurring cost for gas fire testing is $8,784. Many costs are identical between the two systems, such as anticipated repair costs per year and the cost to update and maintain safety documentation. The liquid pool fire does have some significant yearly costs that the propane burner does not. Environmental requirements to collect and analyze the containment area, as well as the environmental reporting required, make up $5,561. Maintaining the fuel delivery truck is also expensive at $19,380 per year. Finally, the thermite grenades required to ignite the liquid pool fire and the associated ammunition transfer fees that go along with them total $14,213 per year. This results in a total annualized recurring savings of $36,598.

Table 4. Annualized recurring cost of FCO testing

Item	Liquid Fire	Frequency	Cost/year		Propane Fire	
Repair and replace expanded	2 man days	1/per year	$ 2,384		n.a.	
metal grates	materials		$ 500			
Burner tube replacement	n.a.	1/year			2 man days	$ 2,384
Repair wind screens	n.a.	1/year			2 man days	$ 2,384
					materials	$ 176
Propane tank rental	n.a	1/year			2- 500 gallon	$ 100
Liquid waste pump and haul		5 years			n.a.	
Collect samples	4 man days		$ 954			
Labortory analysis	3 man days		$ 715			
Vendor contract	2 man days		$ 477			
Award contact	1 man day		$ 238			
Schedule range	.2 man day		$ 48			
Meet vender, transfer liquid	5 man days		$ 715			
Fuel Truck with Pump						
Parts			$ 1,500			
Maintenace of SOPs-Inert	2 man days	4 years	$ 596		2 man days	$ 596
Maintenace of SOPs-Energetic	3 man days	4 years	$ 894		3 man days	$ 894
Post test clean up w/hazmat	4 man days	1/year	$ 4,768		n.a.	
Environmental reporting	2 man days	1/year	$ 2,384		n.a.	
Thermite grenades					n.a.	
receive shipment	1250	1/yr	$ 1,250			
ammo transfer to EEA	2500	2/year	$ 5,000			
grenade unit cost	34	72/year	$ 2,448			
squib unit cost	29	72/year	$ 2,088			
storage						
requisitions(alocate, expend)	.5 man days	1/year	$ 745			
expenditure forms	.125 man days	1/test	$ 2,682			
		Total	**$ 45,382**		**Total**	**$6,534**

SUMMARY AND CONCLUSIONS

The cost of fast cook-off testing with propane has been obtained by careful tracking of expenses over a significant number of tests. These costs are compared to liquid fuel fire testing. The costs consist of nonrecurring costs, the costs directly attributable to a given test, and recurring costs of damage repair, maintenance, and environmental compliance. The nonrecurring costs are design, siting, materials, chamber fabrication, fuel distribution systems, fabrication, and calibration. The costs attributable to given test are mainly planning, construction of test stands, instrumentation, field crews, fuel, data analysis, and reporting. Recurring costs of damage repair, maintenance of the cook-off facility including fuel equipment, and environmental compliance are itemized.

These costs have been compared to the corresponding costs of liquid fuel fire testing. The cost of testing with propane is shown to be significantly less than with liquid fuels.

Once the costs were itemized over several years and a significant number of tests, the propane test was compared with liquid fuel test. The costs of environmental impacts were not calculated. The costs having a “no test” result as a consequence of weather changes between commitment to do the test and executing the “no test” (which can include the cost of a very expensive test item), has not been included. This happens because once the fuel is poured and the thermite grenades are in place, safety rules prevent the test from being stopped.

The total cost of the propane fast cook-off test was found to be $25,886, compared to $36,791 for the liquid fuel test.

REFERENCES

1. MIL-STD-2105D, Department of Defense Test Method Standard. *Hazard Assessment Tests for Non-Nuclear Munitions*, 19 April 2011.

2. STANAG 4240 edition 2, NATO *Liquid fuel/External Fire, Munition Test Procedures*, 15 April 2003.