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A Publication for AGA Members

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Natural Gas Workers and Natural Gas Fires

Observations and Analysis of Heat Intensity, Escape Time, Extinguish Time and

Flame Resistant Garments

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This document is intended for the scientific community and for discussion purposes.

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Executive Summary

Consensus standards used to establish protective levels for garments used in a potentially flammable environment may not reflect the unique circumstances and actual conditions experienced by natural gas workers. As a result, AGA member companies have no natural gas utility industry-specific data on which to base decisions related to the evaluation of fire resistant (FR) personal protective equipment (PPE). Over many years, the AGA Safety & Occupational Health Committee considered this issue again and again. In response to the charge issued by the Committee chair to "Slay the FR Dragon" along with widespread request of AGA member companies, the Technical Subcommittee initiated this study to provide natural gas safety professionals information for making informed choices for the purpose of improving worker safety.

A collaboration of AGA member company safety professionals and DuPont fire science specialists came together to design and execute a series of comprehensive tests and develop a methodology for a foundational understanding of potential risks associated with being exposed to a natural gas fire. Based upon the input of AGA member companies, four separate studies were conducted:

1) An escape time study to understand how long it would take workers to exit a typical gas line leak excavation. This work was completed using variables of excavation depth, worker demographics, PPE type and worker function.
2) A study to determine the time needed by a safety attendant to recognize, respond and extinguish a natural gas fire in an excavation. Testing was completed using variables of excavation depth, personnel demographics and fire extinguishing agent.
3) A first-of-its-kind capability was developed to measure intensity of a natural gas fire in the most common leak scenarios, leveraging instrumentation and sensor technology widely used to measure fire exposures.
4) Fire resistant (FR) garments supplied by AGA member companies were evaluated in a UL certified, controlled lab environment for protection performance using fire intensity and exposure times from the studies above to determine predicted body burn.

With relatively few exceptions, test results confirmed fire intensity in typical excavation fires was about 2 calories/cm^2-second. Observations from time tests showed 6 seconds is typically required to either escape from, or extinguish a fire in an excavation. Burn testing of different FR PPE garments showed significant differences in the performance of materials in both predicted body burn and integrity of the garments following fire exposure. Some levels of predicted body burn observed during testing were high enough to project fatality rates exceeding 50% for workers involved in 6 or 8 second fires. A surprising observation was the decrease in predicted body burn by simply wearing a long sleeve 100% cotton, non-FR work shirt as part of the PPE ensemble. This low-cost item of clothing reduced the average predicted body burn by about half as compared to tests that did not include this work shirt. The results of these tests along with burn test data documented in the appendices of this report provide AGA member companies information useful for making informed choices with respect to safety of workers potentially exposed to natural gas fires.

Participating Companies

- Philadelphia Gas Works
- Spire Inc.
- Xcel Energy
- Washington Gas Light Co.
- ONE Gas, Inc.
- Avista Utilities
- Vectren Co.
- Consolidated Edison, Inc.
- UGI Utilities Inc.
- Chesapeake Utilities Co.

A special recognition to DuPont, Columbia Gas of Pennsylvania – a NiSource Company, Questar (now Dominion Energy) and National Fuel Gas Company for significant contributions in logistics, time and talent to make this study possible.

Methodology, Data Sets in Appendices

Escape Time Testing

Purpose

To understand the time required for a worker to escape an excavation

Scope

Establish the time necessary for workers to move a safe distance away from a fire

Three variables:

- Excavations
  - 4’ deep sloped
  - 4’ deep w/shoring box
  - 6’ deep w/shoring box
  - 4’ deep pit w/concrete walls and sand bottom
- Demographics - 5 different employees
- PPE – 5 different configurations
  - standard workwear
  - lightweight FR PPE
  - heavyweight FR PPE
  - heavyweight FR PPE with added respirator configuration
  - welding gear

Starting Conditions:

- Worker on one knee at a buried pipe within the excavation
- Workers were engaged in simulated job activities
- Stopwatch begins with the “Go” command
- Ladder used in the 6’ excavation as the escape mechanism

End Condition:

- When the worker crosses a point 10’ away from the pipe centerline

Key Observations

- Based on observations, it appears 5.4 seconds to 6.8 seconds is typically required to escape from excavations
- Personnel demographics resulted in high escape time variability
- The deeper the excavation, the longer the escape time
- It appears restricted vision, in this case as a result of a respirator, caused test subjects difficulty in looking down to find the 1st step on the ladder. Missteps increased escape time by approximately 1 second.

For a detailed explanation of escape time testing see Appendix D.

Fire Intensity Testing

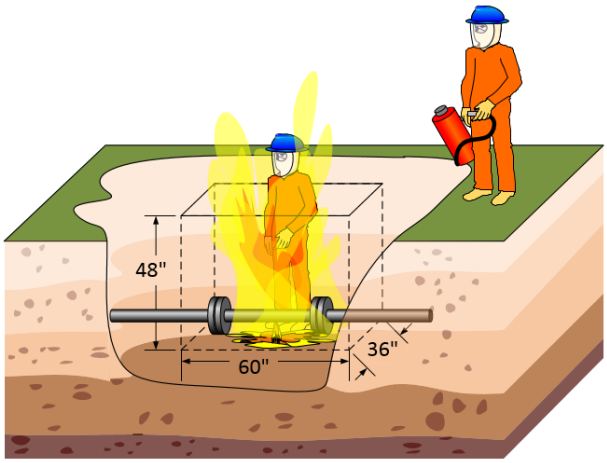
Purpose

To measure the intensity of natural gas-fed fires in excavations for typical leak scenarios defined by AGA member companies

Scope

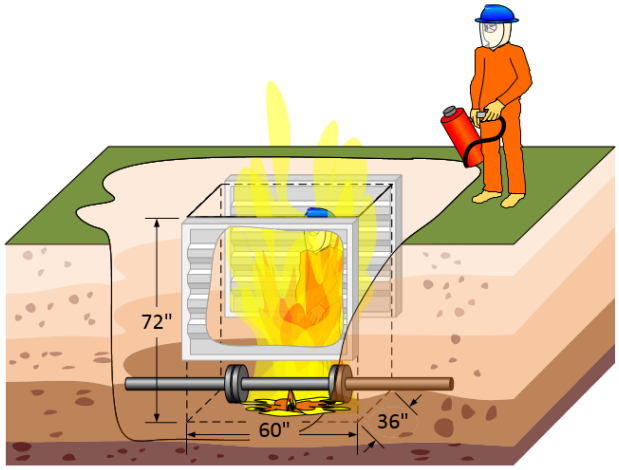
Three variables:

- Two excavation depths
  - 4’ un-shored, approximately 3’ wide x 5’ long
  - 6’ shored, approximately 3’ wide x 5’ long
- Two leak scenarios
  - 12” WC with a 7/8” diameter hole
  - 55 psig with a 3/8” diameter hole
- Burn times of 4, 6 and 8 seconds



3/8" orifice 55 psi pressure

7/8" orifice 12" water column pressure

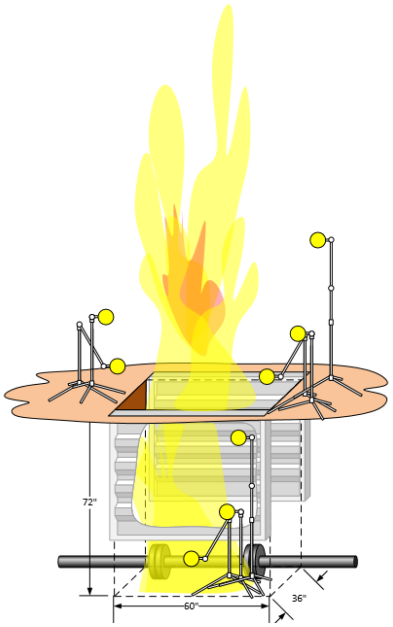


3/8" orifice 55 psi pressure

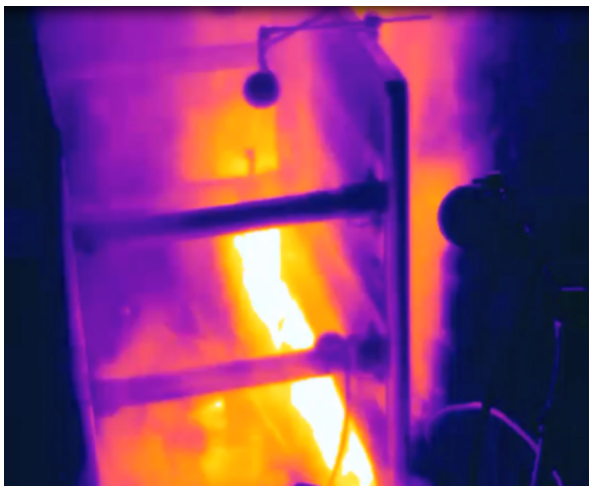
7/8" orifice 12" water column pressure

Starting Conditions:

- 8 sensors strategically placed in and around the excavation at locations:
  - identified by infrared imagery to be high heat areas
  - represent locations of interest (e.g. position of leak worker and standby person)
- Leak located on the bottom of 4” pipe in each situation
- Pilot light lit within excavation prior to introduction of fuel
- Hi-resolution infrared camera and video equipment positioned to capture data



6’ shored excavation with sensors in



FLIR camera image showing heat

End Condition:

- Fuel supply ended at test time conclusion
- The heat intensity reported is the highest heat intensity observed by any sensor during a specific test

Key Observations

- With relatively few exceptions observations confirmed heat intensity in typical excavations fires was 2 calories/cm^2-second
- Within the excavation the highest heat intensity was observed at approximately 3’ off the floor of the excavation
- Outside the excavation the highest heat intensity occurred downwind of the excavation
- There were no significant differences observed between average intensities of the 12” W.C. and 55 psig fires

For a detailed explanation of fire intensity testing, see Appendix C.

Fire Extinguisher Testing

Purpose

Understand the length of time it may take a standby person to extinguish a fire in an excavation

Scope

Create excavation fire scenarios and measure the time to extinguish

Five Variables:

- Dry powder-type CO2 cartridge fire extinguishers; 20# and 30# with flow rates of 1.3 and 1.8 lbs./second
- Two powder agent types
  - sodium bicarbonate
  - potassium bicarbonate
- Demographics – 4 different workers
- Excavation Depth – 4’ and 6’ excavations
- Leak scenarios – 7/8” diameter hole at 12” WC and 3/8” diameter hole at 55 psi

Starting Conditions:

- Worker in full FR PPE including balaclava, full visor, hardhat and gloves
- Standing at a 10’ distance upwind from leak location
- Fire extinguisher upright on ground next to worker
- Fire initiated within the excavation
- Timing starts with a “Go” command or the onset of combustion
- Once an extinguisher’s CO_2 cartridge was activated, the extinguisher was re-used until empty; in these circumstances, workers simulated depressing the activation button

End Conditions:

- Test timing ended when flames were no longer visible

For the fire extinguishing time test, one worker extinguished the fire. The second worker served as a safety attendant and did not take part in extinguishing the flames.

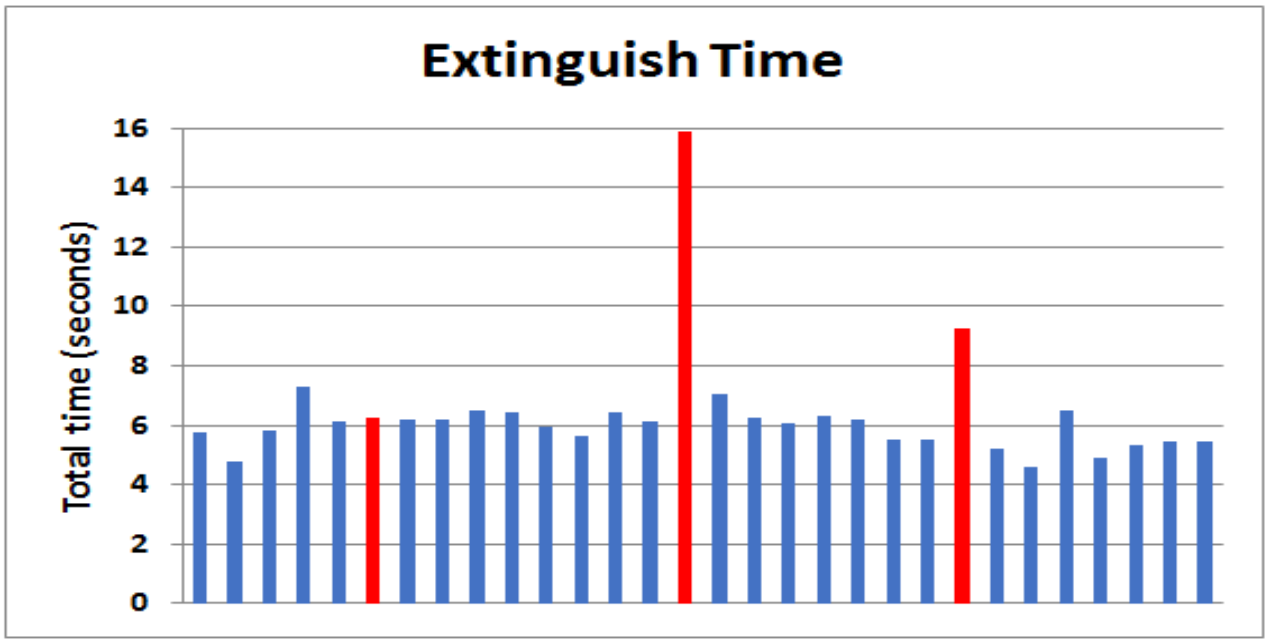
Test Time Explanation:
Total fire extinguishing time was comprised of three separate stages:

1. Reaction time - time from onset of ignition to taking action. Video footage of tests was replayed in slow motion to record this time from when fire first appears in the excavation, to visual recognition, and ending with operator taking action.
2. Engagement - the time required to puncture the CO_2 cylinder (or simulate puncture on previously charged extinguisher), gain control of the discharge hose, squeeze the trigger, and ends the moment extinguishing media exits the discharge hose.
3. Powder delivery - time in video from the moment extinguishing media exits the discharge hose to when the fire is extinguished.

Since operators repeatedly extinguished fires during this exercise and were expecting a fire, reaction time was likely faster than could be expected in actual field conditions when a fire is not anticipated. An important question is how long would it take for an operator to respond to an event if it was not anticipated. To account for this concern, operators reaction times observed in slow motion videos of the tests were subtracted from the total time of each trial and replaced with 1.5 seconds reaction time. This time is a commonly accepted reaction time recognized by reputable organizations (i.e. Commonwealth of Virginia, National Highway Traffic Safety Administration (NHTSA), Transportation Research Board).

Key Observations
Once powder flow was initiated to the fire, the fire quickly went out during every test

- There was no significant difference in time needed to extinguish a fire between the two extinguisher weights or powder types
- Despite the broad range of variables involved in the tests, times required to extinguish fires were consistent
- Operator error was the dominant source of variability in times required to extinguish fires
- With the operator error data removed from the calculation, average extinguishing time was 5.97 +/- 0.24 seconds. With operator error data included, average extinguishing time was 6.36 +/- 0.71 seconds.



In the chart above, blue bars include both sodium bicarbonate and potassium bicarbonate extinguishing agents, demographics from a broad range of operators, gas pressure (55 psi and 12" water column pressures), and excavation depths (4 ft. un-shored and 6 ft. shored excavations). Variability was too great to draw conclusions about these variables without a much larger data set.

Red bars represent trials with new (un-punctured CO_2 cartridge) extinguishers. During testing, once an extinguisher was charged with pressure, it was used again until exhausted, then refilled with extinguishing agent and fresh (un-punctured) CO_2 cartridge. Two of the three extinguishers equipped with new CO_2 cartridges required multiple strikes by the operators to puncture the internal seal compared to extinguisher where operators simulated the puncture step. This resulted in longer times required to extinguish the excavation fires.

FR PPE Burn Testing

Purpose

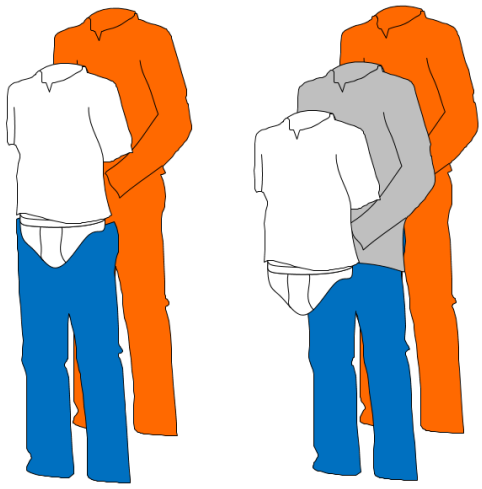
To understand the level of predicted body burn of various FR PPE coveralls

Scope

Using fire exposure times predicted by escape time testing and confirmed by fire extinguisher time testing, burn test FR PPE garments at an intensity of 2 calorie/cm^2-second as observed in the fire intensity testing

Five variables:

- Garment FR materials in 3 categories
  - FR treated cotton (42 tests)
  - blends (33 tests)
  - Inherent FR (24 tests)
- Garment weight
- Garment style
- Garment manufacturer
- Burn times of 4, 6 or 8 seconds



Starting Conditions:

- NFPA 2112 standard requires the use of the ASTM F 1930 burn test protocol. This protocol was used in all cases with the following modifications:
  - Actual FR PPE garments were burned versus ASTM defined standard coverall silhouette
  - Garments were burned over a base layer of:
    - 100 % cotton t-shirt, briefs and denim jeans
    - 100 % cotton t-shirt, briefs, denim jeans and a long sleeve 100% cotton work shirt
  - Burn times were 4, 6 and 8 seconds versus the ASTM protocol of 3 seconds
  - Coveralls were 1 size larger than ASTM guidelines to account for a layer of workwear underneath
  - Mannequin head was protected with fiberglass and/or para-aramid fabric wrap to minimize extended fire exposure damage to the mannequin
- Only FR coveralls were tested; no FR pants, FR shirts, FR rainwear, etc.
- All 99 tests completed in a UL certified lab
- All testing witnessed by AGA members

Images depict typical flame test progression

End Conditions:

- FR PPE garments were burn tested at an intensity of 2 calorie/cm^2-second
- Thermal mannequin predicted burn injury was recorded for each test
- Garments tested were removed with shears and examined after every burn for garment integrity and testing responses
- Garment integrity observations were recorded for each test

Key Observations

- Burn testing of different FR PPE garments showed significant differences in the performance of materials in both predicted body burn and integrity of the garments following fire exposure
- Resulting body burn percentage of some FR garments was high enough to predict worker fatality rates exceeding 50% based upon worker age and historical burn injury analysis compiled by the American Burn Association (see Appendix B)
- Test results indicated the addition of a long sleeve 100% cotton work shirt to the standard burn test configuration (100% cotton t-shirt, briefs, denim jeans, FR coveralls) reduced predicted burn injury by 47% as compared to tests with just the standard configuration
- Only one garment system resulted in less than 10% body burn at the 8 second exposure - 16.9 oz./sq. yd. (9.4 oz./sq. yd. quilting plus 7.5 oz. outer layer) inherent FR material
- Test results demonstrated a significant impact of FR garment sizing. For example, garments constructed of inherent FR 6.0 oz./sq. yd. material when tested at the 8 second exposure with a 100% cotton long sleeve work shirt undergarment, test results showed a reduction from 40% to 25% predicted body burn when properly sized garments were tested as compared to garments that were too tight (i.e. size XL vs. LG).
- Test results showed inconsistent performance of blends and FR-treated cotton garments. Some garments constructed of lighter weight fabrics performed better than garments constructed of heavier weight fabrics. Garment weight alone is not a reliable predictor of performance for blends or FR treated cotton garments.

- When normalized for different garment fabric weights, garments constructed of inherent FR materials resulted in less predicted body burn than either treated FR cottons or blend materials (based on results of 8 second burn tests with 100% cotton work shirt added to the standard burn test configuration). See Appendix A
- During stationary burn tests, some FR garments became brittle and many actually broke open exposing undergarments directly to the flame (see image) at the 6 or 8 second exposure time. Garments that were brittle or had already broke open during burn testing were further compromised when subjected to even minimal movement after they were removed from the mannequin.

Example of FR garment that became brittle and broke open on the mannequin during a burn test

- Test observers noted significant smoke generation during testing of blend materials at 4, 6 and 8 seconds

Conclusions Based On Observations

Burn injuries from natural gas fires in excavations are affected by a multitude of variables. Many are unique to the particular circumstances giving rise to a burn injury event, while others may be considered as a contributing element of each event, e.g., exposure time, fire heat intensity and the performance of personal protective equipment (PPE). Exposure time (the time a worker is exposed to a fire) can be limited by either escaping from the excavation or by extinguishing the fire. To identify realistic escape times of typical gas workers, the Technical Subcommittee measured results of more than 500 discrete tests with multiple variables and demographics. The findings correlate well with previous AGA member escape time hazard analyses and their practical experiences. Escape time for the most agile workers averaged 5.4 seconds for excavations 4 feet in depth and 6.8 seconds for excavations 6 feet deep. Less agile workers averaged 30% slower escape times. When wearing an air-supplied respirator that impaired vision, an additional 1 second was required to escape an excavation. Due to the observed variability of escape times and actual industry experience, relying solely upon the worker (e.g. agility) to escape an excavation to limit exposure to the fire hazard is not prudent.

To identify realistic times required to extinguish a natural gas fire in an excavation, the Technical Subcommittee conducted 55 discrete tests using multiple variables and demographics as recommended by subject matter experts of AGA member companies. On average, a safety attendant positioned 10 feet from the center of the excavation at the time of ignition took a total of about 6 seconds to react, execute and extinguish the fire using typical CO_2-powered, dry powder-type extinguishers. There were observed variabilities in the time to extinguish the excavation fire, primarily driven by fumbling with the extinguisher to either puncture the charger or gain control of the nozzle. Based on the findings of the extinguisher response tests, relying solely upon fire extinguisher response to limit worker exposure to the fire hazard is not prudent.

With respect to fire intensity analysis, testing scenarios were established by subject matter experts of AGA member companies. After extensive work with instrumentation, calibration, data acquisition and data analysis of 55 discrete tests, the heat intensity of a natural gas fire in a typical excavation was confirmed to be about 2 calories/cm^2-second. This finding validated the fire heat intensity used in lab conditions to evaluate the performance of FR garments.

FR apparel currently used by AGA member companies was supplied and evaluated in a certified and controlled lab environment for exposure times identified by the escape time and fire extinguisher analysis. Fire heat intensity was controlled to reproduce the actual measured field conditions. Nineteen different garment ensembles were tested and 99 discrete burn tests were completed.

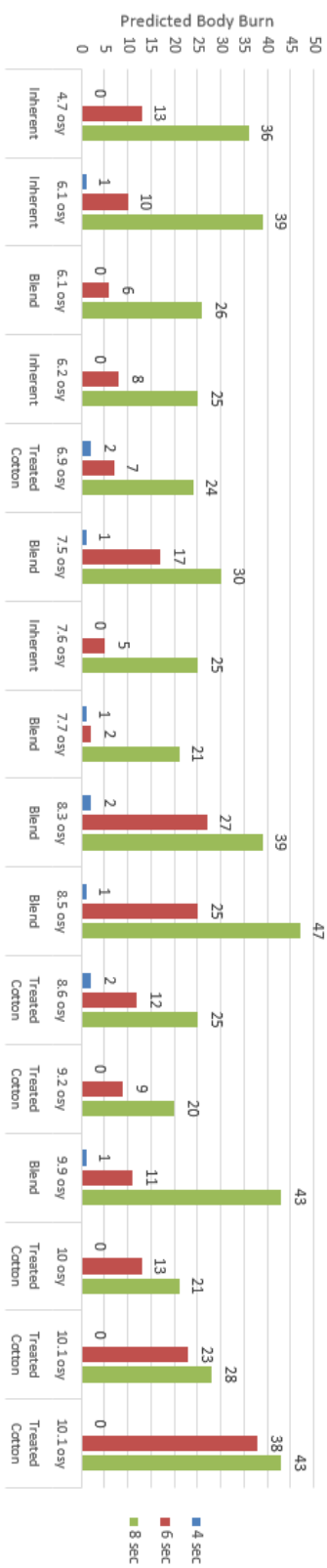
Key observations uncovered during the lab burn testing were:

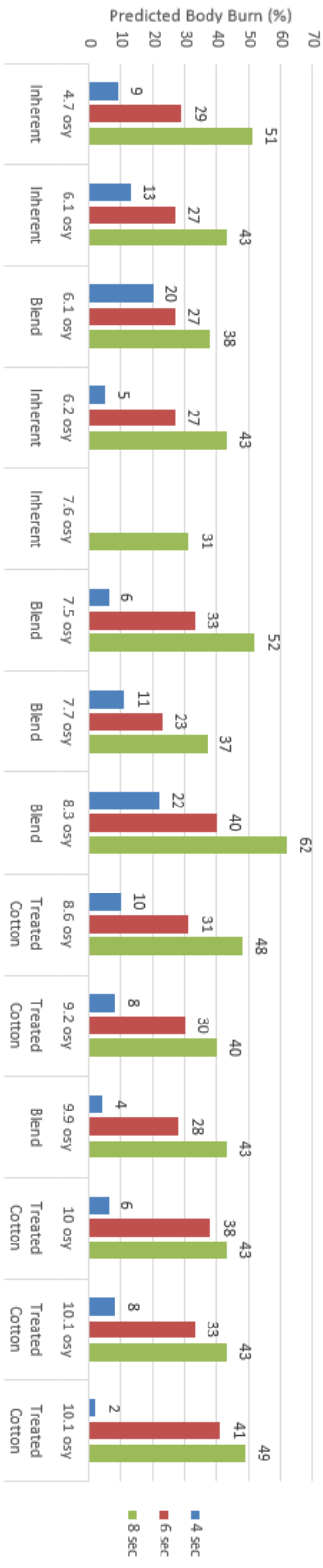
- Resulting body burn percentage of some FR garments provided by some AGA member companies was high enough to predict worker fatality rates in excess of 50% based upon worker age and historical burn injury analysis compiled by the American Burn Association
- Adding a standard, long sleeved, 100% cotton, non-FR work shirt under the outer layer of FR PPE improved performance by 47%

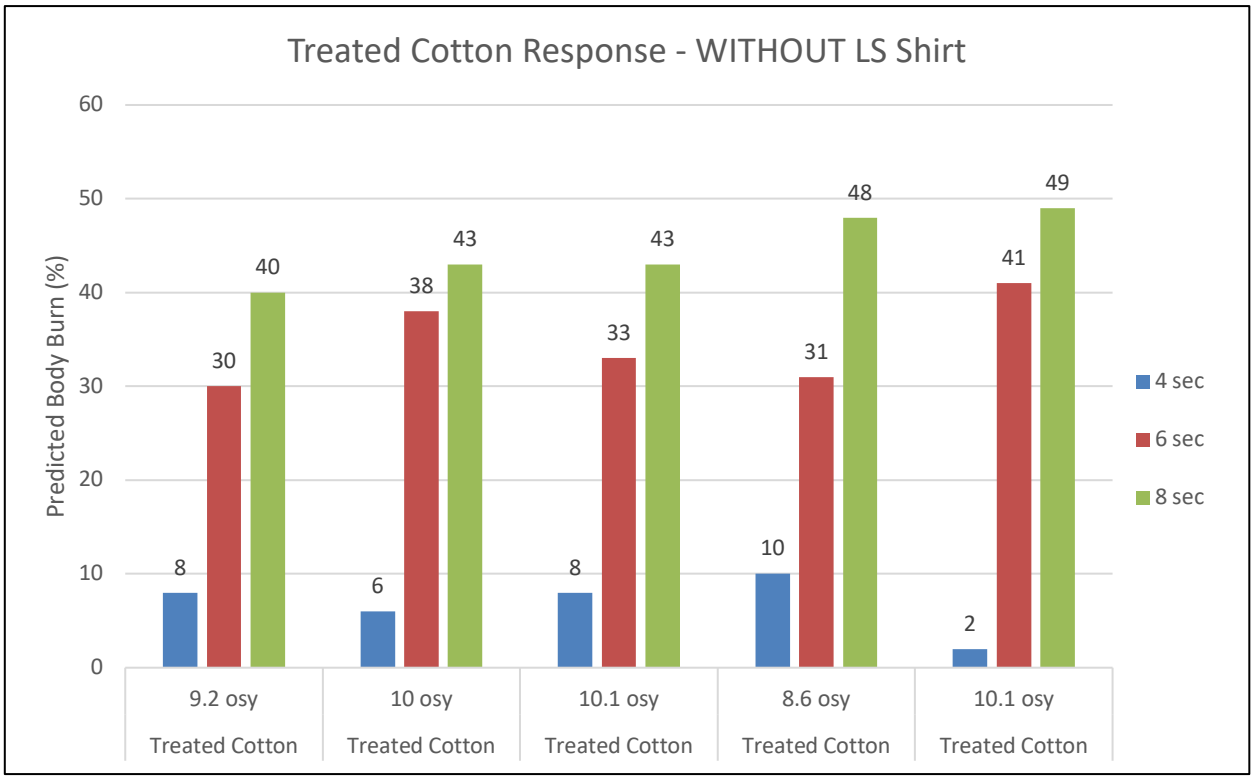
- Some FR garments became brittle during the stationary lab burn test and some garments broke open. In actual field conditions during a dynamic escape, it is reasonable to conclude this type of deterioration could cause the garment to break apart, fall off and potentially result in increased burn injury should the worker's underlying garments ignite.
- Test results showed inconsistent performance of blends and FR-treated cotton garments. Some garments constructed of lighter weight fabrics performed better than garments constructed of heavier weight fabrics. Tests showed garment weight alone is not a reliable predictor of performance for blends or FR treated cotton garments.

Based on information provided by AGA Safety and Occupational Health Committee members, there are a variety of identified hazards and employee safety protocols currently in use throughout the industry. Detailed results of all burn, escape time and extinguishing tests found in the appendices of this report may enable AGA member companies to make informed choices with respect to safety of workers exposed to typical natural gas fires in excavations.

APPENDIX A – FR Burn Testing Results






Treated Cotton Response - WITHOUT LS Shirt
Predicted Body Burn (%)
60
50
40
30
20
10
0
8
30
40
6
38
43
8
33
43
10
31
48
2
41
49
4 sec
6 sec
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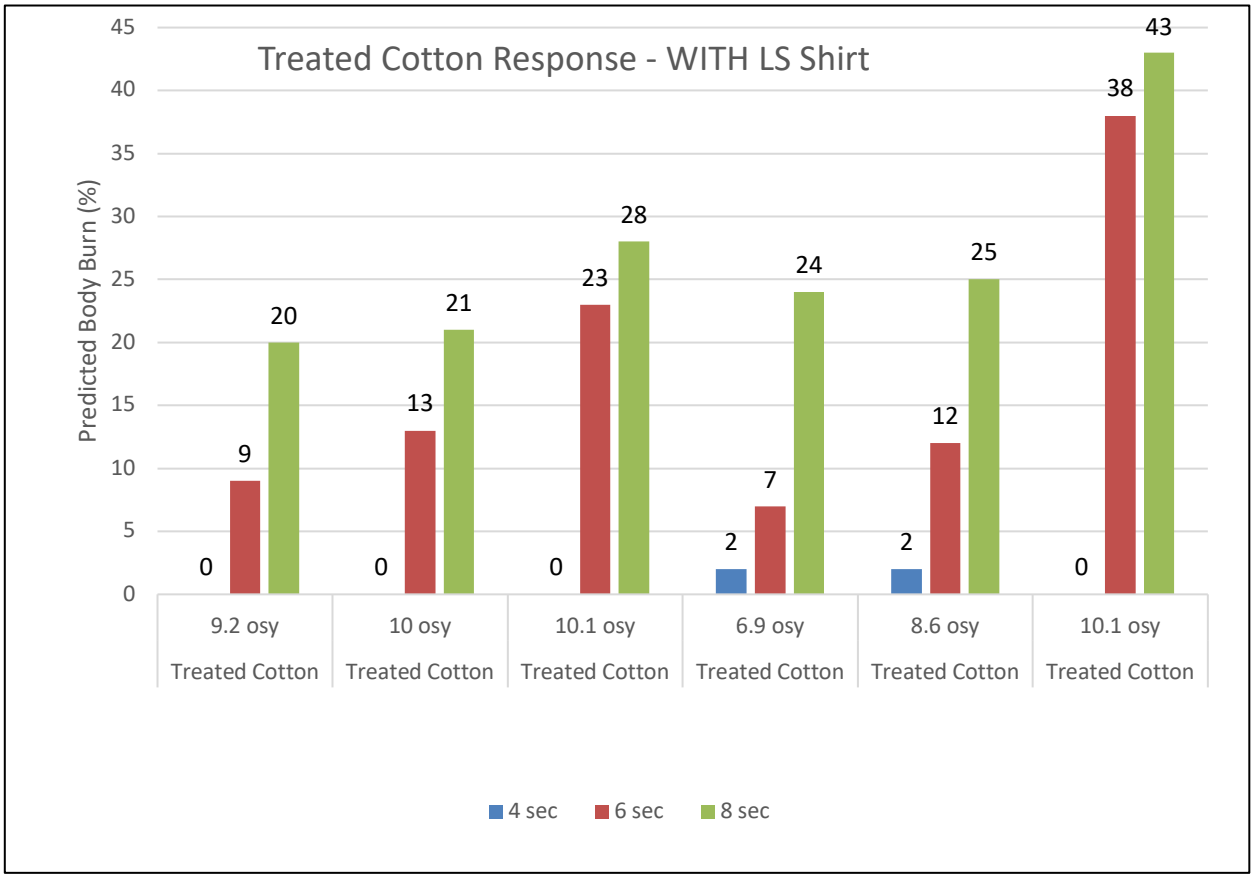
9.2 osy Treated Cotton
10 osy Treated Cotton
10.1 osy Treated Cotton
8.6 osy Treated Cotton
10.1 osy Treated Cotton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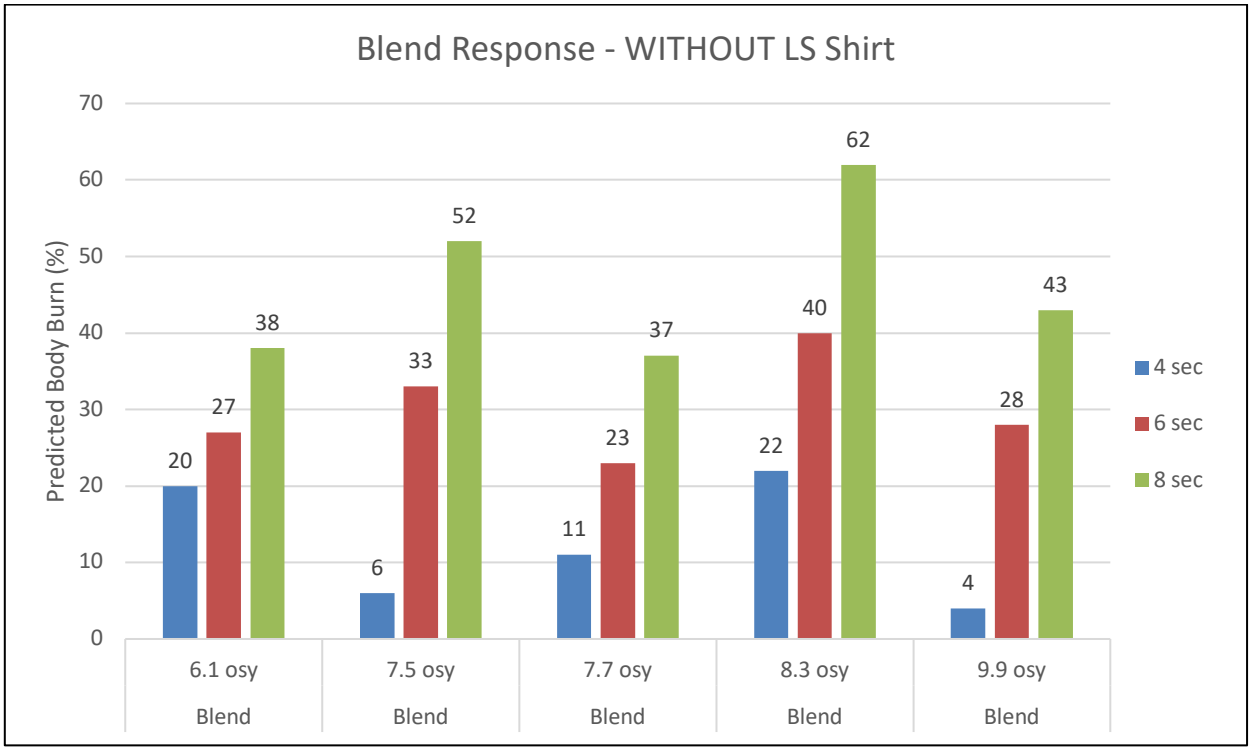
Predicted Body Burn (%)
45
40
35
30
25
20
15
10
5
0
0
9
20
0
13
21
0
23
28
2
7
24
2
12
25
0
38
43
9.2 osy Treated Cotton
10 osy Treated Cotton
10.1 osy Treated Cotton
6.9 osy Treated Cotton
8.6 osy Treated Cotton
10.1 osy Treated Cotton
4 sec
6 sec
8 sec


Blend Response - WITHOUT LS Shirt
Predicted Body Burn (%)
70
60
50
40
30
20
10
0
20
27
38
6
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52
11
23
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62
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7.5 osy Blend
7.7 osy Blend
8.3 osy Blend
9.9 osy Blend
4 sec
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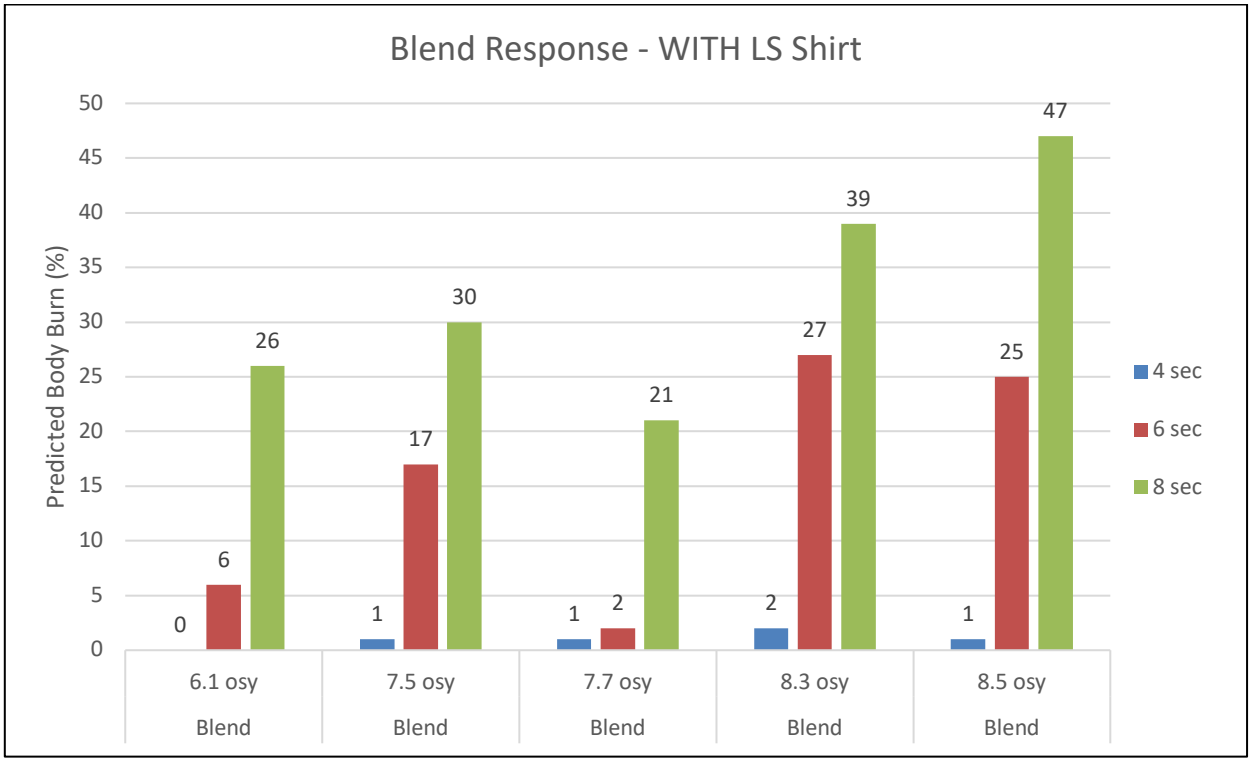
Blend Response - WITH LS Shirt
Predicted Body Burn (%)
50
45
40
35
30
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20
15
10
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0
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6
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17
30
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8.3 osy Blend
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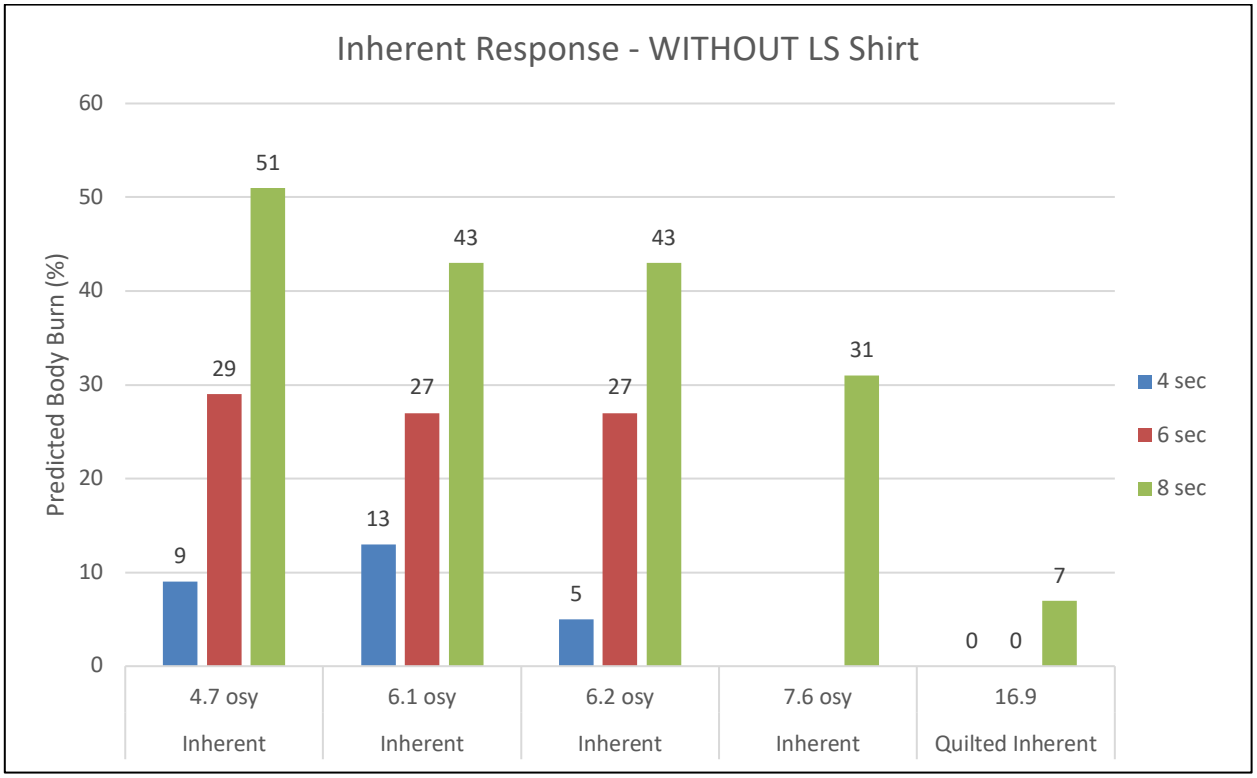
Inherent Response - WITHOUT LS Shirt
Predicted Body Burn (%)
60
50
40
30
20
10
0
9
29
51
13
27
43
5
27
43
31
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6.2 osy Inherent
7.6 osy Inherent
16.9 Quilted Inherent
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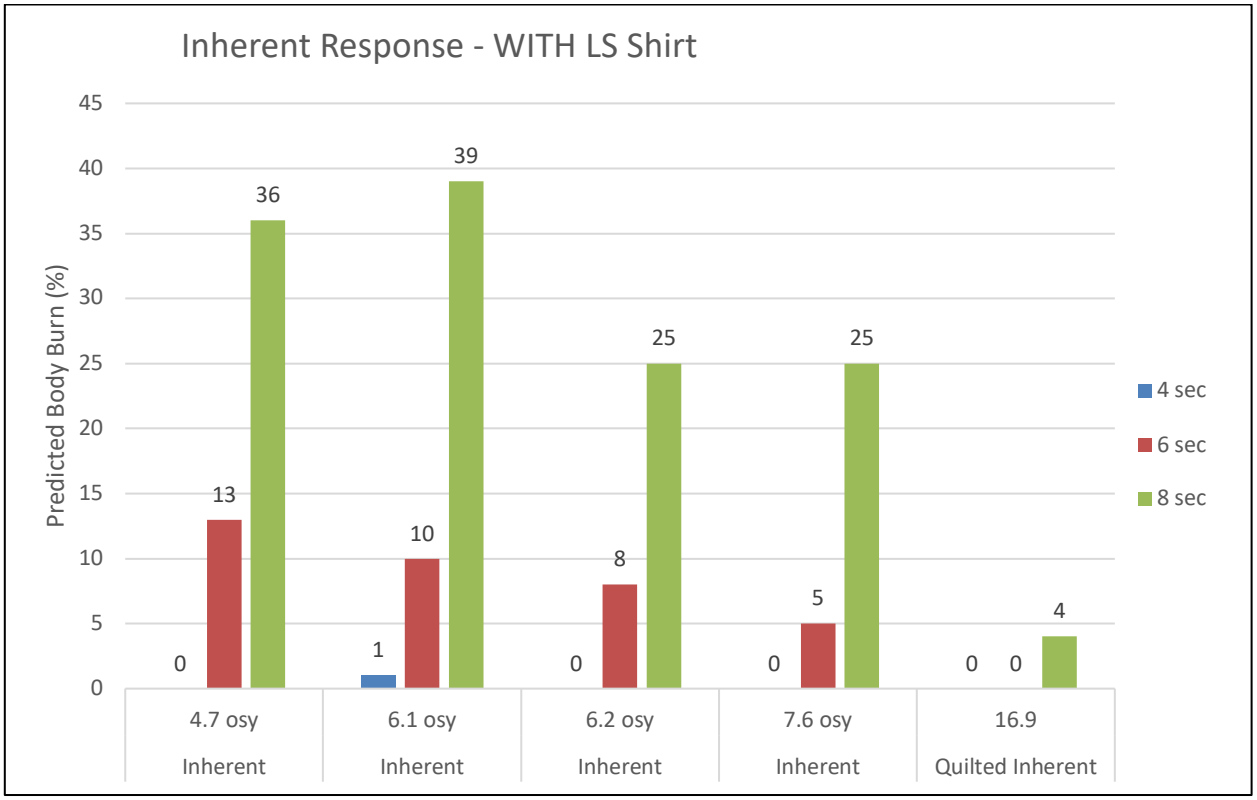
6 sec
8 sec


Inherent Response - WITH LS Shirt
Predicted Body Burn (%)
45
40
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30
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5
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0
13
36
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0
8
25
0
5
25
0
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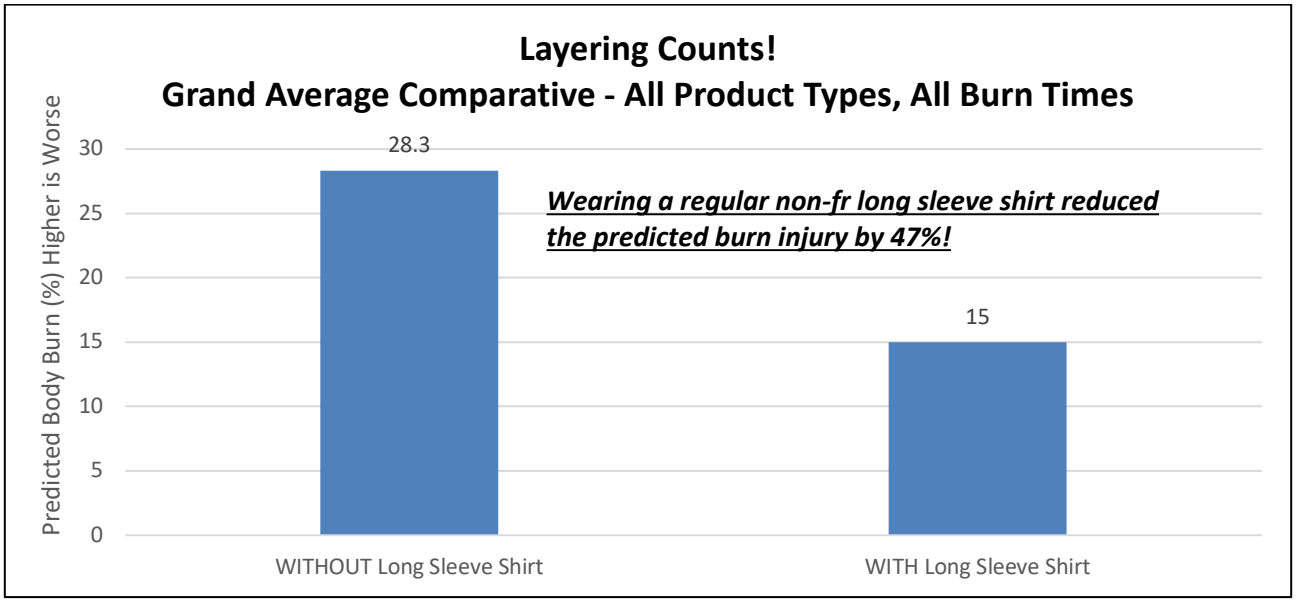
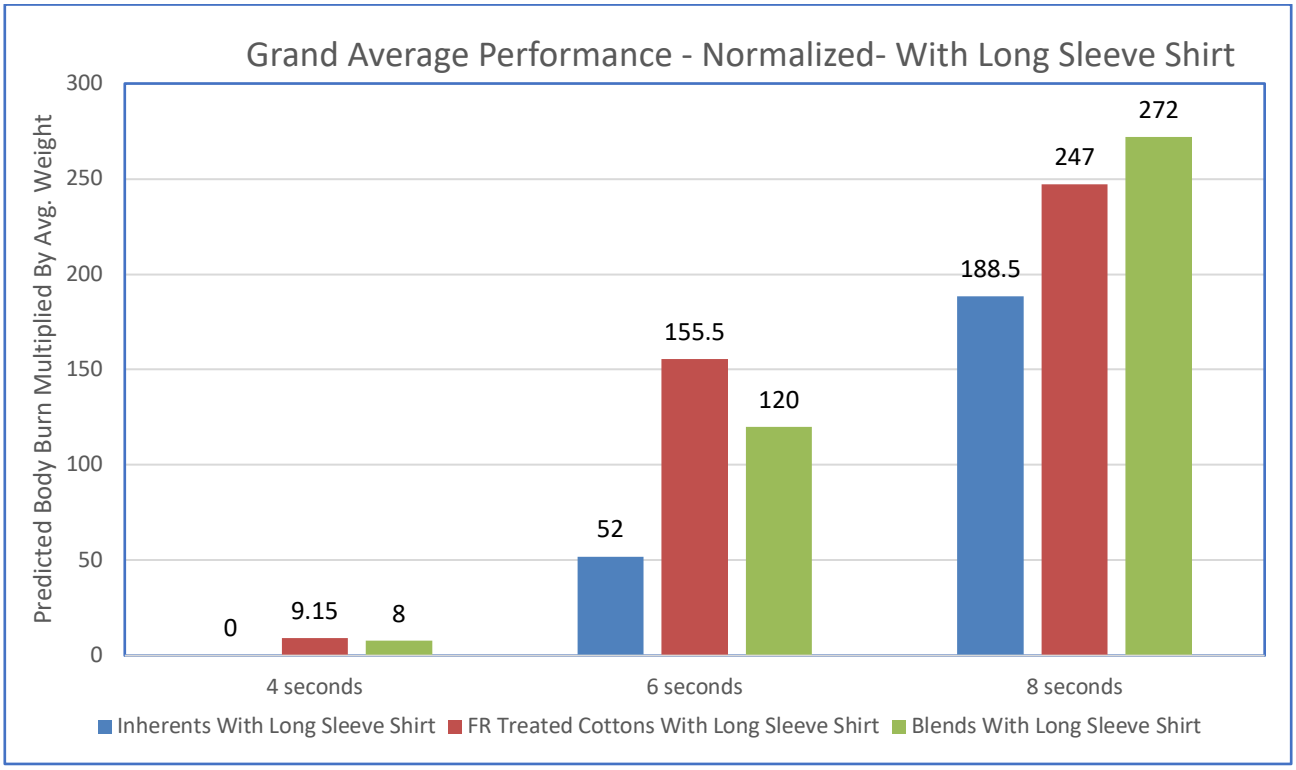
16.9 Quilted Inherent
4 sec
6 sec
8 sec


Layering Counts!
Grand Average Comparative - All Product Types, All Burn Times
Predicted Body Burn (%) Higher is Worse
30
25
20
15
10
5
0
28.3
15
Wearing a regular non-fr long sleeve shirt reduced the predicted burn injury by 47%!
WITHOUT Long Sleeve Shirt
WITH Long Sleeve Shirt


Grand Average Performance - Normalized- With Long Sleeve Shirt
Predicted Body Burn Multiplied By Avg. Weight
300
250
200
150
100
50
0
0
9.15
8
52
155.5
120
188.5
247
272
4 seconds
6 seconds
8 seconds
Inherents With Long Sleeve Shirt
FR Treated Cottons With Long Sleeve Shirt
Blends With Long Sleeve Shirt

Test #1

Base layer	Standard garment	Test Garment	Test Time	Garment weights, stated/actual (oz/yd^2)	Total Burn	2nd degree	3rd degree
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Treated Cotton, one industrial laundering	4 sec	shirt - 5.8 oz/yd^2 pants - 13.3 oz/yd^2 coveralls - 10.1 oz/yd^2	0%	0%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Treated Cotton size 46R, one industrial laundering	6 sec	shirt - 5.8 oz/yd^2 pants - 13.3 oz/yd^2 coveralls - 10.1 oz/yd^2	23%	23%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Treated Cotton size 46R, one industrial laundering	8 sec	shirt - 5.8 oz/yd^2 pants - 13.3 oz/yd^2 coveralls - 10.1 oz/yd^2	28%	28%	0%
100% cotton t-shirt and briefs	100% cotton denim jeans	Treated Cotton size 46R, one industrial laundering	4 sec	pants - 13.3 oz/yd^2 coveralls - 10.1 oz/yd^2	4%	4%	0%
100% cotton t-shirt and briefs	100% cotton denim jeans	Treated Cotton size 46R, one industrial laundering	6 sec	pants - 13.3 oz/yd^2 coveralls - 10.1 oz/yd^2	39%	34%	5%
100% cotton t-shirt and briefs	100% cotton denim jeans	Treated Cotton size 46R, one industrial laundering	8 sec	pants - 13.3 oz/yd2 coveralls - 10.1 oz/yd2	48%	37%	11%

Test #2

Base layer	Standard garment	Test Garment	Test Time	Garment weights, stated/actual (oz/yd^2)	Total Burn	2nd degree	3rd degree
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Treated Cotton size 46R, one industrial laundering	4 sec	shirt - 5.8 oz/yd^2 pants - 13.3 oz/yd^2 coveralls - 6.9 oz/yd^2	2%	2%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Treated Cotton size 46R, one industrial laundering	6 sec	shirt - 5.8 oz/yd^2 pants - 13.3 oz/yd^2 coveralls - 6.9 oz/yd^2	7%	7%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Treated Cotton size 46R, one industrial laundering	8 sec	shirt - 5.8 oz/yd^2 pants - 13.3 oz/yd^2 coveralls - 6.9 oz/yd^2	24%	19%	5%

Test #3

Base layer	Standard garment	Test Garment	Test Time	Garment weights, stated/actual (oz/yd^2)	Total Burn	2nd degree	3rd degree
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Inherent, one industrial laundering	4 sec	shirt - 5.8 oz/yd^2 pants - 13.3 oz/yd^2, coveralls - 7.7 oz/yd^2	0%	0%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Inherent, one industrial laundering	6 sec	shirt - 5.8 oz/yd^2 pants - 13.3 oz/yd^2 coveralls - 7.7 oz/yd^2	5%	5%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Inherent, one industrial laundering	8 sec	shirt - 5.8 oz/yd^2 pants - 13.3 oz/yd^2 coveralls - 7.7 oz/yd^2	25%	23%	2%
100% cotton t-shirt and briefs	100% cotton denim jeans	Inherent, one industrial laundering	8 sec	pants - 13.3 oz/yd^2 coveralls - 7.6 oz/yd^2	31%	18%	13%

Test #4

Base layer	Standard garment	Test Garment	Test Time	Garment weights, stated/actual (oz/yd^2)	Total Burn	2nd degree	3rd degree
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Inherent - **Quilted**, one industrial laundering	8 sec	shirt - 5.8 oz/yd^2 pants - 13.3 oz/yd^2 coveralls - 16.9 oz/yd^2	4%	4%	0%
100% cotton t-shirt and briefs	100% cotton denim jeans	Inherent - **Quilted**, one industrial laundering	8 sec	pants - 13.3 oz/yd^2 coveralls - 16.9oz/yd^2	7%	7%	0%

Test #5

Base layer	Standard garment	Test Garment	Test Time	Garment weights, stated/actual (oz/yd^2)	Total Burn	2nd degree	3rd degree
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Blend, size 46R, one industrial laundering	4 sec	shirt - 5.8 oz/yd^2 pants - 13.3 oz/yd^2 coveralls - 8.5 oz/yd^2	1%	1%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Blend, size 46R, one industrial laundering	6 sec	shirt - 5.8 oz/yd^2 pants - 13.3 oz/yd^2 coveralls - 8.5 oz/yd^2	25%	25%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Blend, size 46R, one industrial laundering	8 sec	shirt - 5.8 oz/yd^2 pants - 13.5 oz/yd^2 coveralls - 8.5oz/yd^2	47%	45%	2%

Test #6

Base layer	Standard garment	Test Garment	Test Time	Garment weights, stated/actual (oz/yd^2)	Total Burn	2nd degree	3rd degree
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Blend, size 46R, one industrial laundering	4 sec	shirt - 5.8 oz/yd^2 pants - 14.3 oz/yd^2 coveralls - 8.3oz/yd^2	2%	2%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Blend, size 46R, one industrial laundering	6 sec	shirt - 5.8 oz/yd^2 pants - 14.3 oz/yd^2 coveralls - 8.3 oz/yd^2	27%	27%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Blend, size 46R, one industrial laundering	8 sec	shirt - 5.8 oz/yd^2 pants - 14.3 oz/yd^2 coveralls - 8.3oz/yd^2	39%	37%	2%
100% cotton t-shirt and briefs	100% cotton denim jeans	Blend, size 46R, one industrial laundering	4 sec	pants - 13.6 oz/yd^2 coveralls - 8.3oz/yd^2	22%	22%	0%
100% cotton t-shirt and briefs	100% cotton denim jeans	Blend, size 46R, one industrial laundering	6 sec	pants - 13.6 oz/yd^2 coveralls - 8.3oz/yd^2	40%	37%	3%
100% cotton t-shirt and briefs	100% cotton denim jeans	Blend, size 46R, one industrial laundering	8 sec	pants - 13.6 oz/yd^2 coveralls - 8.3oz/yd^2	62%	45%	17%

Test #7

Base layer	Standard garment	Test Garment	Test Time	Garment weights, stated/actual (oz/yd^2)	Total Burn	2nd degree	3rd degree
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Treated Cotton size 46R, one industrial laundering	4 sec	shirt - 5.8 oz/yd^2 pants - 13.5 oz/yd^2 coveralls - 9.2 oz/yd^2	0%	0%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Treated Cotton size 46R, one industrial laundering	6 sec	shirt - 5.8 oz/yd^2 pants - 13.5 oz/yd^2 coveralls - 9.2oz/yd^2	9%	9%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Treated Cotton size 46R, one industrial laundering	8 sec	shirt - 5.8 oz/yd^2 pants - 13.5 oz/yd^2 coveralls - 9.2 oz/yd^2	20%	19%	1%
100% cotton t-shirt and briefs	100% cotton denim jeans	Treated Cotton size 46R, one industrial laundering	4 sec	pants - 13.5 oz/yd^2 coveralls - 9.2 oz/yd^2	8%	8%	0%
100% cotton t-shirt and briefs	100% cotton denim jeans	Treated Cotton size 46R, one industrial laundering	6 sec	pants - 13.5 oz/yd^2 coveralls - 9.2 oz/yd^2	30%	30%	0%
100% cotton t-shirt and briefs	100% cotton denim jeans	Treated Cotton size 46R, one industrial laundering	8 sec	pants - 13.5 oz/yd^2 coveralls - 9.2 oz/yd^2	40%	30%	10%

Test #8

Base layer	Standard garment	Test Garment	Test Time	Garment weights, stated/actual (oz/yd^2)	Total Burn	2nd degree	3rd degree
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Treated Cotton size 46R, one industrial laundering	4 sec	shirt - 5.9 oz/yd^2 pants - 14.3 oz/yd^2 coveralls - 10 oz/yd^2	0%	0%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Treated Cotton size 46R, one industrial laundering	6 sec	shirt - 5.9 oz/yd^2 pants - 14.3 oz/yd^2 coveralls - 10 oz/yd^2	13%	13%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Treated Cotton size 46R, one industrial laundering	8 sec	shirt - 5.9 oz/yd^2 pants - 14.3 oz/yd^2 coveralls - 10 oz/yd^2	21%	21%	0%
100% cotton t-shirt and briefs	100% cotton denim jeans	Treated Cotton size 46R, one industrial laundering	4 sec	pants - 14.3 oz/yd^2 coveralls - 10 oz/yd^2	6%	6%	0%
100% cotton t-shirt and briefs	100% cotton denim jeans	Treated Cotton size 46R, one industrial laundering	6 sec	pants - 14.3 oz/yd^2 coveralls - 10 oz/yd^2	38%	34%	4%
100% cotton t-shirt and briefs	100% cotton denim jeans	Treated Cotton size 46R, one industrial laundering	8 sec	pants - 14.3 oz/yd^2 coveralls - 10 oz/yd^2	43%	29%	14%

Test #9

Base layer	Standard garment	Test Garment	Test Time	Garment weights, stated/actual (oz/yd^2)	Total Burn	2nd degree	3rd degree
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Blend, size XL, one industrial laundering	4 sec	shirt - 5.8 oz/yd^2 pants - 13.3 oz/yd^2 coveralls - 6.1 oz/yd^2	0%	0%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Blend, size XL, one industrial laundering	6 sec	shirt - 5.8 oz/yd^2 pants - 13.3 oz/yd^2 coveralls - 6.1 oz/yd^2	6%	6%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Blend, size XL, one industrial laundering	8 sec	shirt - 5.8 oz/yd^2 pants - 13.3 oz/yd^2 coveralls - 6.1 oz/yd^2	26%	23%	3%
100% cotton t-shirt and briefs	100% cotton denim jeans	Blend, size XL, one industrial laundering	4 sec	pants - 13.3 oz/yd^2 coveralls - 6.1 oz/yd^2	20%	20%	0%
100% cotton t-shirt and briefs	100% cotton denim jeans	Blend, size XL, one industrial laundering	6 sec	pants - 13.3 oz/yd^2 coveralls - 6.1 oz/yd^2	27%	25%	2%
100% cotton t-shirt and briefs	100% cotton denim jeans	Blend, size XL, one industrial laundering	8 sec	pants - 13.3 oz/yd^2 coveralls - 6.1 oz/yd^2	38%	19%	19%

Test #10

Base layer	Standard garment	Test Garment	Test Time	Garment weights, stated/actual (oz/yd^2)	Total Burn	2nd degree	3rd degree
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Treated Cotton size XL, one industrial laundering	4 sec	shirt - 5.8 oz/yd^2 pants - 13.6 oz/yd^2 coveralls - 8.6 oz/yd^2	2%	2%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Treated Cotton size XL, one industrial laundering	6 sec	shirt - 5.8 oz/yd2 pants - 13.6 oz/yd2 coveralls - 8.6 oz/yd2	12%	12%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Treated Cotton size XL, one industrial laundering	8 sec	shirt - 5.8 oz/yd^2 pants - 13.6 oz/yd^2 coveralls - 8.6 oz/yd^2	25%	24%	1%
100% cotton t-shirt and briefs	100% cotton denim jeans	Treated Cotton size XL, one industrial laundering	4 sec	pants - 13.6 oz/yd^2 coveralls - 8.6 oz/yd^2	10%	10%	0%
100% cotton t-shirt and briefs	100% cotton denim jeans	Treated Cotton size XL, one industrial laundering	6 sec	pants - 13.6 oz/yd^2 coveralls - 8.6 oz/yd^2	31%	29%	2%
100% cotton t-shirt and briefs	100% cotton denim jeans	Treated Cotton size XL, one industrial laundering	8 sec	pants - 13.6 oz/yd^2 coveralls - 8.6 oz/yd^2	48%	36%	12%

Test #11

Base layer	Standard garment	Test Garment	Test Time	Garment weights, stated/actual (oz/yd^2)	Total Burn	2nd degree	3rd degree
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Treated Cotton size XL, one industrial laundering	4 sec	shirt - 5.8 oz/yd^2 pants - 14.3 oz/yd^2 coveralls - 10.1 oz/yd^2	0%	0%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Treated Cotton size XL, one industrial laundering	6 sec	shirt - 5.8 oz/yd^2 pants - 14.3 oz/yd^2 coveralls - 10.1 oz/yd^2	38%	37%	1%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Treated Cotton size XL, one industrial laundering	8 sec	shirt - 5.8 oz/yd^2 pants - 14.3 oz/yd^2 coveralls - 10.1 oz/yd^2	43%	41%	2%
100% cotton t-shirt and briefs	100% cotton denim jeans	Treated Cotton size XL, one industrial laundering	4 sec	pants - 14.3 oz/yd^2 coveralls - 10.1 oz/yd^2	2%	2%	0%
100% cotton t-shirt and briefs	100% cotton denim jeans	Treated Cotton size XL, one industrial laundering	6 sec	pants - 14.3 oz/yd^2 coveralls - 10.1 oz/yd^2	41%	40%	1%
100% cotton t-shirt and briefs	100% cotton denim jeans	Treated Cotton size XL, one industrial laundering	8 sec	pants - 14.3 oz/yd^2 coveralls - 10.1 oz/yd^2	49%	46%	3%

Test #12

Base layer	Standard garment	Test Garment	Test Time	Garment weights, stated/actual (oz/yd^2)	Total Burn	2nd degree	3rd degree
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Inherent, Size XL-Reg, one industrial laundering	4 sec	shirt - 5.8 oz/yd^2 pants - 13.5 oz/yd^2 coveralls - 6.1 oz/yd^2	1%	1%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Inherent, Size XL-Reg, one industrial laundering	6 sec	shirt - 5.8 oz/yd^2 pants - 14 oz/yd^2 coveralls - 6.1 oz/yd^2	10%	10%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Inherent, Size XL-Reg, one industrial laundering	8 sec	shirt - 5.8 oz/yd^2 pants - 14 oz/yd^2 coveralls - 6.1oz/yd^2	39%	33%	6%
100% cotton t-shirt and briefs	100% cotton denim jeans	Inherent, Size XL-Reg, one industrial laundering	4 sec	pants - 14 oz/yd^2 coveralls - 6.1oz/yd^2	13%	12%	1%
100% cotton t-shirt and briefs	100% cotton denim jeans	Inherent, Size XL-Reg, one industrial laundering	6 sec	pants - 13.5 oz/yd^2 coveralls - 6.1oz/yd^2	27%	20%	7%
100% cotton t-shirt and briefs	100% cotton denim jeans	Inherent, Size XL-Reg, one industrial laundering	8 sec	pants - 13.5 oz/yd^2 coveralls - 6.1oz/yd^2	43%	24%	19%

Test #13

Base layer	Standard garment	Test Garment	Test Time	Garment weights, stated/actual (oz/yd^2)	Total Burn	2nd degree	3rd degree
100% cotton t-shirt and briefs	100% cotton denim jeans	Treated Cotton size 46R, one industrial laundering	4 sec	pants - 13.4 oz/yd^2 coveralls - 10.1 oz/yd^2	8%	8%	0%
100% cotton t-shirt and briefs	100% cotton denim jeans	Treated Cotton size 46R, one industrial laundering	6 sec	pants - 13.4 oz/yd^2 coveralls - 10.1 oz/yd^2	33%	31%	2%
100% cotton t-shirt and briefs	100% cotton denim jeans	Treated Cotton size 46R, one industrial laundering	8 sec	pants - 13.4 oz/yd^2 coveralls - 10.1 oz/yd^2	43%	31%	12%

Test #14

Base layer	Standard garment	Test Garment	Test Time	Garment weights, stated/actual (oz/yd^2)	Total Burn	2nd degree	3rd degree
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Blend, one industrial laundering	4 sec	shirt - 5.8 oz/yd^2 pants - 13.4 oz/yd^2 coveralls - 7.7 oz/yd^2	1%	1%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Blend, one industrial laundering	6 sec	shirt - 5.8 oz/yd^2 pants - 13.4 oz/yd^2 coveralls - 7.7 oz/yd^2	2%	2%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Blend, one industrial laundering	8 sec	shirt - 5.8 oz/yd^2 pants - 13.4 oz/yd^2 coveralls - 7.7 oz/yd^2	21%	21%	0%
100% cotton t-shirt and briefs	100% cotton denim jeans	Blend, one industrial laundering	4 sec	pants - 13.4 oz/yd^2 coveralls - 7.7 oz/yd^2	11%	11%	0%
100% cotton t-shirt and briefs	100% cotton denim jeans	Blend, one industrial laundering	6 sec	pants - 13.4 oz/yd^2 coveralls - 7.7 oz/yd^2	23%	21%	2%
100% cotton t-shirt and briefs	100% cotton denim jeans	Blend, one industrial laundering	8 sec	pants - 13.4 oz/yd^2 coveralls - 7.7 oz/yd^2	37%	24%	13%

Test #15

Base layer	Standard garment	Test Garment	Test Time	Garment weights, stated/actual (oz/yd^2)	Total Burn	2nd degree	3rd degree
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Inherent, one industrial laundering	4 sec	shirt - 5.8 oz/yd^2 pants - 13.4 oz/yd^2 coveralls - 4.7 oz/yd^2	0%	0%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Inherent, one industrial laundering	6 sec	shirt - 5.8 oz/yd^2 pants - 13.4 oz/yd^2 coveralls - 4.7 oz/yd^2	13%	13%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Inherent, one industrial laundering	8 sec	shirt - 5.8 oz/yd^2 pants - 13.4 oz/yd^2 coveralls - 4.7 oz/yd^2	36%	34%	2%
100% cotton t-shirt and briefs	100% cotton denim jeans	Inherent, one industrial laundering	4 sec	pants - 13.4 oz/yd^2 coveralls - 4.7 oz/yd^2	9%	7%	2%
100% cotton t-shirt and briefs	100% cotton denim jeans	Inherent, one industrial laundering	6 sec	pants - 14.0 oz/yd^2 coveralls - 4.7 oz/yd^2	29%	17%	12%
100% cotton t-shirt and briefs	100% cotton denim jeans	Inherent, one industrial laundering	8 sec	pants - 14.0 oz/yd^2 coveralls - 4.7 oz/yd^2	51%	30%	21%

Test #16

Base layer	Standard garment	Test Garment	Test Time	Garment weights, stated/actual (oz/yd^2)	Total Burn	2nd degree	3rd degree
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Inherent, Size XLG-RG, one industrial laundering	4 sec	shirt - 5.8oz/yd^2 pants - 13.4 oz/yd^2 coveralls - 6.2 oz/yd^2	0%	0%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Inherent, Size XLG-RG, one industrial laundering	6 sec	shirt - 5.8oz/yd^2 pants - 13.4 oz/yd^2 coveralls - 6.2 oz/yd^2	8%	8%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Inherent, Size XLG-RG, one industrial laundering	8 sec	shirt - 5.8oz/yd^2 pants - 13.4 oz/yd^2 coveralls - 6.2 oz/yd^2	25%	22%	3%
100% cotton t-shirt and briefs	100% cotton denim jeans	Inherent, Size XLG-RG, one industrial laundering	4 sec	pants - 13 oz/yd^2 coveralls - 6.2 oz/yd^2	5%	5%	0%
100% cotton t-shirt and briefs	100% cotton denim jeans	Inherent, Size XLG-RG, one industrial laundering	6 sec	pants - 13 oz/yd^2 coveralls - 6.2 oz/yd^2	27%	19%	8%
100% cotton t-shirt and briefs	100% cotton denim jeans	Inherent, Size XLG-RG, one industrial laundering	8 sec	pants - 13 oz/yd^2 coveralls - 6.2 oz/yd^2	43%	22%	21%

Test #17

Base layer	Standard garment	Test Garment	Test Time	Garment weights, stated/actual (oz/yd^2)	Total Burn	2nd degree	3rd degree
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Blend, Size XL, previously laundered	4 sec	shirt- 5.5 oz/yd2 pants - 13.2 oz/yd^2 coveralls - 7.5 oz/yd^2	1%	1%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Blend, Size XL, previously laundered	6 sec	shirt- 5.5 oz/yd2 pants - 13.2 oz/yd^2 coveralls - 7.5 oz/yd^2	17%	17%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Blend, Size XL, previously laundered	8 sec	shirt- 5.5 oz/yd2 pants - 13.2 oz/yd^2 coveralls - 7.5 oz/yd^2	30%	29%	1%
100% cotton t-shirt and briefs	100% cotton denim jeans	Blend, Size XL, previously laundered	4 sec	pants - 13.2 oz/yd^2 coveralls - 7.5 oz/yd^2	6%	6%	0%
100% cotton t-shirt and briefs	100% cotton denim jeans	Blend, Size XL, previously laundered	6 sec	pants - 13.2 oz/yd^2 coveralls - 7.5 oz/yd^2	33%	27%	6%
100% cotton t-shirt and briefs	100% cotton denim jeans	Blend, Size XL, previously laundered	8 sec	pants - 13.2 oz/yd^2 coveralls - 7.5 oz/yd^2	52%	32%	20%

Test #18

Base layer	Standard garment	Test Garment	Test Time	Garment weights, stated/actual (oz/yd^2)	Total Burn	2nd degree	3rd degree
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Blend, Size XL, previously laundered	4 sec	shirt - 5.5 oz/yd2 pants - 13.2 oz/yd^2 coveralls - 9.9 oz/yd^2	1%	1%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Blend, Size XL, previously laundered	6 sec	pants - 13.2 oz/yd^2 shirt - 5.5 oz/yd^2 coveralls - 9.9 oz/yd^2	11%	10%	1%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Blend, Size XL, previously laundered	8 sec	pants - 13.9 oz/yd^2 shirt - 5.5 oz/yd^2 coveralls - 9.9 oz/yd^2	43%	42%	1%
100% cotton t-shirt and briefs	100% cotton denim jeans	Blend, Size XL, previously laundered	4 sec	pants - 13.9 oz/yd^2 coveralls - 9.9 oz/yd^2	4%	4%	0%
100% cotton t-shirt and briefs	100% cotton denim jeans	Blend, Size XL, previously laundered	6 sec	pants - 13.9 oz/yd^2 coveralls - 9.9 oz/yd^2	28%	28%	0%
100% cotton t-shirt and briefs	100% cotton denim jeans	Blend, Size XL, previously laundered	8 sec	pants - 13.9 oz/yd^2 coveralls - 9.9 oz/yd^2	43%	34%	9%

Test #19

Base layer	Standard garment	Test Garment	Test Time	Garment weights, stated/actual (oz/yd^2)	Total Burn	2nd degree	3rd degree
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Treated Cotton size 46 Tall, one industrial laundering	4 sec	shirt - 5.8 oz/yd^2 pants - 13.4 oz/yd^2 coveralls - 7.7 oz/yd^2	2%	2%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Treated Cotton size 46 Tall, one industrial laundering	6 sec	shirt - 5.8 oz/yd^2 pants - 13.4 oz/yd^2 coveralls - 7.7 oz/yd^2	9%	9%	0%
100% cotton t-shirt and briefs	100% cotton button down long sleeve shirt 100% cotton denim jeans	Treated Cotton size 46 Tall, one industrial laundering	8 sec	shirt - 5.8 oz/yd^2 pants - 13.0 oz/yd^2 coveralls - 7.7 oz/yd^2	25%	25%	0%
100% cotton t-shirt and briefs	100% cotton denim jeans	Treated Cotton size 46 Tall, one industrial laundering	4 sec	pants - 13 oz/yd^2 coveralls - 7.7 oz/yd^2	20%	20%	0%
100% cotton t-shirt and briefs	100% cotton denim jeans	Treated Cotton size 46 Tall, one industrial laundering	6 sec	pants - 13 oz/yd^2 coveralls - 7.7 oz/yd^2	33%	28%	5%
100% cotton t-shirt and briefs	100% cotton denim jeans	Treated Cotton size 46 Tall, one industrial laundering	8 sec	pants - 13 oz/yd^2 coveralls - 7.7 oz/yd^2	44%	28%	16%

APPENDIX B – Fatality Rates from Burn Injury

Burn Fatality Rates by Age and Percent Burn to Total Body Surface Area

	Burn Size (% TBSA)										
Age Group	0.1 - 9.9	10 - 19.9	20 - 29.9	30 - 39.9	40 - 49.9	50 - 59.9	60 - 69.9	70 - 79.9	80 - 89.9	> 90	Total
Birth - .9	0.0	0.6	3.4	6.9	15.7	13.8	68.4	42.9	41.2	40.0	0.8
Died/Total	3/6940	7/1194	9/261	9/130	8/51	4/29	13/19	9/21	7/17	2/5	71/8667
1 - 1.9	0.0	0.4	0.6	1.0	8.5	22.2	19.2	22.2	20.0	60.0	0.2
Died/Total	0/11585	7/1954	2/311	1/101	4/47	4/18	5/26	2/9	1/5	3/5	29/14061
2 - 4.9	0.1	0.1	0.3	3.6	7.3	16.7	22.9	21.1	50.0	65.0	0.7
Died/Total	13/9597	2/1628	1/377	7/193	8/109	12/72	11/48	4/19	15/30	13/20	86/12093
5 - 15.9	0.1	0.3	0.9	1.6	4.4	2.9	10.3	11.7	48.9	61.5	0.6
Died/Total	12/12962	7/2166	6/637	5/308	8/182	3/103	9/87	7/60	23/47	16/26	96/16578
16 - 19.9	0.1	0.3	1.5	2.4	2.8	6.3	18.8	29.6	54.8	71.1	1.0
Died/Total	10/6844	4/1303	6/392	4/167	3/109	4/63	9/48	8/27	17/31	27/38	92/9022
20 - 29.9	0.2	0.5	1.6	5.1	10.5	16.8	26.9	41.5	59.6	80.6	1.4
Died/Total	34/20082	20/3936	20/1233	27/526	31/295	29/173	39/145	39/94	59/99	83/103	381/26686
30 - 39.9	0.3	1.0	2.5	7.1	11.5	17.5	33.6	47.4	69.2	91.8	2.0
Died/Total	44/16487	33/3412	27/1075	38/536	33/287	28/160	44/131	46/97	63/91	90/98	446/22374
40 - 49.9	0.5	1.3	4.5	10.2	22.9	40.2	39.9	55.8	78.7	86.7	2.8
Died/Total	87/17981	50/3805	55/1214	60/589	74/323	82/204	55/138	43/77	85/108	104/120	695/24559
50 - 59.9	0.9	3.1	10.2	22.0	38.7	52.8	64.6	74.0	83.7	87.7	4.8
Died/Total	143/15287	100/3207	105/1033	103/468	115/297	93/176	82/127	74/100	87/104	93/106	995/20905
60 - 69.9	1.9	6.0	19.3	39.4	55.3	65.6	91.5	90.0	95.1	94.1	7.5
Died/Total	168/8711	115/1904	118/610	122/310	94/170	82/125	65/71	54/60	39/41	48/51	905/12053
70 - 79.9	3.7	14.1	34.9	57.9	77.1	81.4	91.7	84.6	82.9	90.9	12.9
Died/Total	174/4681	151/1068	130/372	124/214	101/131	57/70	44/48	22/26	29/35	30/33	862/6678
80 or Greater	6.0	26.0	60.0	75.2	89.1	95.6	93.2	95.1	94.7	100.0	21.7
Died/Total	176/2949	203/782	180/300	121/161	82/92	65/68	41/44	39/41	36/38	35/35	978/4510
Total	**0.6**	**2.7**	**8.4**	**16.8**	**26.8**	**36.7**	**44.7**	**55.0**	**71.4**	**85.0**	**3.2**
Died/Total	**864/134106**	**699/26359**	**659/7815**	**621/3703**	**561/2093**	**463/1261**	**417/932**	**347/631**	**461/646**	**544/640**	**5636/178186**

Total N= 178,186 (Excluding 25,236 Unknown/Missing)

Source: American Burn Association, National Burn Repository, 2015 Annual Report

TBSA = Total body surface area

For additional information see: American Burn Association
www.ameriburn.org

In conjunction with worker age, predicted body burn percentage from Appendix A can be used to predict worker fatality rates.

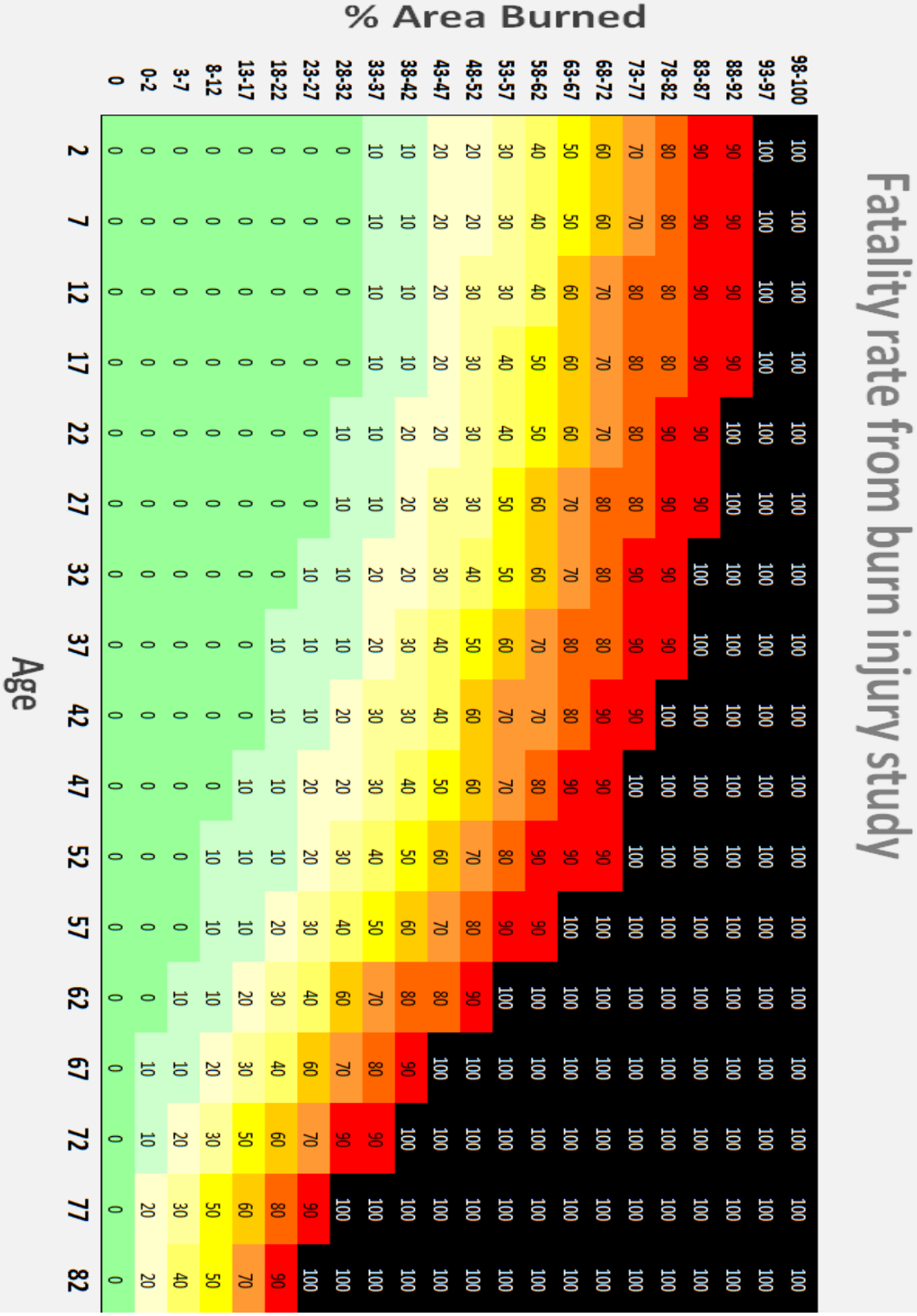


Chart based on data in American Burn Association, National Burn Repository, 2015 Annual Report

APPENDIX C - Fire Intensity Detailed Description

Fire intensity was measured in several excavation scenarios to improve understanding of heat and flame threats. Laboratory burns have decades of experience and consistency using calibrated and traceable heat intensity sensors in a controlled environment. Wind, gas leak rate, excavation geometry, and other variables are not controlled in the field and result in variable thermodynamics compared to the lab environment.

An instrument array was designed and constructed using the same calorimeters used in thermal manikin testing and the same materials of construction. High-temperature fiber epoxy composite was formed to house calorimeters and control boundary conditions for each sensor. Instrument connections were protected inside each device. A 4-inch diameter sphere geometry was chosen with one calorimeter per sphere which allowed mounting on adjustable stands. The system provided adjustment to elevation, orientation, and placement in each excavation scenario identified by AGA S&OH Committee members as most commonly experienced in the industry.

For the testing, un-shored excavations of 4 and 6-feet depth were used as well as a 6-foot shored excavation. To represent typical leakage scenarios, a 7/8" circular hole was tapped near the bottom of a 4" steel gas main operating at 12" water column and a 7/8" diameter hole was tapped near the bottom of a 4" steel main operating at 55 psig. The buried steel lines were exposed and centered in the excavations about 12" above the bottom. Gas flow was controlled remotely through a valve manifold located safely outside the burn area and propane was used to feed a small pilot flame which was used as the ignition source inside the excavation.

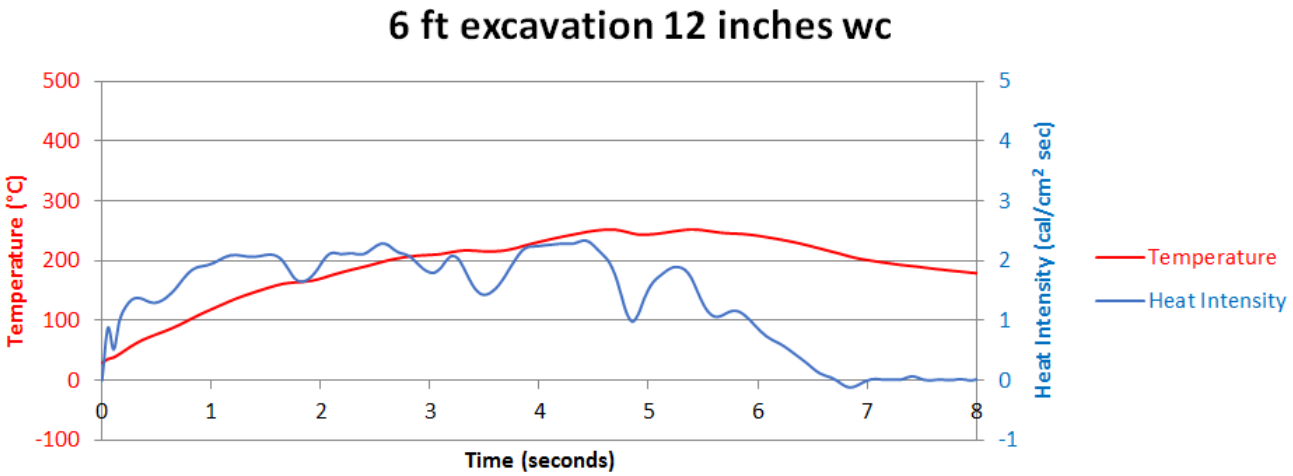
The test procedure began with ignition of the pilot flame followed by introduction of gas flow. Once a combustible mixture of gas and air reached the pilot flame, a fireball ignited, the ignited gas mixture expanded rapidly ("whoosh"), rose up and steady state combustion emanated from the leak source. Upon ignition, a stop watch was used to track time until a signal was given to the valve operator and supply gas was terminated at the time specified for each test. This technique created a clean start and relatively clean end to each event. Use of slow-motion infrared video imagery confirmed the accuracy of the timed tests. For reference, thermal manikin testing performed in controlled laboratory conditions use the same general procedures as ASTM F 1930 test protocol.

Weather conditions were not controlled and over two days of testing ranged from 58-69°F, 41-62% relative humidity (and for a stint, up to 90% RH with light rain), 29.06"-28.49" Hg atmospheric pressure, 0-12 mph wind velocity with direction changes. Most of the weather fluctuations resulted in negligible differences during experiments, however wind did create significant differences. As expected, low or no wind resulted in reasonably consistent ignitions and flame dynamics during steady state burn of natural gas in the excavation. Higher wind conditions resulted in less predictable ignitions, more variable flame dynamics during the burn along with a more rapid release of energy and higher heat intensity.

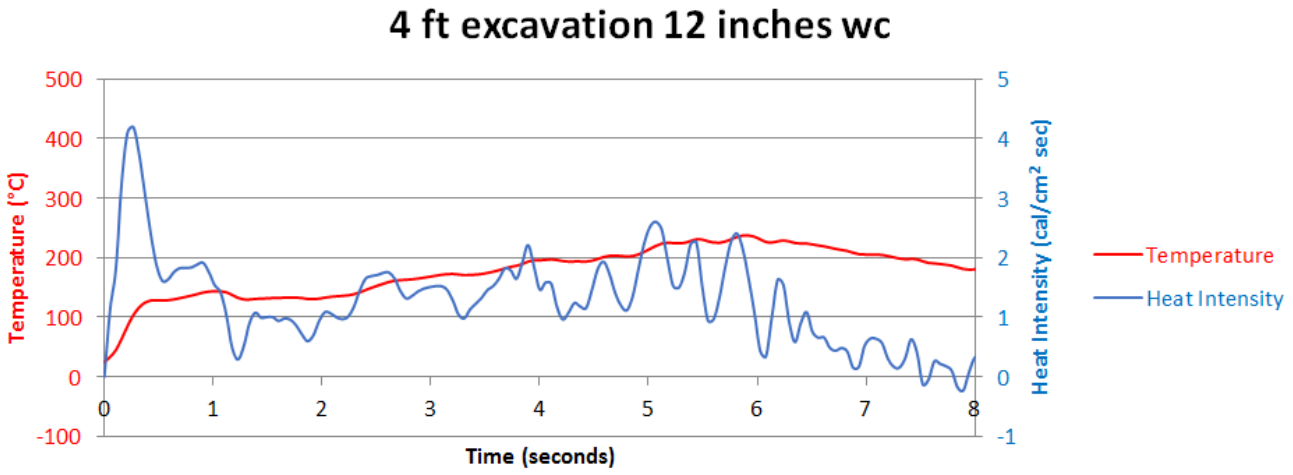
High definition images were captured and videos were filmed to document heat intensity measurements, however some of the fires were difficult to see. Sometimes fire was only apparent by the visual distortion of extremely hot gas rising up through cooler more dense air. An infrared

camera was valuable for identifying boundary and location of heat and flame. For reference, IR systems are commonly available for cell phones which can be used to measure temperatures in a fire. For this testing, a high-resolution FLIR T640 calibrated infrared camera was used.

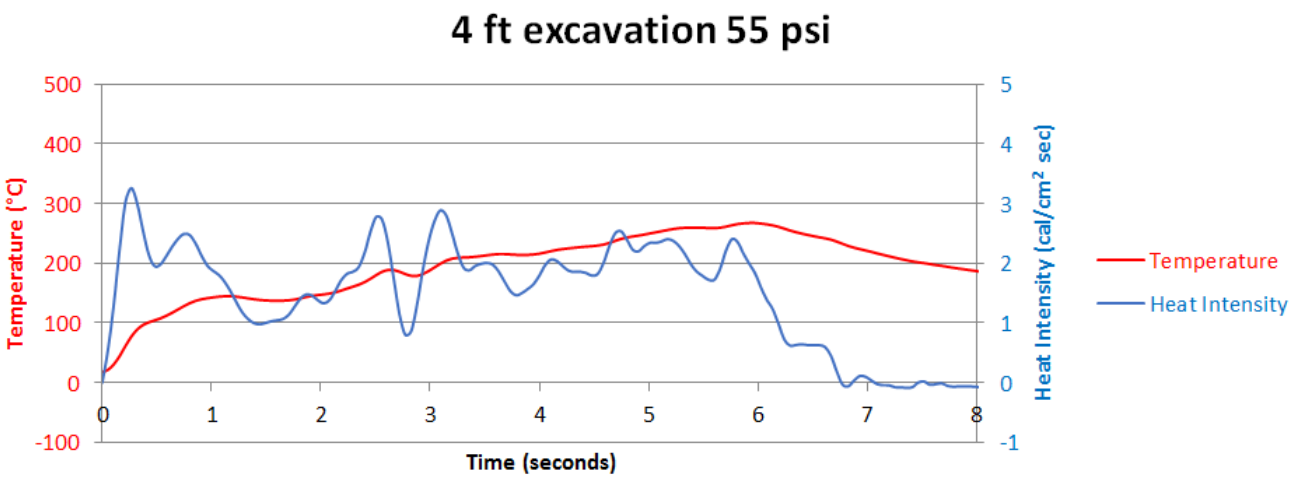
Generally, heat intensity of 2 calories/cm^2-second was measured in regions of fire for 4 and 6-foot excavations with 7/8" leak at 12" of water column gas pressure and 3/8" leak at 55 psig gas pressure. Following are detailed results for each burn scenario:



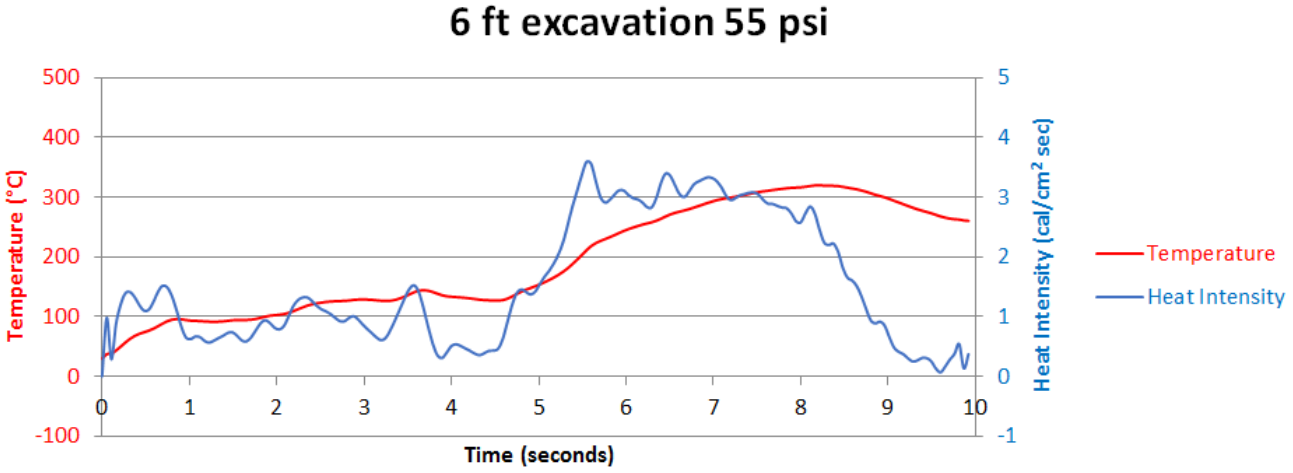
12" water column in the 6' shored excavation used a 7/8" diameter orifice and resulted in 2 calories/cm^2-second heat exposure.



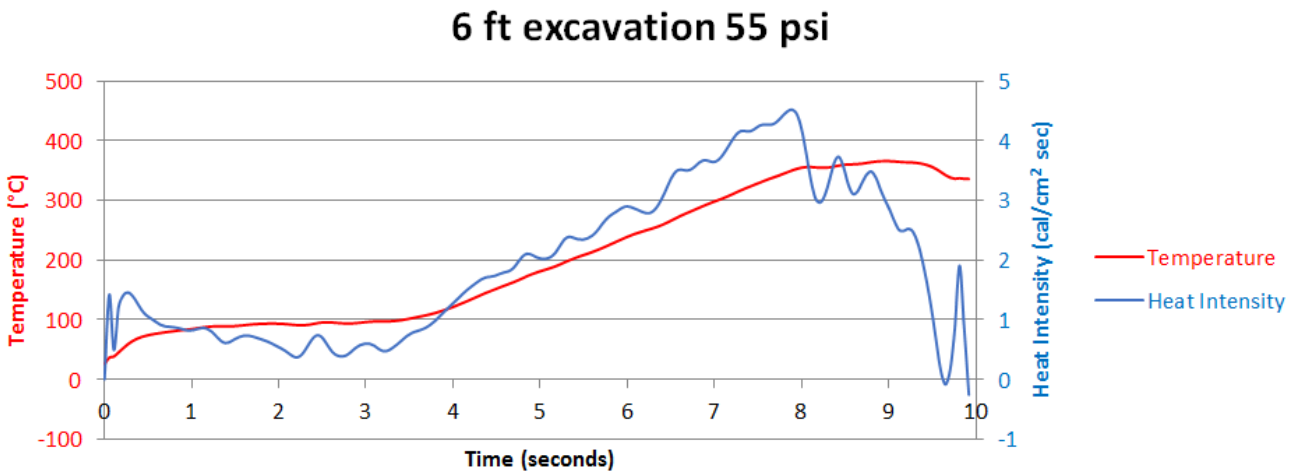
12" water column in the 4' un-shored excavation resulted in average 1.8 calories/cm^2-second heat exposure. Note the greater heat intensity up to 4 calories/cm^2-second captured in this test at the initial onset of ignition. This was the "whoosh" and dependent upon the volume of combustible gas, and the mixture ratio with air.



55 psi pressure in the 4' un-shored excavation resulted in average 2 calories/cm^2-second heat exposure.



55 psig pressure in the 6-foot shored excavation averaged 2 calories/cm^2-second, but heat intensity up to 3 calories/cm^2-second was measured when turbulence from high winds mixed air with natural gas at a rapid rate as occurred in this example when the wind shifted half way through the event.



Heat intensities up to 4 calories/cm^2-second were measured when 55 psi natural gas was mixed with air in turbulent conditions in a jet-like fire, although the average was still 2 calories/cm^2-second.

APPENDIX D – Questar Escape Time Study

Escape Time Study

Completed for the AGA Safety & Occupational Health Committee

Conducted at Questar Gas Company's Operations Training Center
In Coordination with Dupont and Questar Gas Company
August 17 – 18, 2015

Purpose and Scope

- Purpose
  - To better understand possible employee thermal exposures in the event of a fire.
- Scope
  - Establish the time necessary for workers to move a safe distance away from a fire.
  - Four variables:
    - Excavations - A slope, pit, 4’ and 6’ excavation
    - Demographics - 5 different employees
    - PPE - 4 different configurations
    - Effect of welding PPE
    - 510 discrete data points

Sloped Excavation

4’ deep; 1 to 1.5 slope
Assumed Class C soil
Plastic pipe with squeeze
Escape is 10’ circle from pipe

Sloped Excavation - Welder

1 to 1.5 Slope assuming Class C soil
10’ escape line from pipe CL

Pit Excavation

Sand bottom
Vertical concrete walls
44' – 48' deep

4’ Box Excavation

The 4’ excavation testing was intended to simulate a straight wall excavation. A trench box was used to keep the sides from collapsing from repeated test “escapes”.
The trench box did allow some test personnel to shorten their escape time by vaulting out of the excavation.

4 ' depth box and pit
accelerated escape,
no ladder used by
2 of 5 workers
(Welder, low service male)

6’ Box Excavation

The ladder was used by all test subjects

Demographics

- 5 Questar Gas employees:

Demographic	Height	Age	Coveralls Size	Questar Service	Job Function
low service	6' 0"	22	54	2 months	Operator
husky	6' 3"	30	58	6 months	Operator
welder	5' 11"	36	52	15 years	Welder
female	5'4"	36	40	1 year	EHS Coordinator
high service	5' 9"	54	48	34 years	Training Coordinator

All physically fit and capable of test participation.

PPE Variables

Test Garments					
Configuration 1	t-shirt	jeans			hard hat, gloves & ear plugs
Configuration 2	t-shirt	jeans	lightweight coveralls		hard hat, gloves & ear plugs
Configuration 3	t-shirt	jeans	heavyweight coveralls		hard hat, gloves & ear plugs
Configuration 4	t-shirt	jeans	heavyweight coveralls	baladava, full face respirator & supplied air	gloves & ear plugs
Welding configuration	t-shirt	jeans	welders hood & ppe	pancake visor, welding gloves, cap	ear plugs

All configurations tested with a hi-vis mesh vest (Questar standard).
T-shirt / jeans base layer representing lightweight single layer.
"lightweight coveralls" – 6 oz/yd2 standard coveralls.
"heavyweight coveralls" – 7 oz/yd2 standard coveralls with 10 oz/yd2 quilting.

Single Layer Testing

Lightweight Coveralls

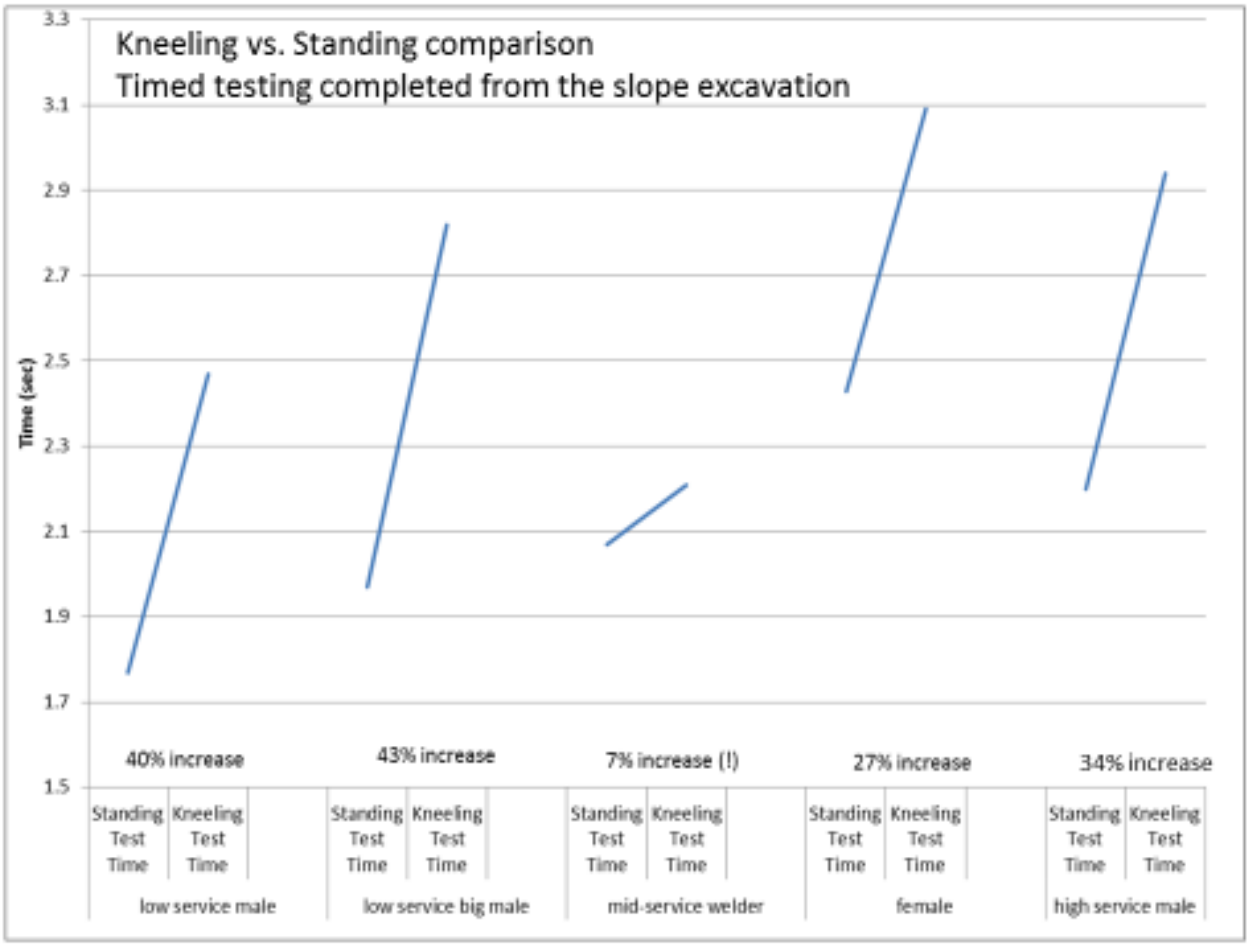
Heavyweight Coveralls

Heavyweight with supplied air

With Welding PPE

How The Testing Was Done

Escape Time Testing Conditions
1 - Test starting condition: Volunteer on one knee working with a squeeze or simulated welding.
2 - "Escape" initiated by voice command "GO", timed with stopwatch to nearest 1/100 second
3 - "Escape" concluded when the volunteer crossed a point 10' from the pipe centerline
4 - The volunteers had the freedom to choose how and in what direction they escaped.
5 - Each escape time determination repeated 5 times per test condition

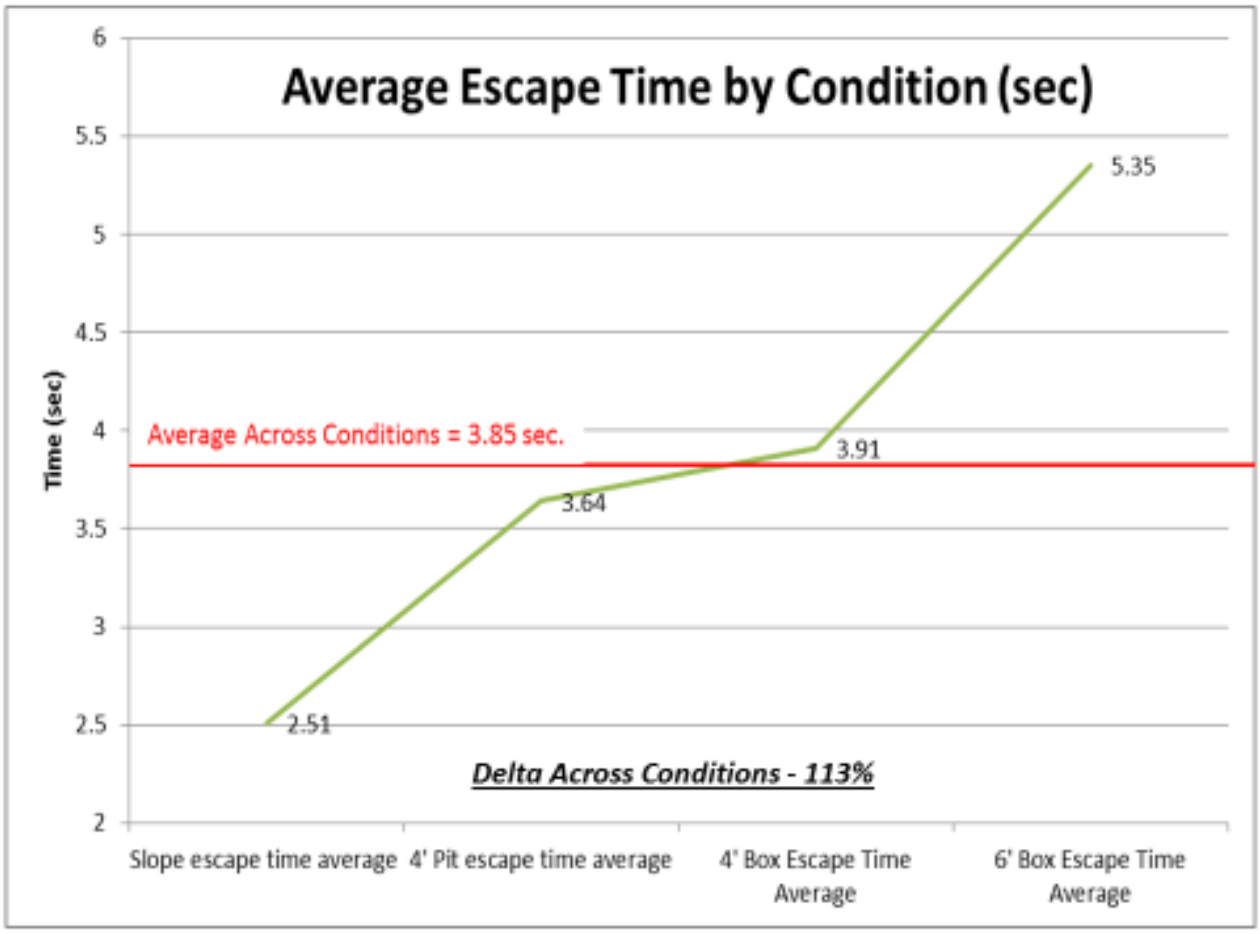

Kneeling vs. Standing comparison
Timed testing completed from the slope excavation
Time (sec)
3.3
3.1
2.9
2.7
2.5
2.3
2.1
1.9
1.7
1.5
40% increase
43% increase
7% increase (!)
27% increase
34% increase
Standing Test Time
Kneeling Test Time
low service male
low service big male
mid-service welder
female
high service male

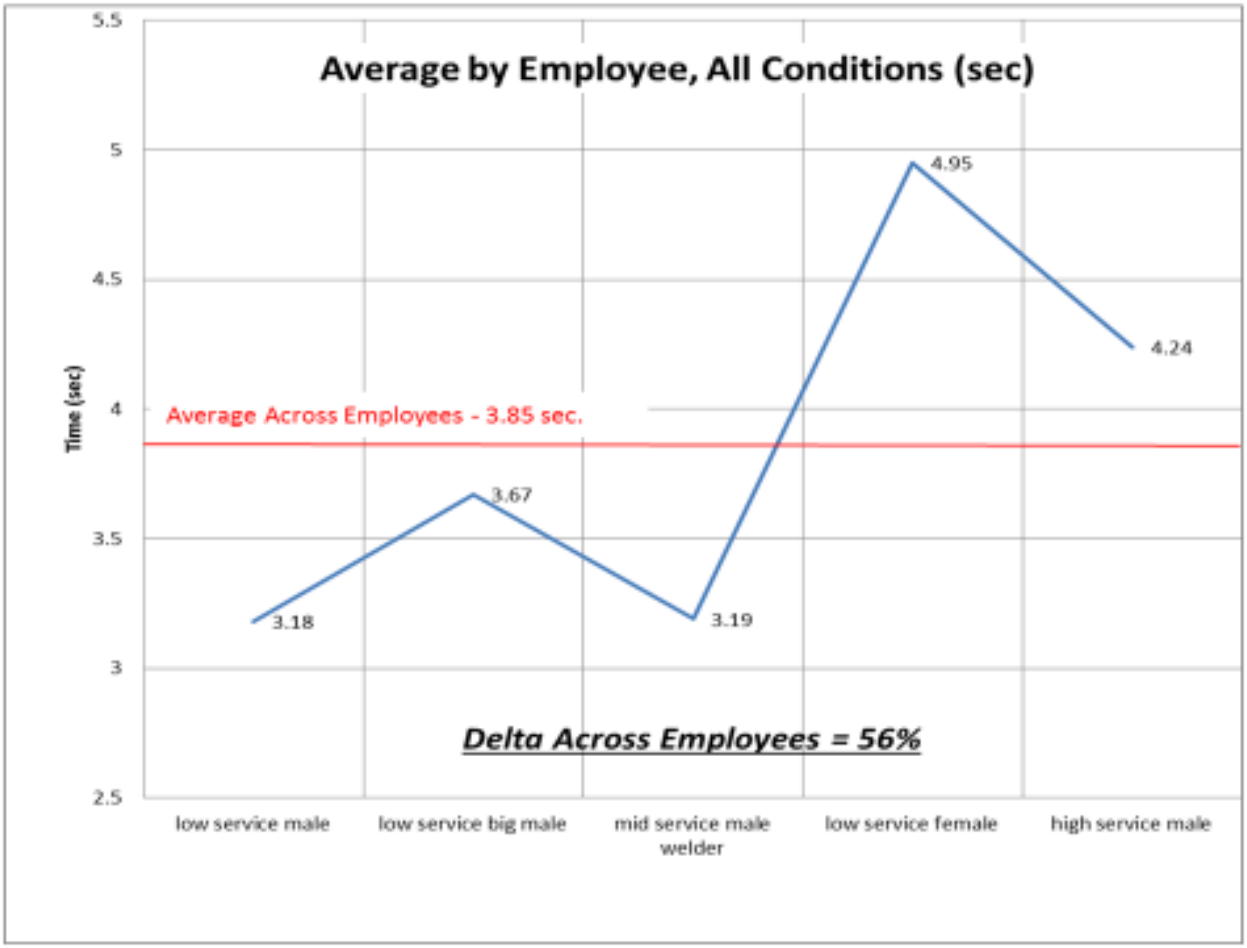
Overarching Result

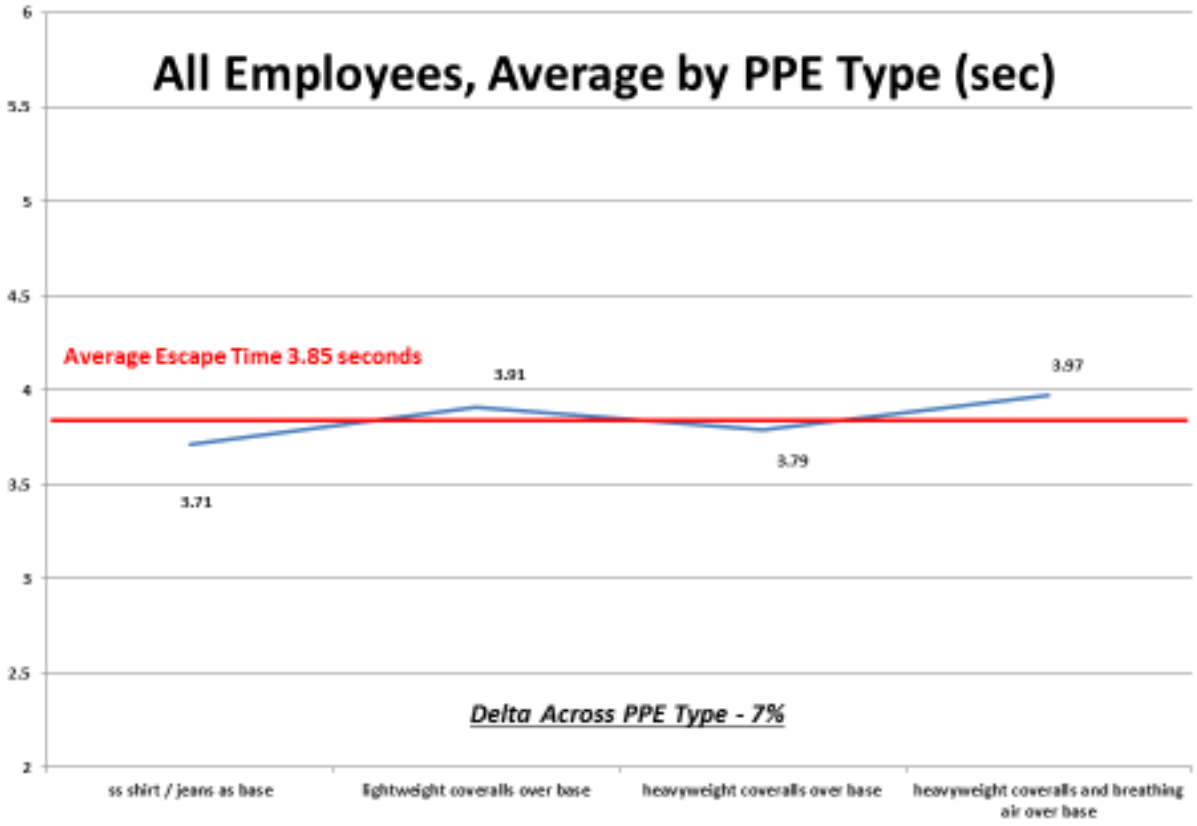
- The master average escape time across all conditions, demographics and PPE levels was 3.85 seconds.
- This testing confirmed the previous escape time research conducted by other AGA member companies, Xcel Energy and NW Natural come immediately to mind.
- The 3.85 second average escape time represents aware and involved employees and does not include a safety factor nor does it account for specific job and personnel differences.

Summary and Conclusions

- Escape times vary significantly by age, gender and excavation depth.
- Something as simple as missing a ladder step adds between 0.6 and 1 second to the escape time.
- Escape time is not affected by the weight of the PPE being worn.
- Although the welding PPE had only a marginal effect on escape time the testing did not account for a laying position while welding or a possible delay in becoming aware of fire due to shaded lens.


Average Escape Time by Condition (sec)
Time (sec)
6
5.5
5
4.5
4
3.5
3
2.5
2
Average Across Conditions = 3.85 sec.
2.51
3.64
3.91
5.35
Delta Across Conditions - 113%
Slope escape time average
4' Pit escape time average
4' Box Escape Time Average
6' Box Escape Time Average


Average by Employee, All Conditions (sec)
Time (sec)
5.5
5
4.5
4
3.5
3
2.5
Average Across Employees - 3.85 sec.
3.18
3.67
3.19
4.95
4.24
Delta Across Employees = 56%
low service male
low service big male
mid service male welder
low service female
high service male


All Employees, Average by PPE Type (sec)
6
5.5
5
4.5
4
3.5
3
2.5
2
Average Escape Time 3.85 seconds
3.71
3.91
3.79
3.97
Delta Across PPE Type - 7%
ss shirt / jeans as base
lightweight coveralls over base
heavyweight coveralls over base
heavyweight coveralls and breathing air over base