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16. Abstract

In July 2012 the Moving Ahead for Progress in the 21st Century (MAP-21) Act was enacted, which instructed NHTSA to research the most prevalent causes of motorcoach fires and methods to prevent them, both inside and on the exterior of the vehicles. Southwest Research Institute was contracted to develop test procedures and performance criteria to assess fire detection and suppression for engine compartment fires and fire detection in wheel wells. SwRI was also tasked to develop a bench scale test to evaluate the performance of exterior fire-hardening materials. The goal of this program was to develop and validate procedures and metrics to evaluate current and future detection, suppression, and exterior fire-hardening technologies that prevent or delay fire penetration into the passenger compartment of a motorcoach, in order to increase passenger evacuation time.

Objective tests, methods, and metrics were developed for analyzing wheel well detection/warning systems, engine compartment detection and suppression/extinguishment systems, and flammability/fire-hardening of exterior materials between the wheel well and the passenger compartment. A literature review and characterization of the thermal environment of motorcoach fires and survey of engine compartments, firewalls, and wheel wells of motorcoaches currently in North American service began. These characterizations assisted in the development of test methods and identification of the metrics for analysis. Test fixtures were designed and fabricated to simulate a representative engine compartment and wheel well. Fire scenarios were developed, the current detection, suppression, and fire-hardening technologies were reviewed, and a sample set selected to validate the test procedures developed during this program. Based on the results, test methods and metrics were developed to evaluate wheel well warning systems, engine compartment detection and suppression systems, and fire-hardening systems.

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EXECUTIVE SUMMARY

The National Highway Traffic Safety Administration awarded a contract to Southwest Research Institute (SwRI) to conduct research and testing in accordance with Solicitation No. DTNH22-12-R-00574. The goal of this program was to develop and validate procedures and metrics to evaluate current and future detection, suppression, and exterior fire-hardening technologies that prevent or delay fire penetration into the passenger compartment of a motorcoach, in order to increase passenger evacuation time. In 2007, NHTSA published a comprehensive plan to assess motorcoach safety in several areas to improve occupant protection, including evaluation of fire protection technologies. The same year, the National Transportation Safety Board (NTSB) made recommendations to NHTSA related to motorcoach fire safety, stemming from their investigation of the 2005 Wilmer, Texas, motorcoach fire that resulted in 23 fatalities. In 2008, NHTSA initiated research at the National Institute of Standards and Technology (NIST) to understand the development of motorcoach fires, assess tenability within the occupant compartment, identify bench-scale flammability tests, and determine feasibility of requirements for fire-hardening of exterior components. In 2009, DOT published the department-wide Motorcoach Safety Action Plan which directed multiple agencies to pursue an integrated approach to enhance motorcoach safety, including fire safety.

This research is a follow-on to the NIST research program, and is responsive to the requirement at Section 32704(a) of the Moving Ahead for Progress in the 21st Century Act (MAP-21),[1] that NHTSA[2] conduct research to assess the most prevalent causes of motorcoach fire, and the best methods to prevent such fires, and mitigate the damage from them. As specified in the solicitation, objective tests, methods, and metrics were developed for analyzing wheel well detection/warning systems (Topic 1), engine compartment detection and suppression/extinguishment systems (Topic 2), and flammability/fire-hardening of exterior materials and the bulkhead (firewall) between the engine compartment and the passenger compartment (Topic 3).

The program was initiated with a literature review and characterization of the thermal environment of motorcoach fires and survey of engine compartments, firewalls, and wheel wells of motorcoaches currently in North American service. These characterizations assisted in the development of test methods and identification of the metrics for analysis.

Test fixtures were designed and fabricated to simulate a representative engine compartment and wheel well. Fire scenarios were developed for each fixture, the current detection, suppression, and fire-hardening technologies were reviewed and a sample set selected to validate the test procedures developed during this program. Based on the results of testing and feedback from stakeholders, test methods and metrics were developed for evaluating wheel well warning systems, engine compartment detection and suppression systems, and fire-hardening systems. Detailed program conclusions and

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[1] Public Law 112-141 (July 6, 2012)

[2] MAP-21 directs the Secretary of Transportation to conduct this research. This authority has been delegated the the NHTSA Administrator.

recommendations for areas of interest for further research and testing are also discussed. A brief summary of the project conclusions are as follows.

Engine Compartment

The following conclusions can be made about the engine compartment test procedure and fixture used to evaluate detection and suppression systems.

- The SwRI team designed, fabricated, and commissioned a simulated motorcoach engine compartment fixture. It is representative of the motorcoaches currently sold in the United States.. It is larger than those used typically in Europe, but has comparable air flow.
- The fixture contains a substantial amount of obstructions to simulate the major components (including the engine) and various hoses, pipes, and electrical wires.
- Criteria are proposed for successfully completing this series of 12 engine compartment fire tests.

Wheel Well

The following conclusions can be made about the wheel well test procedure and fixture used to evaluate hot wheel early warning devices.

- The SwRI wheel well test fixture uses a dragging brake to add heat into the wheel assembly. It is capable of raising both rotating and stationary parts of the wheel assembly to very high temperatures.
- There are several commercially available tire pressure monitoring systems (TPMS) that are capable of detecting a hot wheel and alerting the driver before the tire catches fire. Most motorcoach OEMs that sell in the United States are now installing TPMS as optional or standard equipment.
- There are several locations where a simple thermocouple sensor on a stationary component can detect a hot wheel far in advance of a tire fire. But this solution does not provide high or low tire pressure warnings.
- It is important to train drivers to rapidly stop the motorcoach after receiving a hot wheel warning.

Fire Hardening

The following conclusions can be made about the fire hardening test procedures used to evaluate fire hardening materials.

- A relationship seems to exist between time to flame penetration into the passenger compartment in full-scale tests conducted by the National Institute of Standards and Technology (NIST) and data gathered in a bench-scale (Cone Calorimeter) and intermediate-scale (Parallel Panel) test apparatus.
- A screening heat release rate value of 200 kW or 200 kW/m^2 can be used to indicate a potential propagating or non-propagating fire hardening material in the Parallel Panel or Cone Calorimeter test apparatus, respectively.

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1.0 INTRODUCTION

Southwest Research Institute (SwRI) was awarded the contract under the National Highway Traffic Safety Administration solicitation number DTNH22-12-R-00574, dated June 29, 2012, for Motorcoach Fire Safety Research. This program was conducted by the Fire Technology Department (FTD) in the Chemistry and Chemical Engineering Division, and the Engine and Vehicle Research and Development Department in the Engine, Emissions, and Vehicle Research Division.

In addition, SwRI assembled a team of subject matter experts to assist in the development and review of the test procedures created during this program. These experts have a breadth of knowledge in all aspects of fire hazard assessment and safety of road transportation vehicles.

The following sections discuss the program objectives and goals, findings from the literature review and interaction with industry stakeholders throughout the program, development and fabrication of the test fixtures, development of test procedures, and results from vendor testing. Program conclusions and recommendations for areas of further research and testing are discussed.

2.0 PROGRAM OVERVIEW

The goal of this program was to develop and validate procedures and metrics to evaluate current and future detection, suppression, and exterior fire-hardening technologies that prevent or delay fire penetration into the passenger compartment of a motorcoach, in order to increase passenger evacuation time. As requested in the solicitation, objective tests, methods, and metrics were developed for analyzing wheel well detection/warning systems (Topic 1), engine compartment detection and suppression/extinguishment systems (Topic 2), and flammability/fire-hardening of exterior materials between the wheel well and engine compartment and the passenger compartment (Topic 3).

This report summarizes tasks performed in the design and fabrication of the test fixtures, development of test procedures, representative detection/warning/suppression/fire-hardening supplier testing, and conclusions and recommendations for further areas of interest.

3.0 BACKGROUND

The following sub-sections provide additional background to the current project.

3.1 Background

NHTSA has been conducting flammability and fire protection assessment of motorcoaches and motorcoach materials since 2008, in accordance with agency and departmental plans and NTSB recommendations. In addition, the Motorcoach Enhanced Safety Act of 2012, which is part of the Moving Ahead for Progress in the 21st Century Act (MAP-21),[3] calls for research and testing to improve fire safety through evaluation of flammability criteria for exterior components of motorcoaches, smoke suppression, prevention of and resistance to wheel well fires to mitigate propagation into the passenger compartment, and evaluation of automatic suppression systems.[4]

In response to this statutory requirement, NHTSA has funded research to develop test apparatuses and test procedures to evaluate candidate fire detection and

[3] Public Law 112-141 (July 6, 2012)

[4] Section 32704(a).

suppression systems for motorcoach engine compartments, and hot wheel warning systems to prevent tire fires in the wheel well.

Additionally, the Department of Transportation Motorcoach Safety Action Plan of 2009 includes research on motorcoach occupant protection related to fire safety. Accordingly, NHTSA is evaluating the feasibility of more-stringent flammability requirements for interior and exterior materials, and the need for regulations requiring installation of fire detection and protection systems.

3.2 Literature Review

Motorcoach fires without injury are fairly common. However, in 2005 a motorcoach that was transporting assisted living facility residents in the Hurricane Rita evacuation effort caught fire, killing 23 of the elderly occupants of the vehicle. This event was documented in a highway accident report by the National Transportation Safety Board (NTSB) [1].

Estimates range from 160 reported motorcoach fires to 2,200 total bus fires per year in the United States. The majority of these fires start outside the occupant compartment, in the wheel well or engine compartment, as shown in Figure 1. The components that have been identified to be the most common ignition points are the brakes, turbochargers, tires, electrical sources, and wheel/hub bearings [2].

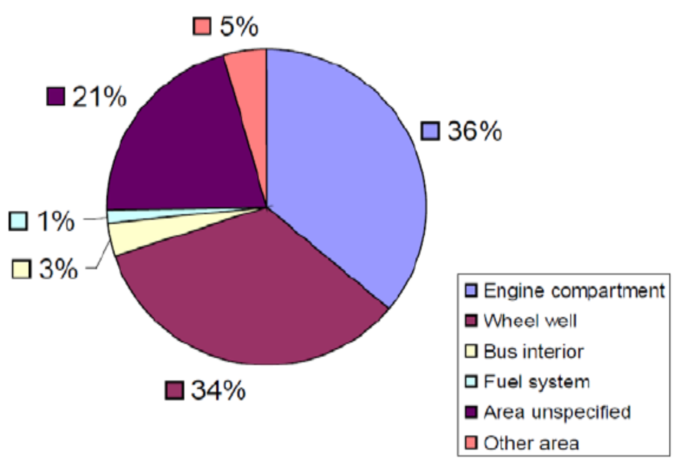


Figure 1. Percentage of Motorcoach Fire Records by Fire Origin Location, (2004-2006) [2].

In 2009 NHTSA funded the National Institute of Standards Technology (NIST), Building and Fire Research Laboratory (BFRL) to conduct research to:

1. Understand the development of motorcoach fires and its subsequent spread into the passenger compartment,
2. Evaluate and identify bench-scale material flammability test methods,
3. Test the effectiveness of fire hardening of motorcoach exterior components around the wheel well, and
4. Assess tenability within the passenger compartment in the event of a wheel-well fire.

Conclusions from the NIST assessment were [3]:

1. Materials designed to meet FMVSS 302, Flammability of Interior Materials, do not meet the more stringent Federal Aviation Administration (FAA) and Federal Rail Administration (FRA) requirements (i.e., vertical burn rate, heat release, smoke density, etc.).
2. Fire-hardening to isolate a tire fire from surrounding combustible materials delayed fire spread.
3. The time from fire penetration to untenable conditions in the vehicle interior was from 5 to 9 min.

There has been prior research focused on the development of test procedures to evaluate engine compartment detection and suppression systems.

Kidde has published research on development of a standard test for transit vehicle (motorcoach) extinguishing (suppression) systems [4] and in comparing various fire detection systems for engine compartment fires [5]. At the 2006 SAE Congress there was a session devoted to fire suppression research needs, which was summarized by Hamins [6].

SP Technical Research Institute of Sweden has published several reports [7-10] on this research topic and has also developed a standard test methodology [11] for evaluating suppression systems installed in a motorcoach engine compartment.

3.3 Research Objectives

The major objectives of this research project were the following:

1. Develop a test fixture and test procedures for evaluating fire detection and fire suppression systems for motorcoach engine compartments.
2. Develop a test fixture and test procedures for evaluating tire fire warning systems for motorcoach wheel well areas.

The secondary objective of the current research project was to further investigate the topic of fire hardening of a motorcoach and propose a standard test method that would be useful to compare potential fire hardening materials for this purpose.

4.0 ENGINE COMPARTMENT AND WHEEL WELL CHARACTERIZATION

The purpose of this task was to characterize several typical engine compartments and wheel wells from current model year motorcoaches. The intent was to allow for a realistic development of an engine compartment and wheel well test mockup consistent with actual designs currently being sold in the United States.. In February of 2013, representatives of the SwRI Project Team conducted on-site surveys at three OEM maintenance facilities to document the engine compartments and wheel wells of 2013 model year motorcoaches by gathering photographs and measurements, and documenting locations of system components and combustibles.

The developed mockups will not necessarily be applicable to all designs, shapes, and sizes of engine compartments and/or wheel wells. However, it should allow comparison with other test beds and an evaluation of the applicability of these other test beds to the motorcoach compartments currently being sold in the US.

4.1 Wheel Well Characterization

During the motorcoach survey, the wheel well area was inspected for each motorcoach OEM. Photographs and measurements of these areas were documented, and analyzed in greater detail between motorcoaches to further determine the impact on the wheel well test fixture. In general, the wheel well areas were very similar between motorcoaches, as compared to the engine compartments. In this regard, the task of developing a representative test fixture for wheel well warning system evaluation is more straightforward than for engine compartments. Figure 2 – Figure 4 provides photographs of the three OEM wheel well areas.

Figure 2. Photograph of Motorcoach A Wheel Well.

Figure 3. Photograph of Motorcoach B Wheel Well (without fender side panel).

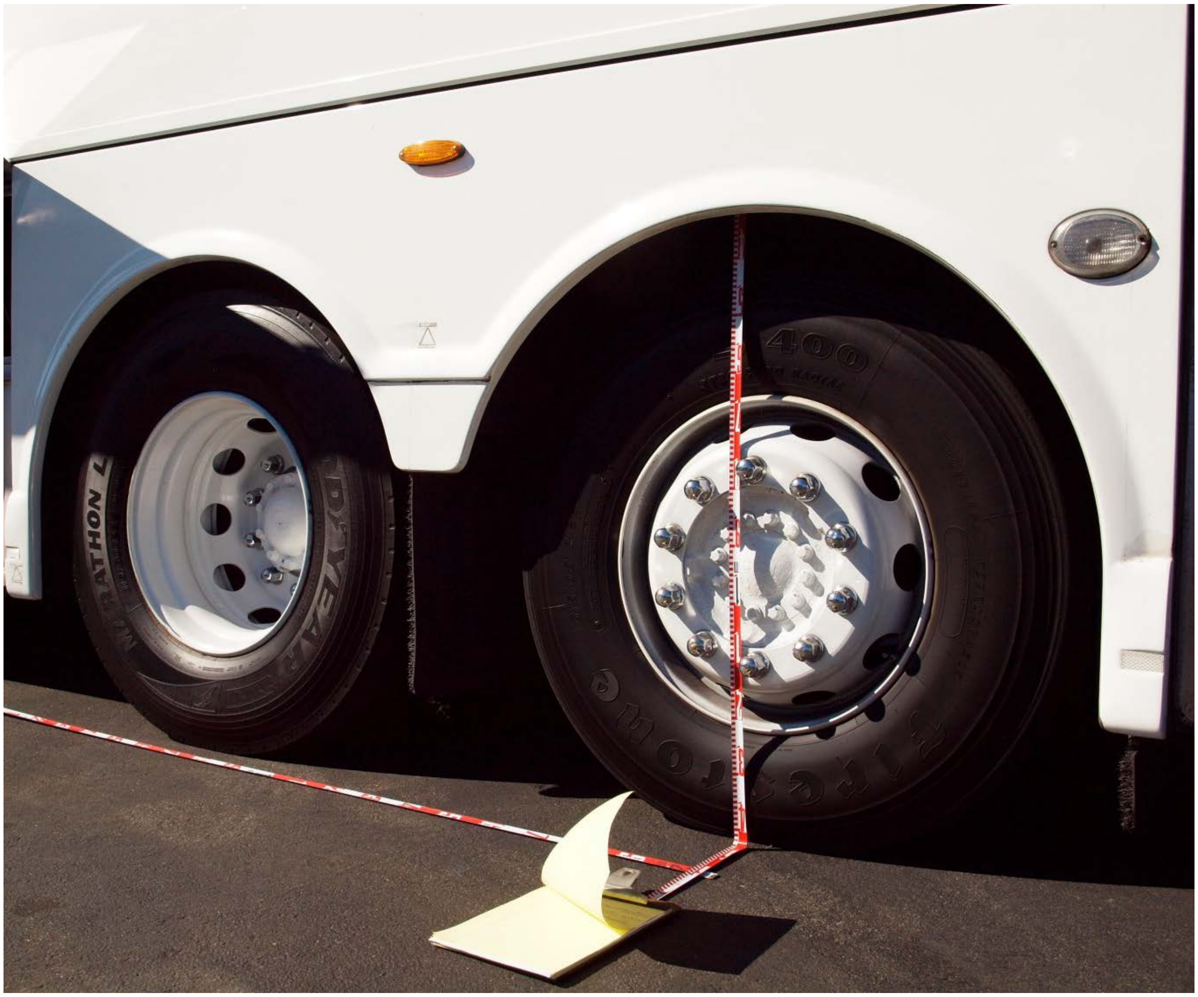


Figure 4. Photograph of Motorcoach C Wheel Well.

4.2 Engine Compartment Characterization

As a result of the survey of motorcoaches work, a few major observations can be made. The largest components of a typical motorcoach engine compartment were noted and Table 1 provides a summary of where several of the major components in the engine compartment are located. Figure 5 – Figure 7 shows a photograph of each motorcoach engine compartment surveyed (view from rear of coach).

It can be observed that the motorcoaches surveyed as part of this project all had engine compartments sizes greater than the range specified in the SP Technical Research Institute of Sweden method - SP 4912. The motorcoaches surveyed had gross volume estimates of 6-9 m^3 and the gross volume range found in SP 4912 is 2–6 m^3. The SP survey included European transit buses in addition to European motorcoaches.

Table 1. Summary of Location of Major Engine Compartment Components

Component Description	Motorcoach A	Motorcoach B	Motorcoach C
Engine assembly	Middle	Middle	Middle
Two coolers and fan	Left	Left	Left
Air filter (vertical/horizontal)	Top - middle	Top - right	Middle – Left
Lavatory equipment	Right	Right	Right
Emissions control (vertical/horizontal)	Lower Left	Middle Left	Top Left
A/C Compressor	Lower right	Lower right	Lower right
Turbo	Left side of engine	Left side of engine	Left side of engine
Surge tank – engine coolant	Above engine cooler	Above engine cooler	Above engine cooler
Alternators	Left side	Left side	Right side

Figure 5. Photograph of Motorcoach A with Gross Volume of 7.4 m^3.

Figure 6. Photograph of Motorcoach B with Gross Volume of 6.3 m^3.

Figure 7. Photograph of Motorcoach C with Gross Volume of 8.7 m^3.

Based on the survey task, three-dimensional models of each motorcoach were developed so that they could be overlaid and compared and contrasted. Figure 8 – Figure 10 show each of these motorcoach representations and provide size comparisons to the SP mockup (white outlines). Based on these models, a single representative model was created, which is shown in Figure 11.

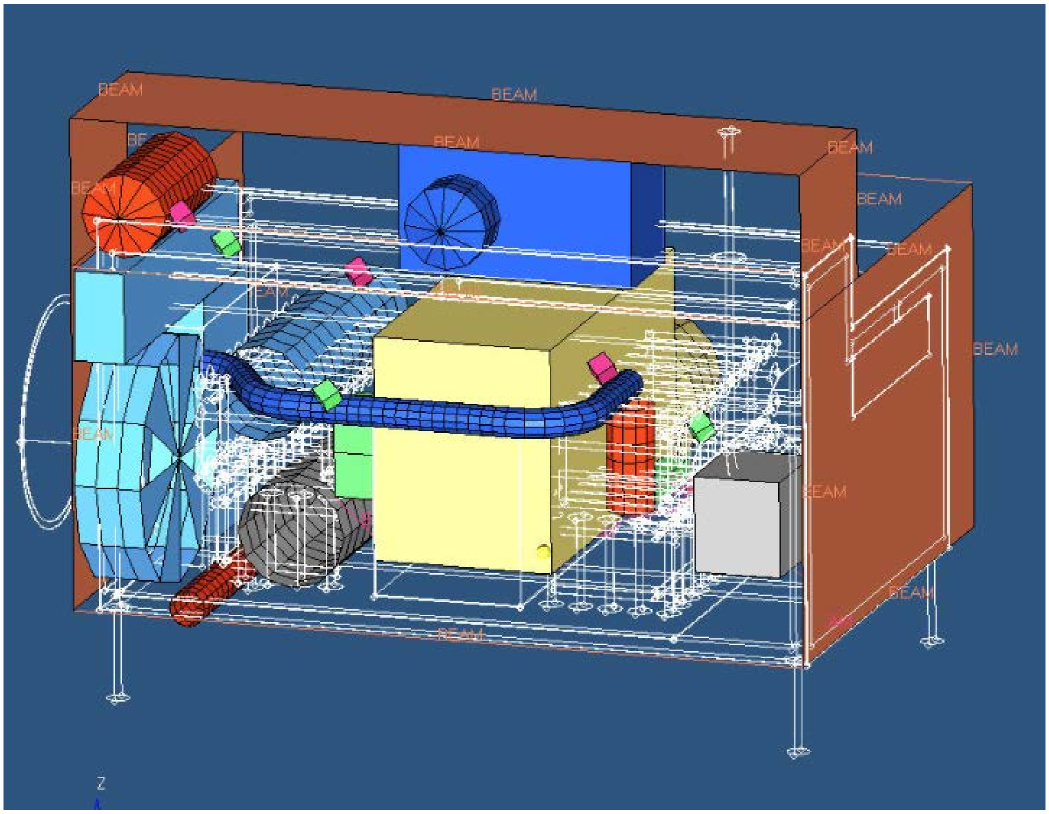


Figure 8. 3-D Model of Motorcoach A Engine Compartment.

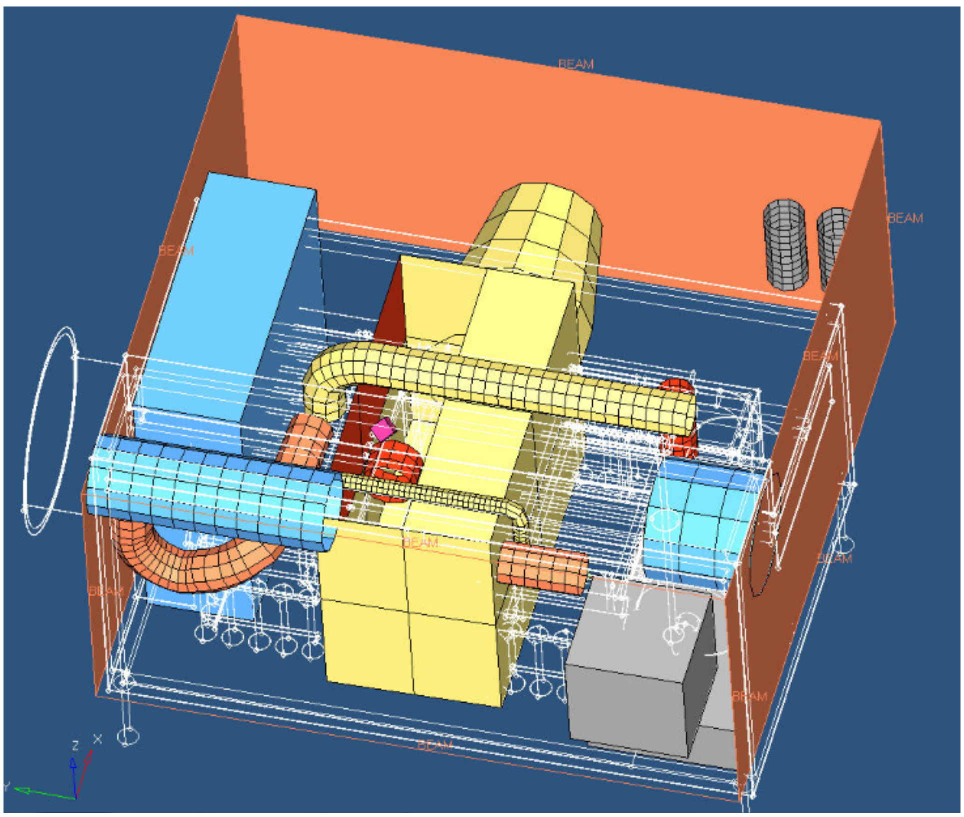


Figure 9. 3-D Model of Motorcoach B Engine Compartment.

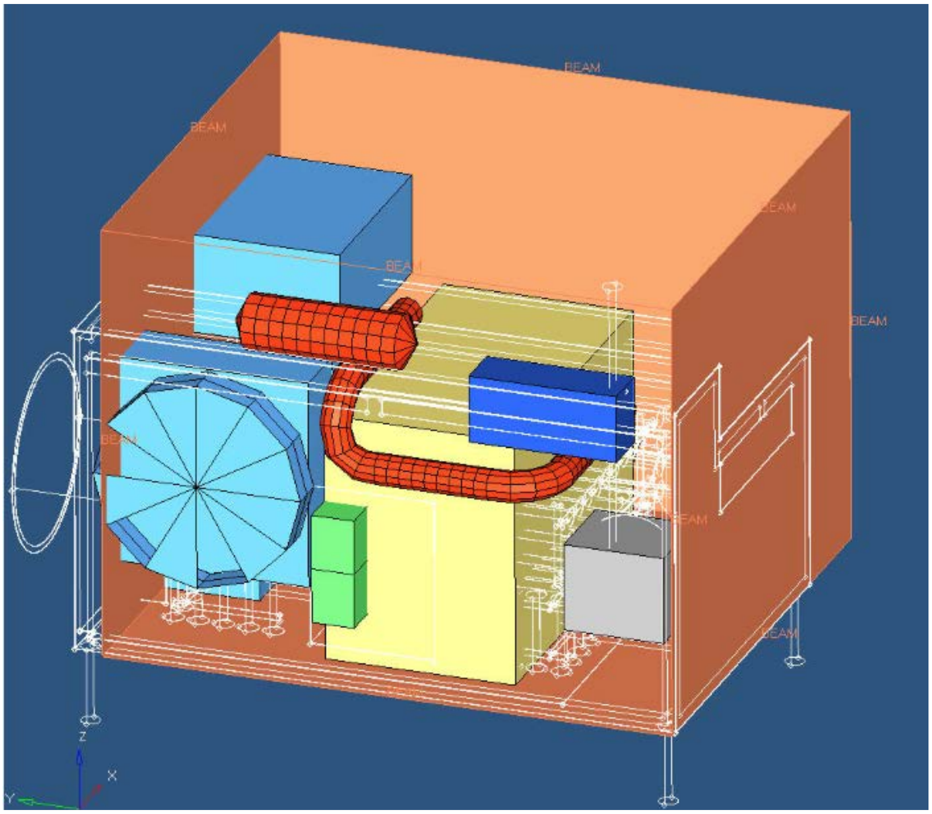


Figure 10. 3-D Model of Motorcoach C Engine Compartment.

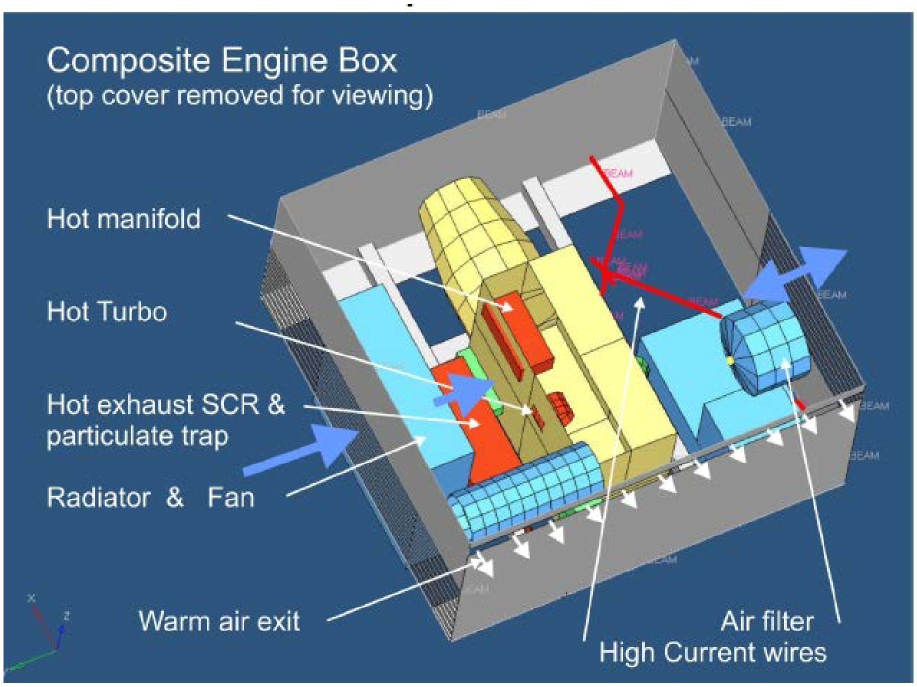


Figure 11. 3-D Model of Representative Motorcoach Engine Compartment.

5.0 ENGINE COMPARTMENT FINAL DESIGN, FIRE SCENARIO DEVELOPMENT AND TESTING

5.1 Engine Compartment Final Test Fixture Design

The average model depicted in Figure 11 was then adapted into a final test fixture design. Two views of this test fixture are shown in Figure 12 and Figure 13.

Appendix B provides detailed drawings of the engine compartment test fixture. The racks of cylindrical and rectangular obstructions colored white/silver in these figures represent clutter in the engine compartment and also are used to support and obstruct ignition sources and to provide secondary combustibles that will be utilized for a given fire scenario.

5.2 Engine Compartment Ventilation

The specifications for the fan, which provides the airflow through the test fixture, were derived from several discussions with motorcoach OEMs, during which they shared detailed information about the airflow through their compartment based both on proprietary experimental measurements and CFD calculations.

It was also determined through these meetings that most of the driving time correlates to a condition when the fan is not operating and there is minimal airflow throughout the engine compartment. In addition, the second most common condition is when the fan is at some intermediate speed, which corresponds to a volumetric flow of approximately 4.2 m^3/s (8,833 CFM) at no static back pressure. Based on this information, it is recommended in the draft test procedures and relevant fire scenarios that two ventilation conditions be represented (fan off and fan at a typical intermediate operating speed).

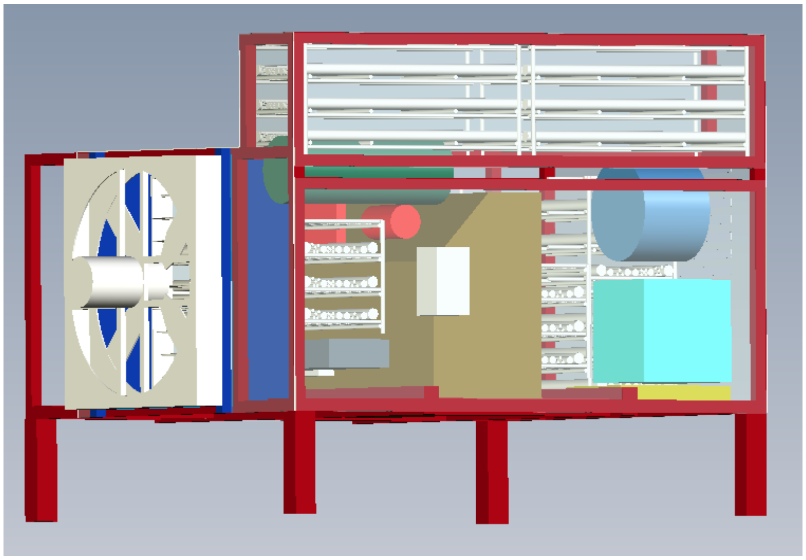


Figure 12. Engine Compartment Mockup Test Fixture Design (View from Rear Driver's Side Corner).

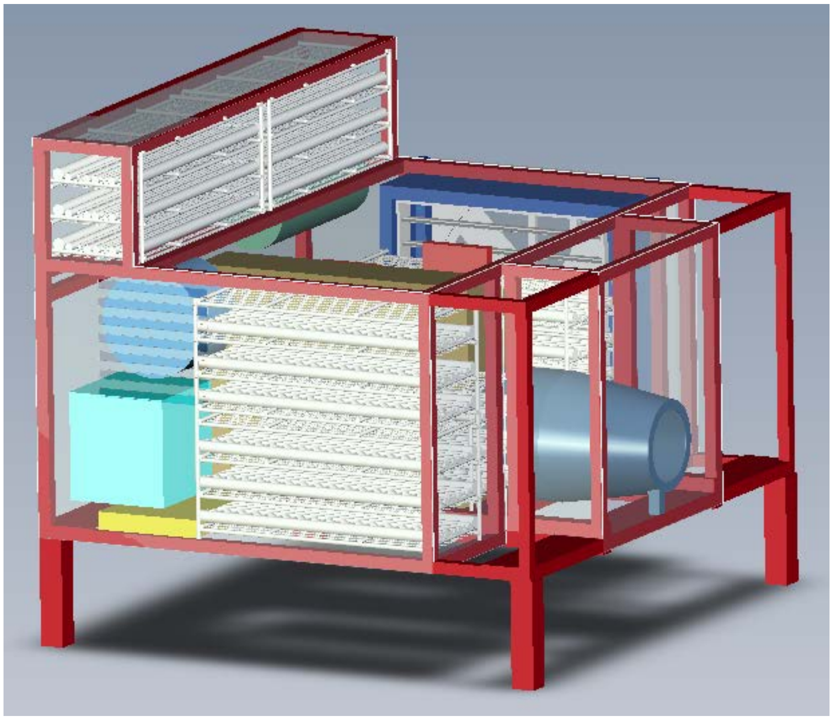


Figure 13. Engine Compartment Mockup Test Fixture Design (View from Front Passenger Side Corner).

In addition to the airflow capacity in the engine compartment, it was also determined that there were two typical airflow designs employed in the engine compartment. In one design, the compartment exhausted most of the airflow through the floor of the compartment, which is about 40–50% open, because of the obstructions such as the emissions control equipment, the engine block, and the lavatory holding tank. In the other design, the floor of the compartment is less open and the fan exhaust airflow is directed to the passenger side louvers, louvers in the rear door, and the floor.

In the final fixture design, it is recommended to represent a worst case condition for detection and suppression systems by combining these two air flow designs and selecting the most open compartment, which will challenge the detection and suppression systems more rigorously. Therefore, the final test fixture design considers a mostly open floor and open passive ventilation vents on the passenger side and rear door.

Figure 14 provides a characterization of the air speed (m/s) from the fan measured between the fan shroud and the louver that simulates the interior edge of the radiator. Figure 15 provides a characterization of the air speed from the fan measured between the louver and the hot side (left as viewed from rear) clutter racks.

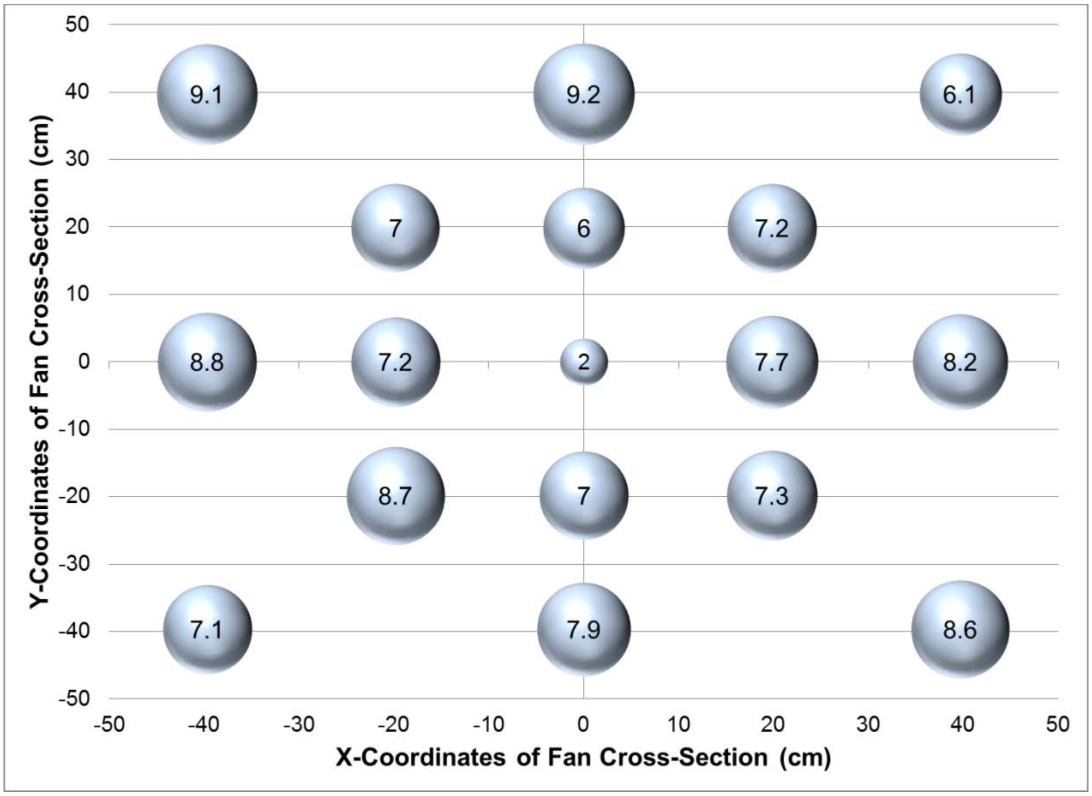


Figure 14. Engine Compartment Ventilation (Between Fan and Louver).

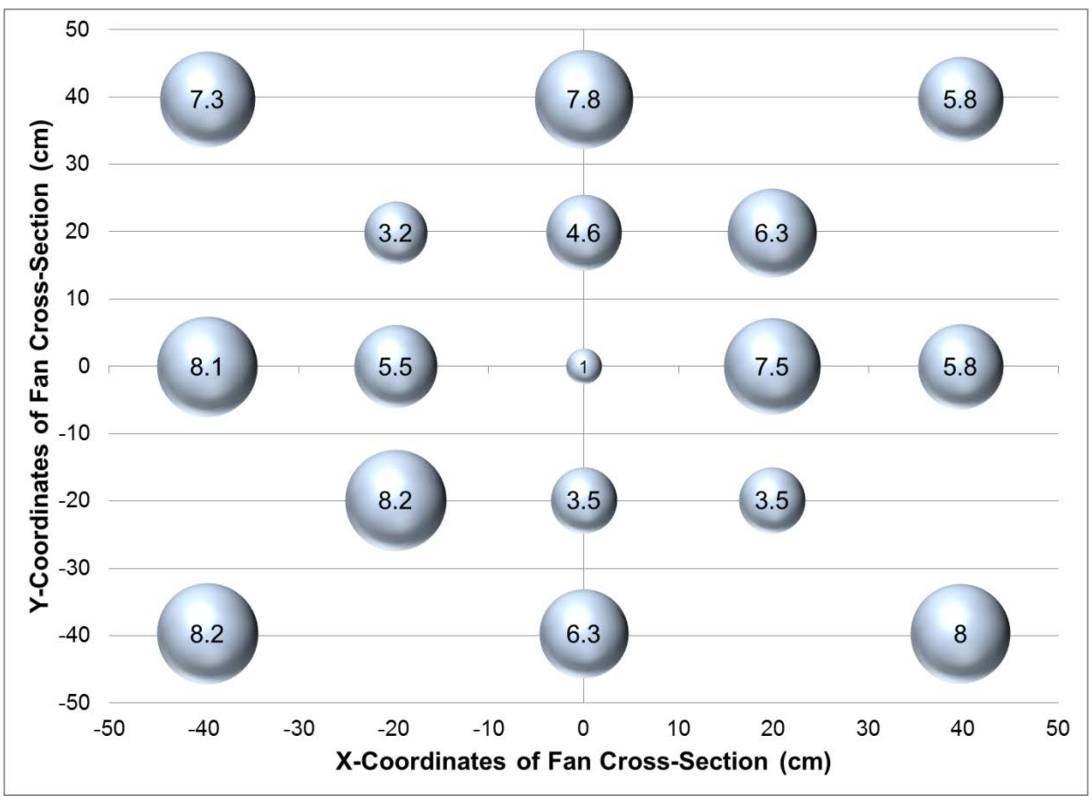


Figure 15. Engine Compartment Ventilation (Between Louver and Hot Side Clutter).

The average air speed and volumetric flow across the fan area between the fan and louver is 7.4 m/s and 3.6 m^3/s, respectively. The average air speed and volumetric flow across the fan area between the louver and hot side engine clutter is 5.9 m/s and 2.9 m^3/s, respectively. Air speed was also measured at each fire source location and this data will presented in Section 5.5 of this report.

5.3 Engine Compartment Test Fixture Fabrication

Figure 16 – Figure 20 show selected photographs during the final assembly of the engine compartment fixture.

Figure 16. Engine Compartment Mockup Test Fixture (View of Rear Driver Side – Prior to Installation of Fan).

Figure 17. Engine Compartment Mockup Test Fixture (View of Forward Passenger Side).

Figure 18. Engine Compartment Mockup Test Fixture (View of Rear Passenger Side).

Figure 19. Engine Compartment Mockup Test Fixture (View of Forward Side).

Figure 20. Engine Compartment Mockup Test Fixture (View of Rear Side).

5.4 Engine Compartment Test Fixture Instrumentation

Several measurements were taken during baseline and vendor testing in this fixture. A single data acquisition unit (DAQ) was used to record 23 channels of data.

There were 4 voltage output devices used to measure pressure and amperage. In addition, 19 thermocouples were used to measure temperature at various locations. Table 2 summarizes the channel layout on the DAQ.

Table 2. Summary of Engine Compartment Test Fixture Instrumentation.

Device No.	Device Identification	Device Units	Comments
1	Diesel Pressure	psig	Used to measure and control pressure during diesel spray fires
2	Power Steering Fluid Pressure	psig	Used to measure and control pressure during PSF spray fires
3	Motor Oil Pressure	psig	Used to measure and control pressure during hot surface re-ignition fires
4	Amp Reader	Amps	Used to measure current in overheated wire in battery compartment fire
5	Heater 1	°C	Surface thermocouple on hot surface (opposite No. 6)
6	Heater 2	°C	Surface thermocouple on hot surface (opposite No. 5)
7	Diesel Spray	°C	Located 0.5 m in front of diesel spray nozzle
8	Plastic Mid	°C	Located halfway up shelf holding plastic fire source materials
9	Plastic Bottom	°C	Located above ignition pan for plastic fire scenario
10	Battery Comp. 32”	°C	Located 32 in. above center of overheated wire
11	Battery Comp. 24”	°C	Located 24 in. above center of overheated wire
12	Battery Comp. 16”	°C	Located 16 in. above center of overheated wire
13	Battery Comp. 8”	°C	Located 8 in. above center of overheated wire
14	Power Steering Spray	°C	Located 0.5 m in front of PSF spray nozzle
15	Back Right Top	°C	Viewed from the rear of the coach – local gas temperature
16	Back Right Bottom	°C	Viewed from the rear of the coach – local gas temperature

Table 2. Summary of Engine Compartment Test Fixture Instrumentation (continued).

Device No.	Device Identification	Device Units	Comments
17	Back Left Top	°C	Viewed from the rear of the coach – local gas temperature
18	Back Left Bottom	°C	Viewed from the rear of the coach – local gas temperature
19	Front Left Top	°C	Viewed from the front of the coach – local gas temperature
20	Front Left Middle	°C	Viewed from the front of the coach – local gas temperature
21	Front Left Bottom	°C	Viewed from the front of the coach – local gas temperature
22	Front Right Top	°C	Viewed from the front of the coach – local gas temperature
23	Front Right Bottom	°C	Viewed from the front of the coach – local gas temperature

5.5 Engine Compartment Fire Scenarios

The scope of the project requires the development of test procedures to evaluate both detection and suppression systems in the engine compartment. As such, it is planned to include fire scenarios which incorporate both the detection and suppression system in a given test. In addition to this integrated testing, there will be the option to conduct one or more tests with the detection system assumed to either have failed or not be present (as in a manual activation system). In this way, the final test protocol will be applicable to both detection and suppression system evaluation.

In order to identify the most common fire scenarios for the engine compartment, detailed discussions with the NHTSA Office of Defects Investigation (ODI) were held in addition to discussions with motorcoach manufacturers, suppliers, and operators. As a result, the following fire scenarios (12 total tests) are included in the testing protocol for evaluating engine compartment detection and suppression systems:

1. Hot Surface Re-Ignition Test (One Test)
    a. Real Bus Hazard: hot surface in engine compartment such as turbo and exhaust manifold.
    b. Ignition Material: continuous feed of lube oil through Hago Model 1.50/80°H nozzle to drip oil at nominally 7 ml/min.
    c. Ignition Source: steel plate representing hot surface of turbo/exhaust manifold. Heated from behind by quartz IR panel heater.
    d. Location: upper left (hot) side of engine.
    e. General Procedure: raise nominal temperature of hot plate to 750 °C, open oil valve, observe dripping fire, after 15 s, turn off power to heaters for hot surface, after additional 15 s, discharge suppression system and record time to re-ignition, if any.
    f. Ventilation: conduct test without the fan running.

2. Diesel Spray Fires (Four tests)
    a. Real Bus Hazard: diesel spray fire as a result of a leak in the Diesel Particulate Filter (DPF) system. The diesel flow rate nominally equates to a 1.25 mm leak diameter with nominal operating conditions per motorcoach OEM for diesel line on DPF.
    b. Ignition Material: continuous feed of diesel fuel through Monarch F-80 nozzle, 10.0 gal/hr flow rate, and 80° spray angle. The diesel spray nozzle is mounted in a small flame stabilizer (metal can nominally 3 in diameter and 3 in long).
    c. Ignition Source: tell-tale cup nominally 3 in diameter and 2 in high, filled with 130 ml heptane (approximate 1-in. depth), positioned below the spray nozzle.
    d. Locations: lower left (hot) side of engine and upper left (hot) side of engine.
    e. General Procedure: ignite the tell-tale cup, after 30 s, discharge the diesel, after an additional 30 s discharge the suppression system and record observations.
    f. Ventilation: perform tests with and without fan running.
        i. Nominal air speeds with fan running:
            1. Lower Diesel Spray: 1.75 m/s
            2. Lower Tell-Tale Cup: 0.60 m/s
            3. Upper Diesel Spray: 0.40 m/s
            4. Upper Tell-Tale Cup: 0.40 m/s
3. Power Steering Fluid (PSF) Fires (Two tests)
    a. Real Bus Hazard: PSF spray fire as a result of a leak in the power steering system. The PSF flow rate will nominally equate to a 0.375 mm leak diameter with nominal operating conditions per motorcoach OEM for PSF line.
    b. Ignition Material: continuous feed of PSF through Monarch F-80 nozzle, 15.5 gal/hr flow rate, and 80° spray angle. The PSF nozzle is mounted in a small flame stabilizer (metal can nominally 3 in diameter and 3 in long).
    c. Ignition Source: tell-tale cup nominally 3 in diameter and 2 in high, filled with 130 ml heptane (approximate 1-in. depth), positioned below the spray nozzle.
    d. Location: middle right (cold) side of engine.
    e. General Procedure: ignite the tell-tale cup, after 30 s, discharge the PSF, after an additional 30 s discharge the suppression system and record observations.
    f. Ventilation: perform tests with and without fan running.
        i. Nominal air speeds with fan running:
            1. PSF Spray: 4.33 m/s
            2. PSF Tell-Tale Cup: 0.82 m/s
4. Distributed Pool Fires (Two tests)
    a. Real Bus Hazard: multiple fire locations after incipient fire have spread through compartment. This fire scenario also evaluates the ability of the system under test to adequately cover the full volume of the test fixture.
    b. Ignition Materials:

i. 8 tell-tale cups, nominally 3 in diameter and 2 in high, each filled with 130 ml of heptane (approximate 1-in. depth)
ii. 2 rectangular pans, each measuring 8 × 18 × 1 in. high, filled with 1750 ml of heptane (approximately 0.5–0.75 in. depth).

c. Location: throughout the entire test fixture, eight tell-tale cups in nominal eight corners of primary compartment space (not including battery compartment), one rectangular pan in left (hot) side clutter and one rectangular pan in right (cold) side clutter.

d. General Procedure: The cups and rectangular pans are ignited within 30 s (pan is the last to be ignited) and 30 s after ignition of pan, the suppression system is manually discharged and observations are recorded.

e. Ventilation: perform tests with and without fan running.
   i. Nominal air speeds with fan running:
      1. View from Front of Coach
         a. Tell-Tale Cup 4: 0.19 m/s
         b. Tell-Tale Cup 5: 0.92 m/s
         c. Tell-Tale Cup 6: 0.62 m/s
         d. Tell-Tale Cup 8: 5.46 m/s
         e. Pan 1: 6.58 m/s
      2. View from Rear of Coach
         a. Tell-Tale Cup 1: 0.40 m/s
         b. Tell-Tale Cup 2: 0.17 m/s
         c. Tell-Tale Cup 3: 0.40 m/s
         d. Tell-Tale Cup 7: 0.34 m/s
         e. Pan 2: 0.35 m/s

5. Plastics Fire (Two Tests)

a. Real Bus Hazard: Class A material (plastics) fire close to the toilet holding tank and air filter housing components.

b. Ignition Materials:
   i. 8 vertical strips of plastic, 4 Acrylonitrile butadiene styrene (ABS) and 4 Polypropylene plastic (PP), each measuring 2 in × 28.75 in. long (nominally 1/8 in. thick)
   ii. 4 horizontal strips of plastic, 1 of each type of plastic on lower two shelves of clutter rack adjacent to vertical strips and ignition pan.
   iii. The material flammability of these materials has been characterized and can be referenced in Appendix C.

c. Ignition Source: 1 rectangular pan (same as pool fire test) with 120 ml of heptane used to ignite the plastic.

d. Location: lower right (cold) side of engine.

e. General Procedure: Ignite the pan fire, after 105 s of pre-burn, discharge the suppression system and record observations.

f. Ventilation: conduct test with and without the fan running.
   i. Nominal air speeds with fan running:
      1. Ignition Pan: 0.43 m/s
      2. Shelf 1 (Lowest): 0.33 m/s
      3. Shelf 2: 0.27 m/s
      4. Shelf 3: 0.25 m/s
      5. Shelf 4 (Highest): 0.34 m/s

6. Battery Compartment Fire (One Test)
    a. Real Bus Hazard: overheated cable in battery compartment, which leads to a growing Class A fire.
    b. Ignition Materials:
        i. 1-in diameter pipe insulation – two horizontal sections 30 in long and one vertical section 25 in long. Prior to installation, each section is sprayed lightly with approximately 25 ml of diesel fuel. These sections are mounted just above the egg-crate foam and over the overheated cable.
        ii. Egg-crate foam plastic insulation – one 16 × 18-in panel applied to back wall of battery compartment directly over the overheated cable.
        iii. Plastic toolboxes – these are used to approximate battery boxes. Four of these boxes are placed in the compartment and 10 ml of grease is applied to the top surface of the back two boxes.
        iv. The material flammability of these materials has been characterized and can be referenced in Appendix C.
    c. Ignition Source: 23.5-in long thermoplastic cable overheated to ignition by discharging a 200-amp load from two motorcoach batteries in series (24 volts). The cable also has approximately 5 ml of lubricating grease applied evenly over the surface of the cable insulation.
    d. Location: battery compartment.
    e. General Procedure: discharge battery current into test cable and allow cable to ignite, 30 s after cable ignition, discharge suppression system and record observations.
    f. Ventilation: conduct test without the fan running.

As discussed in Section 5.2 of this report, it is recommended that the fan speed be set to an intermediate representative speed (volumetric flow rate), typical to that of the majority of motorcoach driving time. This equates to an average air velocity of approximately 6 m/s at the outlet of the fan after the louvered radiator enclosure and nominally 3 m^3/s of volumetric airflow.

Figure 21 – Figure 30 provide drawings of each fire scenario location within the test fixture.

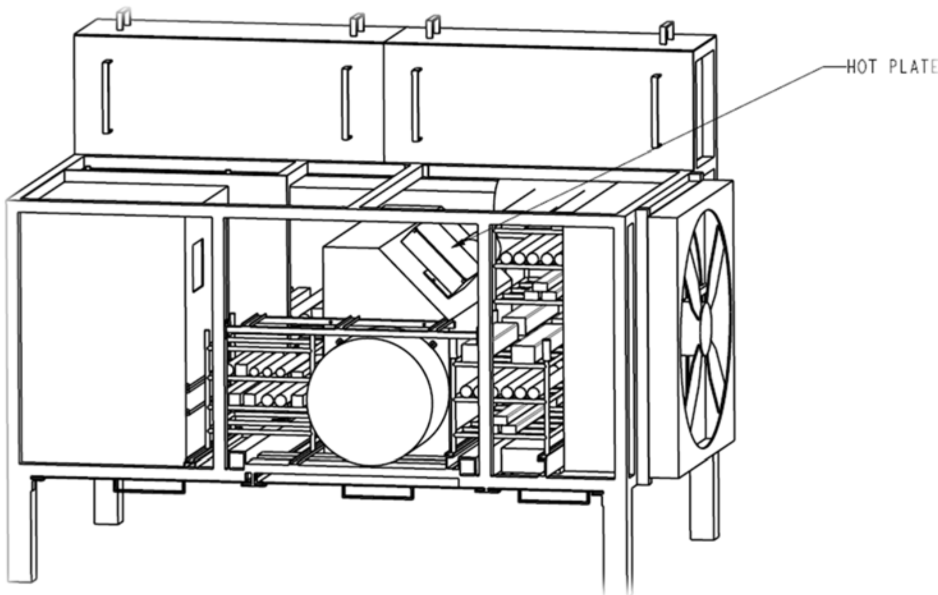


Figure 21. Hot Surface Re-Ignition Fire Scenario (View of Forward Side).

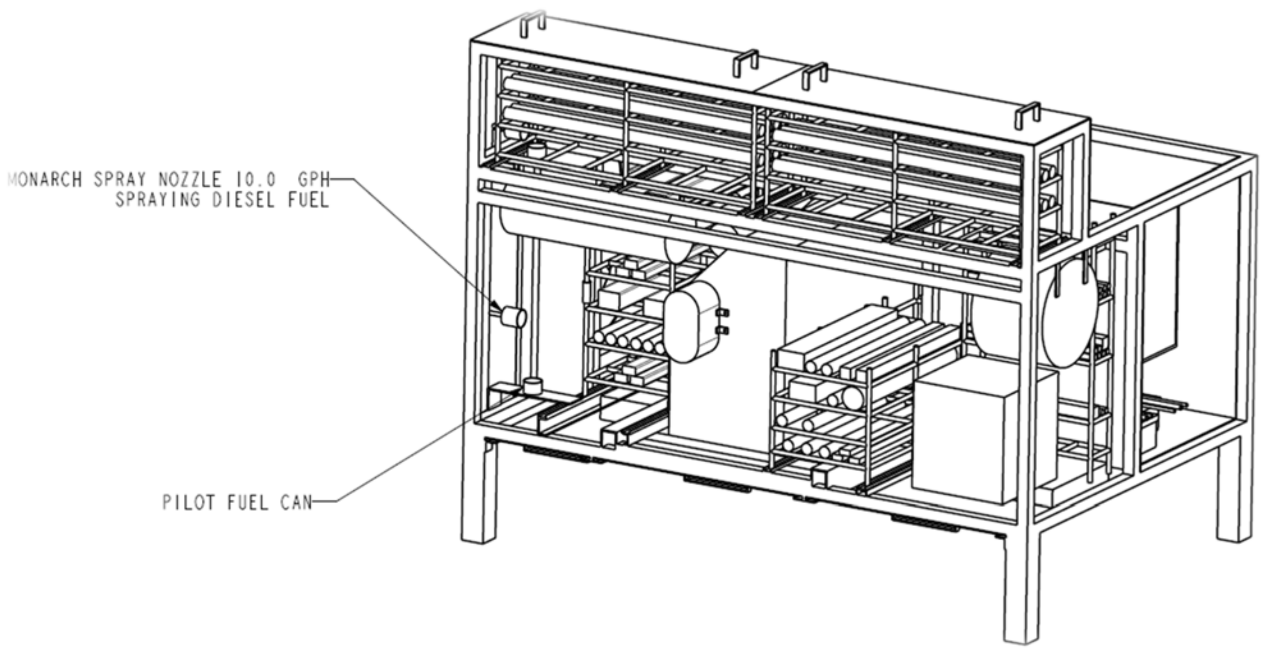


Figure 22. Diesel Spray Fire Scenario (View of Rear Side: Lower Position).

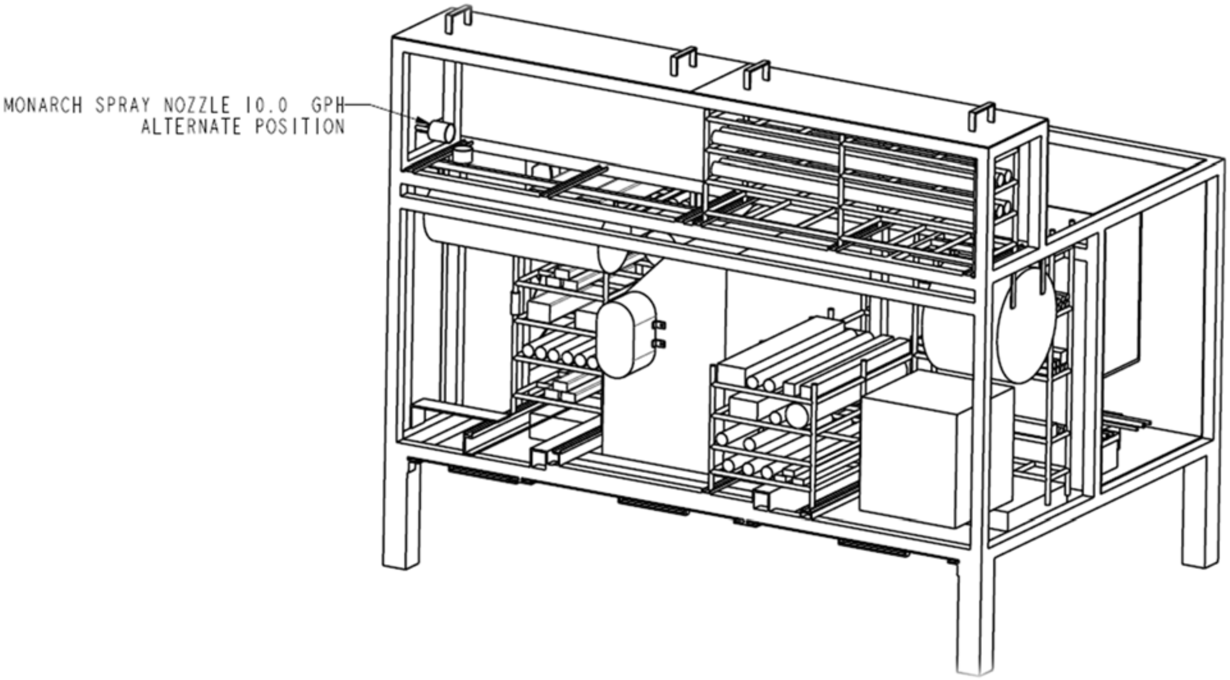


Figure 23. Diesel Spray Fire Scenario (View of Rear Side: Upper Position).

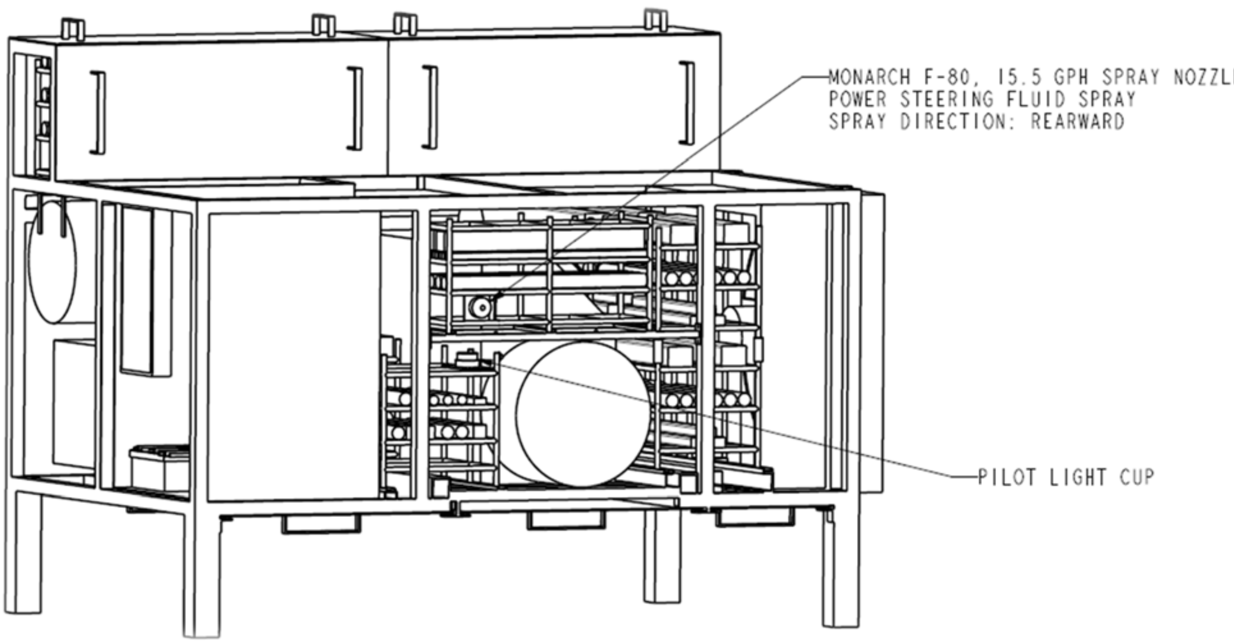


Figure 24. PSF Spray Fire Scenario (View of Forward Side).

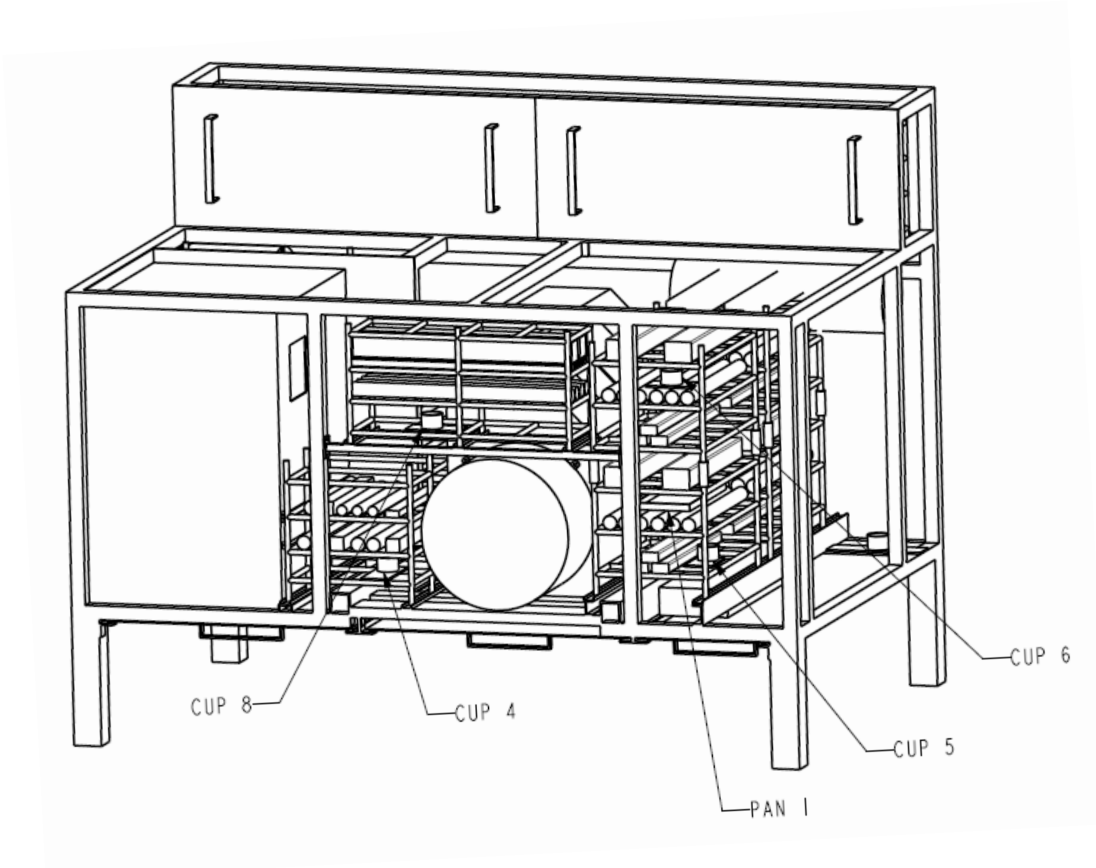


Figure 25. Distributed Pool Fire Scenario (View of Forward Side).

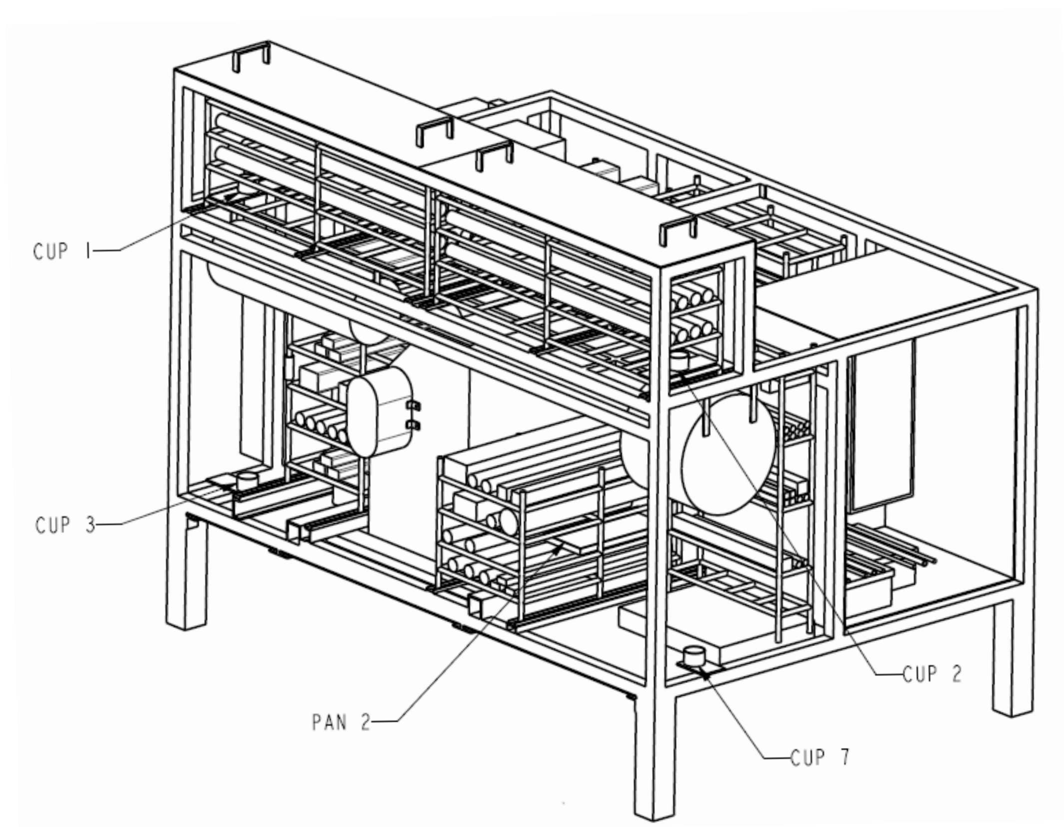


Figure 26. Distributed Pool Fire Scenario (View of Rear Side).

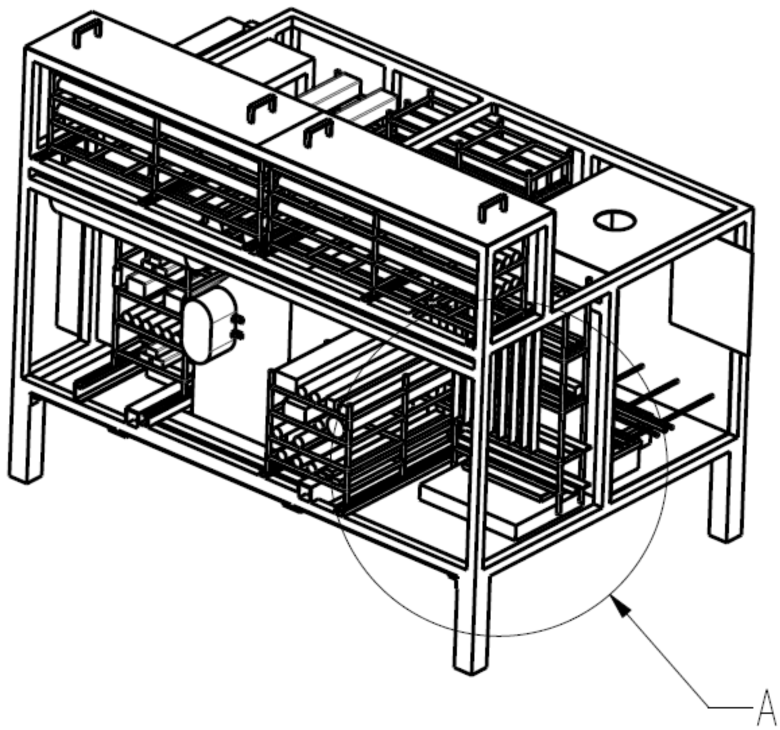


Figure 27. Plastics Fire Scenario (Wide Angle View).

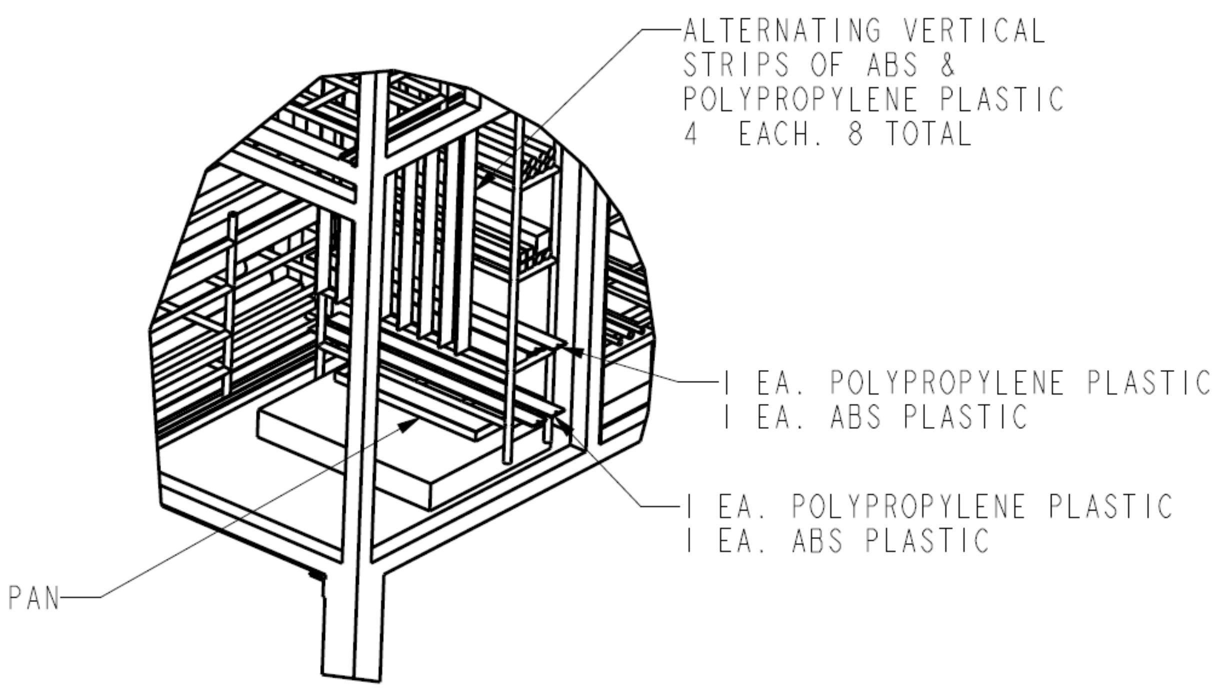


Figure 28. Plastics Fire Scenario (Close-up View).

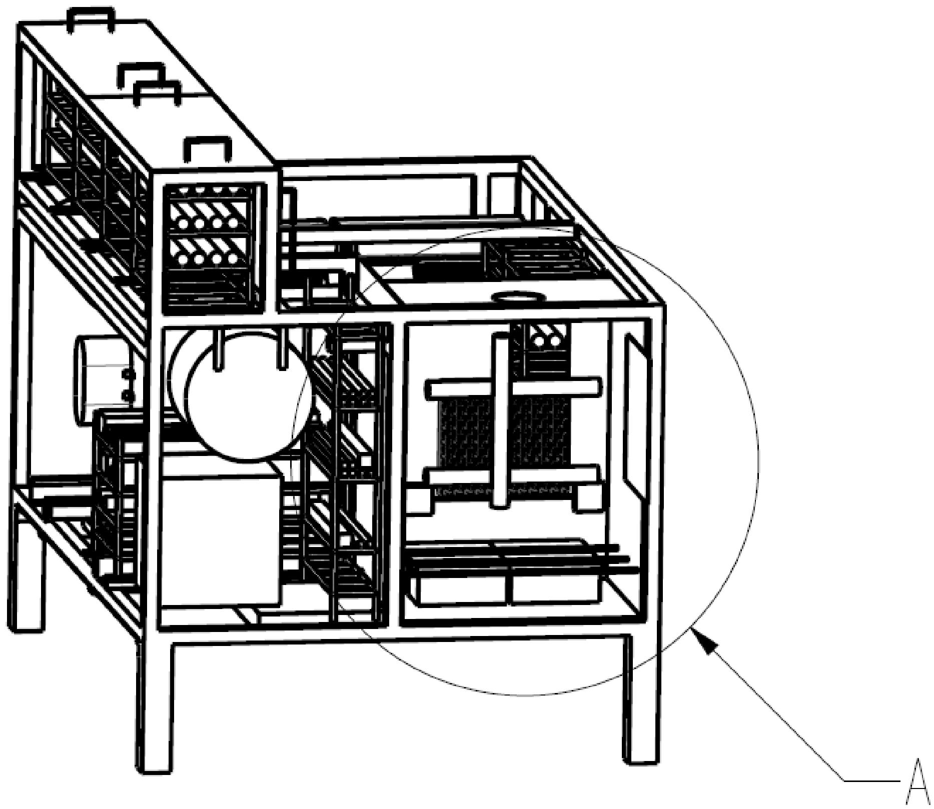


Figure 29. Battery Compartment Fire Scenario (Wide Angle View).

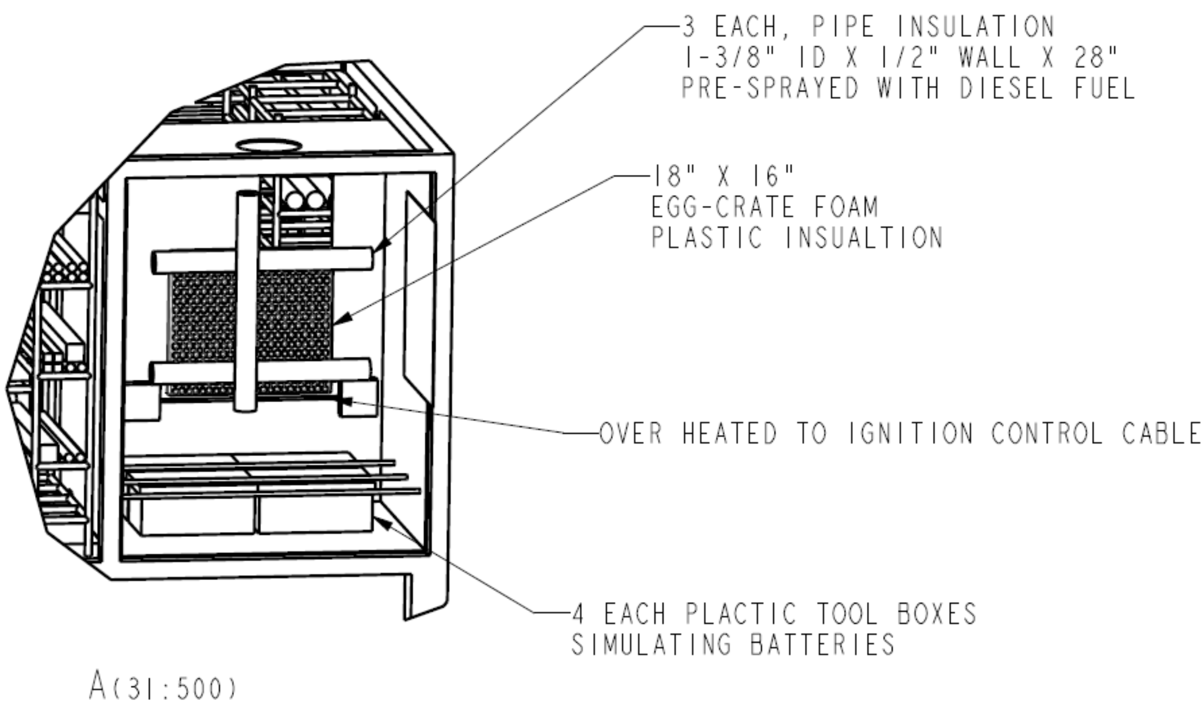


Figure 30. Battery Compartment Fire Scenario (Close-up View).

5.5.1 Engine Compartment Ignition Source Testing (in open)

During the development of the ignition sources for the final fire scenarios described above, several tests were conducted in the open to help select final components and arrangement. Figure 31 – Figure 34 show selected photographs from this initial baseline fire scenario testing.

During this testing, several decisions were made about the fire scenarios, such as the following.

- Operating temperature of hot surface,
- Configuration between electrical heaters and hot surface (steel plate),
- Types of spray nozzles required for testing,
- Optimal way to ignite sources (spray fires, Class A fuels, etc.)
- Flammability of several ignition sources, such as the plastics and other materials required for the battery compartment test, and
- Effect of ventilation on ignition sources.

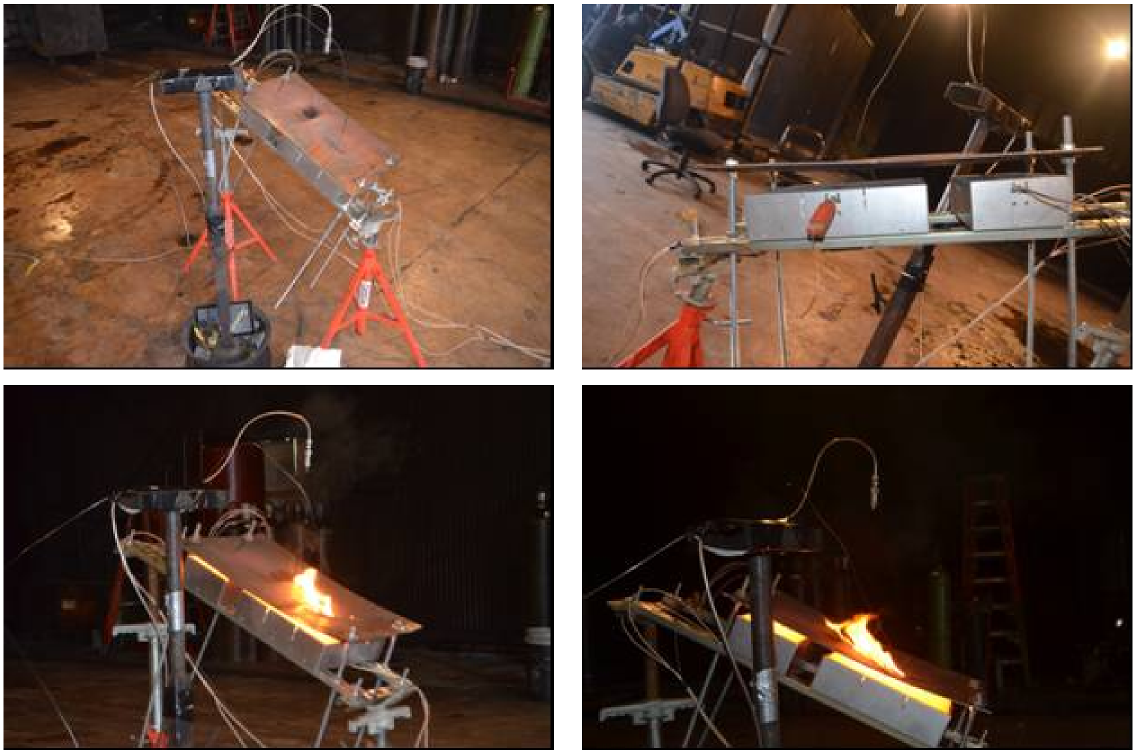


Figure 31. Hot Surface Ignition Testing.

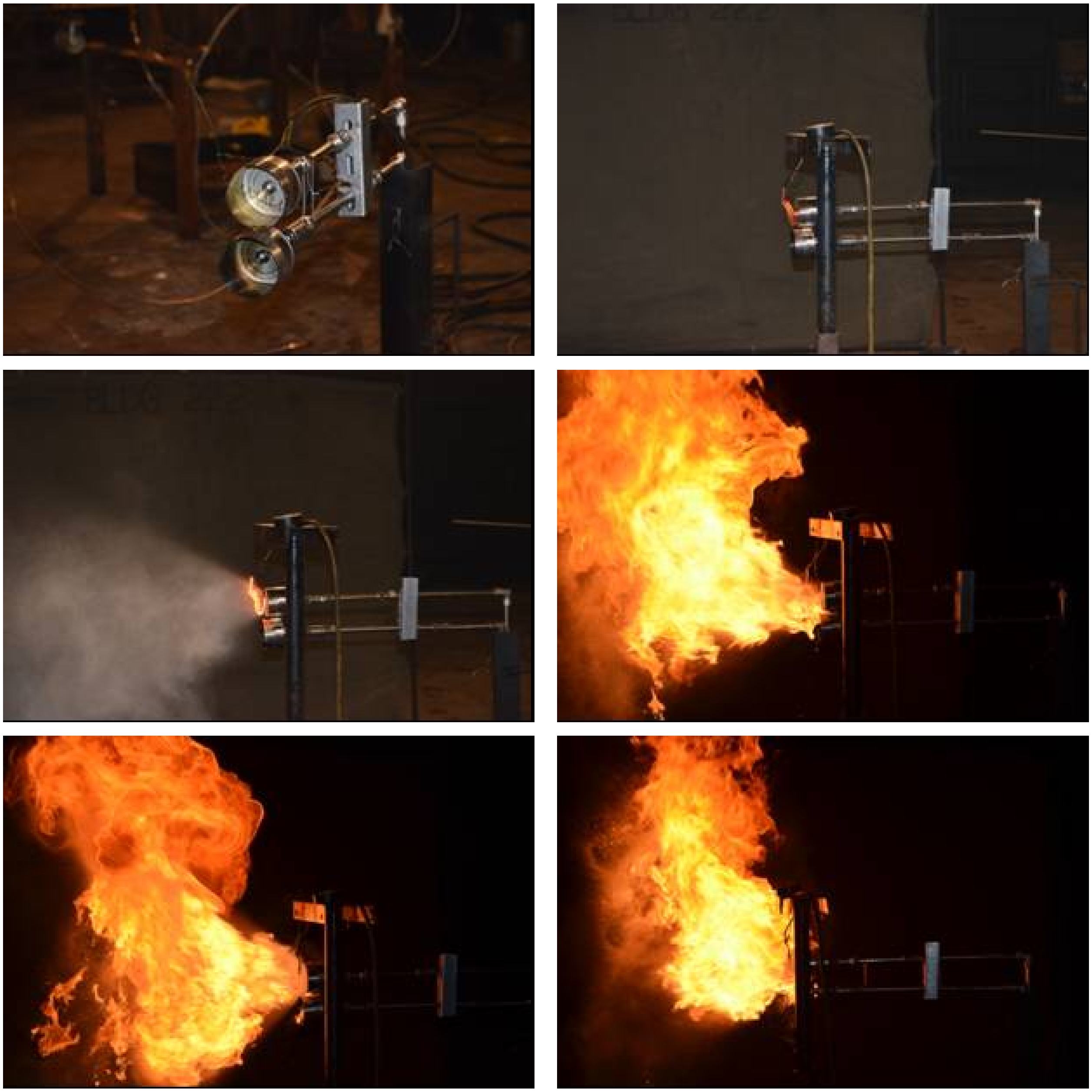


**Figure 32. Spray Fire Ignition Testing
(Power Steering Fluid-Top Nozzle and Diesel Fuel-Bottom Nozzle).**

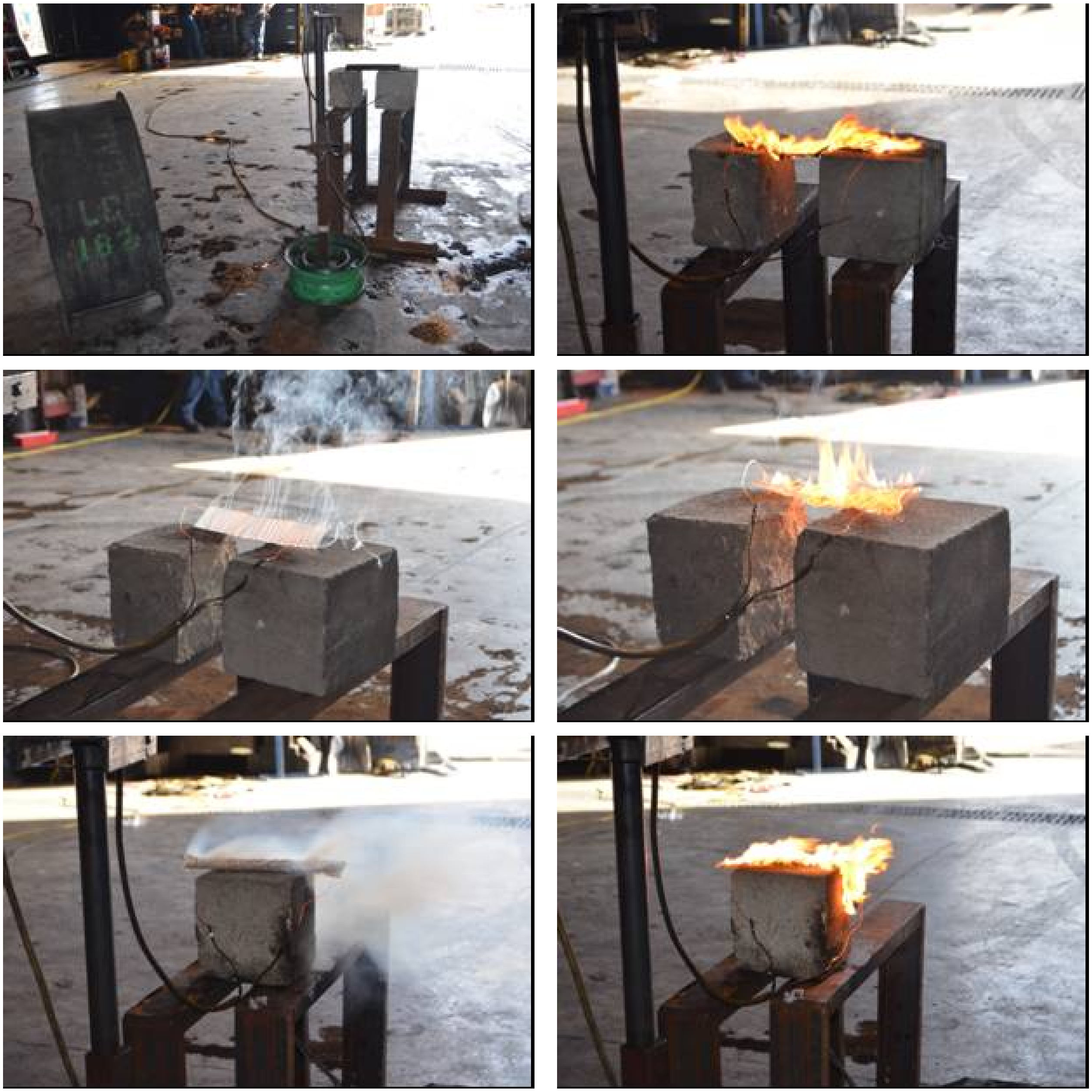


Figure 33. Plastic Fire Ignition Testing (ABS (Black) and PP (White).

Figure 34**. Overheated Cable Ignition Testing**

5.5.2 Engine Compartment Fire Scenario Baseline Testing

After the test fixture was fabricated, the fire scenarios were tested within the fixture and in the absence of a fire detection or suppression system so baseline data could be gathered to help determine appropriate pre-burn times, as well as to understand the overall temperature evolution in the fixture without a fire suppression system. Appendix D provides a summary of these baseline data gathered for each fire scenario described above. Figure 35 provides selected photographs from this baseline testing.

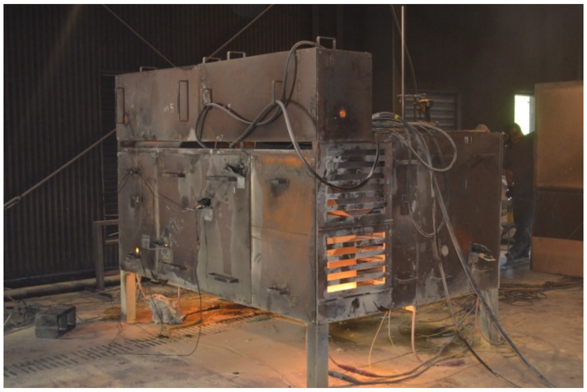



Figure 35. Photographs of Selected Baseline Tests in Progress: Top Left: PSF Spray Fire, Top Right: Diesel Spray Fire, Bottom Left: Pool Fires (Rear View), Bottom Right: Pool Fires (Forward View).

Several baseline tests were conducted with the hot surface ignition scenario to characterize the heating and cool-down periods, as well as to determine the best operating temperature for the hot surface. Figure 36 provides the heating and cooling temperatures.

Figure 36 illustrates approximate linear cooling on the hot surface from ~760 – 500 °C. Over this temperature range, the slope of the line is essentially the same with and without continued oil drip during cool down. A slower cool down rate can be observed with and without continued oil drip between 500 – 300 °C.

During the initial baseline tests in the open, the minimum temperature for oil ignition on the hot plate was observed to be approximately 520 °C. It can be noted from Figure 36 that the natural cool down period of the hot plate between 750-520 °C is approximately 7 min, which is more than adequate to evaluate the cooling capability of a suppression system under test. In other words, the hot plate will remain above the oil ignition temperature for a long time. The only way to prevent re-ignition is to cool the hot surface to below the ignition temperature.

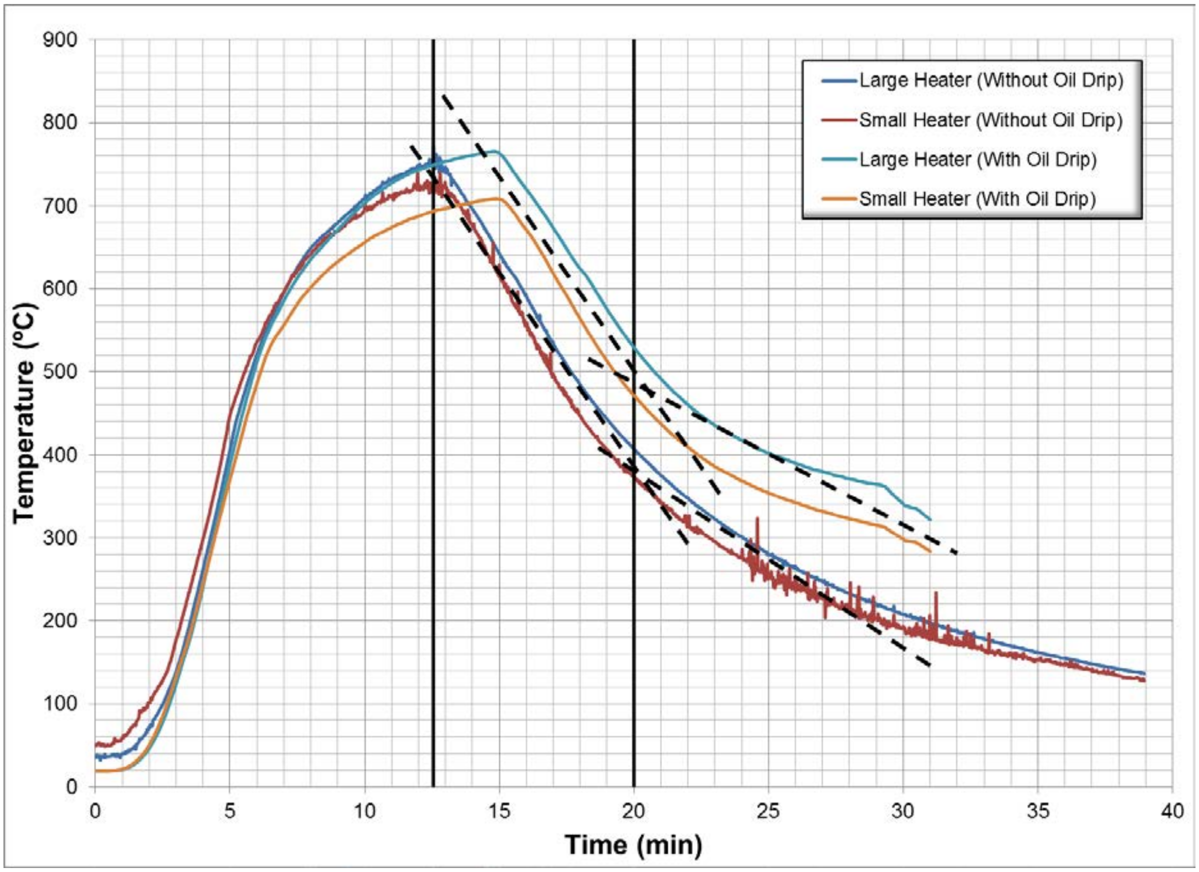


Figure 36. Hot Surface Re-Ignition Test Characterization.

5.6 Engine Compartment Vendor Testing

Several sessions of vendor testing were performed with three companies that sell commercial detection and/or suppression systems. The following subsections provide a brief summary of the testing that was conducted and the results.

5.6.1 Vendor A Test Results

Vendor A conducted two test sessions. The first test session was conducted April 28-30, 2014, and the second session was conducted on July 29, 2014. In total, 14 tests were conducted in the engine compartment test fixture.

<u>Detection/Suppression System Description</u>

The vendor installed their detection and suppression system in the test fixture after an initial survey of the geometry, obstructions and summary of the test fires.

The integrated system consisted of linear thermal detection (LTD) and optical detection as well as a dry chemical based suppression system (5 nozzles, 25 or 30-lb capacity). In addition, a cooling agent was used for the hot surface fire. Table 3 provides a summary of the tests conducted and the detection/suppression devices used for each test.

Table 3. Summary of Vendor A Detection and Suppression System.

Test No.	Fire Scenario	Detector Description	Suppression Description
1	PSF Spray without Fan	No Detector	25-lb dry chemical, 5 nozzles
2	PSF Spray without Fan	Linear Heat Detector Wire	25-lb dry chemical, 5 nozzles
3	Hot Surface Re-Ignition	Linear Heat Detector Wire	Cooling agent only (no dry chemical)
4	Diesel Spray with fan (lower position)	Linear Heat Detector Wire and Optical Detector	25-lb dry chemical, 5 nozzles
5	Battery Compartment Fire with fan	Linear Heat Detector Wire	25-lb dry chemical, 5 nozzles
6	Plastics Fire with Fan	Linear Heat Detector Wire	25-lb dry chemical, 5 nozzles
7	Pool Fires with Fan	No Detection	25-lb dry chemical, 5 nozzles
8	Hot Surface Re-Ignition	No Detection	25-lb dry chemical, 5 nozzles
9	Hot Surface Re-Ignition	No Detection	Cooling agent only (no dry chemical)
10	Diesel Spray with Fan (upper position)	Optical Detector	25-lb dry chemical, 5 nozzles
11	PSF Spray with Fan	Optical Detector	25-lb dry chemical, 5 nozzles
12	Pool Fires with Fan	Optical Detector	25-lb dry chemical, 5 nozzles
13	Pool Fires with Fan	Optical Detector	25-lb dry chemical, 5 nozzles
14	Plastics and Battery Compartment Fire (combined due to time constraints)	No Detector	30-lb dry chemical, 5 nozzles

The cooling agent is typically used by this vendor to address potential hot surfaces in an engine compartment, and is normally integrated into the detection and dry chemical system, which is installed throughout the rest of the engine compartment. For this testing, it was decided on a test-by-test basis if all systems would be used together or separated. In addition, all suppression was initiated manually, with a mechanical valve.

Test Results

Temperature data in the engine compartment for each test can be referenced in Appendix E. Table 4 provides a summary of the test results for Vendor A. Detection times are relative to ignition of the fire source or in the case of the pool fires, ignition of the last rectangular pan. Extinguishment times are relative to the start of agent discharge.

Table 4. Summary of Vendor A Test Results.

Test No.	Fire Scenario	Detection Time (s)	Extinguishment Time (s)
1	PSF Spray without Fan	N/A	1
2	PSF Spray without Fan	14	1
3	Hot Surface Re-Ignition	Activated during heating period at 600 °C, prior to start of test, at 750 °C	2, No Re-ignition
4	Diesel Spray with fan (lower position)	No activation	2
5	Battery Compartment Fire with fan	20	1
6	Plastics Fire with Fan	No activation	1
7	Pool Fires with Fan	N/A	No full extinguishment
8	Hot Surface Re-Ignition	N/A	1, Re-ignition in 32 s
9	Hot Surface Re-Ignition	N/A	1, No Re-ignition
10	Diesel Spray with Fan (upper position)	No activation	1
11	PSF Spray with Fan	No activation	2
12	Pool Fires with Fan	No activation	No full extinguishment
13	Pool Fires with Fan	10 (adjusted settings on optical detector)	3 (adjusted nozzle placement slightly)
14	Plastics and Battery Compartment Fire (combined due to time constraints)*	N/A	2

N/A: not applicable since a detection system was not installed on this test.
*: pre-burn times were aligned such that system could be discharged at appropriate time.

Several interesting observations can be made as a result of this testing.

- If the detection system activated, it did so within the proposed pre-burn times. However, in some cases, the detection system did not activate and this occurred for tests with the fan running, which provides some convective cooling to the linear heat detector and may also affect the fire size and shape for the optical detectors.

- The average discharge time of the dry chemical system is 15–20 s. Typically, if extinguishment is to be observed, it occurs within 3 s. This is the time period that the system has the most momentum to penetrate obstructed fires and if the fire cannot be extinguished quickly, it tends to not be extinguished at all.
- The most challenging fire appears to be the distributed pool fire scenario with the fan running.
- Dry chemical does not seem to be an ideal agent for the hot surface re-ignition scenario and the cooling agent performed much better. In addition, the average discharge time for the cooling agent (discharged at a lower pressure) was 60 s.

5.6.2 Vendor B Test Results

Vendor B conducted a test session July 15-18, 2014. In total, 15 tests were conducted in the engine compartment fixture.

Detection/Suppression System Description

The vendor installed their detection and suppression system in the test fixture after an initial survey of the geometry, obstructions and summary of the test fires.

The integrated system consisted of linear and optical heat detectors as well as a dry chemical based suppression system (2 or 4-nozzle system, 10-kg capacity). The 2-nozzle system is discharged at a higher pressure than the 4-nozzle system. All suppression was initiated manually, with a mechanical valve, after the proposed pre-burn time.

In terms of detection, Vendor B provided four different types of detector circuits that could be monitored during each test. Two different types of LTD wire was used; one set that activates at nominally 180 °C and another that activates at nominally 232 °C. Another LTD was used that averages the heat it senses and is identified as LTD-Avg. In addition to the linear thermal detectors, an optical detector circuit was used, similar to Vendor A.

Table 5 provides a summary of the tests conducted and the detection/suppression devices used for each test.

Table 5. Summary of Vendor B Detection and Suppression System.

Test No.	Fire Scenario	Detector Description	Suppression Description
1	Diesel Spray without Fan (lower position)	LTD-180, LTD-232, Optical, LTD-Avg	10-kg dry chemical, 2 nozzles
2	Diesel Spray with Fan (lower position)	LTD-180, LTD-232, Optical, LTD-Avg	10-kg dry chemical, 2 nozzles
3	PSF Spray with Fan	LTD-180, LTD-232, Optical, LTD-Avg	10-kg dry chemical, 2 nozzles
4	PSF Spray without Fan	LTD-180, LTD-232, Optical, LTD-Avg	10-kg dry chemical, 2 nozzles
5	Pool Fires without Fan	LTD-180, LTD-232, Optical, LTD-Avg	10-kg dry chemical, 2 nozzles
6	Pool Fires with Fan	LTD-180, LTD-232, Optical, LTD-Avg	10-kg dry chemical, 2 nozzles
7	Plastics Fire without Fan	LTD-180, LTD-232, Optical, LTD-Avg	10-kg dry chemical, 2 nozzles
8	Pool Fires with Fan	No Detector Installed	10-kg dry chemical, 4 nozzles
9	PSF Spray with Fan	No Detector Installed	10-kg dry chemical, 4 nozzles
10	PSF Spray without Fan	No Detector Installed	10-kg dry chemical, 4 nozzles
11	Diesel Spray with Fan (lower position)	No Detector Installed	10-kg dry chemical, 4 nozzles
12	Pool Fires without Fan	No Detector Installed	10-kg dry chemical, 4 nozzles
13	Plastics Fire without Fan	No Detector Installed	10-kg dry chemical, 4 nozzles
14	Battery Compartment Fire without Fan	No Detector Installed	10-kg dry chemical, 4 nozzles
15	Battery Compartment Fire without Fan	No Detector Installed	10-kg dry chemical, 2 nozzles

Test Results

Table 6 provides a summary of the test results for Vendor B. Temperature data in the engine compartment for each test can be referenced in Appendix F. Detection times are relative to ignition of the fire source or in the case of the pool fires, ignition of the last rectangular pan. Extinguishment times are relative to the start of agent discharge.

Table 6. Summary of Vendor B Test Results.

Test No.	LTD-180 (s)	LTD-232 (s)	Optical (s)	LTD-Avg (s)	Extinguishment Time (s)
1	No Activation	No Activation	No Activation	No Activation	1
2	No Activation	No Activation	No Activation	No Activation	1
3	32	No Activation	No Activation	No Activation	1
4	N/A	No Activation	1	5	1
5	N/A	28	No Activation	16	8
6	19	22	No Activation	18	5
7	N/A	N/A	No Activation	26	1
8	N/A	N/A	N/A	N/A	No full extinguishment
9	N/A	N/A	N/A	N/A	1
10	N/A	N/A	N/A	N/A	1
11	N/A	N/A	N/A	N/A	3
12	N/A	N/A	N/A	N/A	2
13	N/A	N/A	N/A	N/A	1
14	N/A	N/A	N/A	N/A	4
15	N/A	N/A	N/A	N/A	2

N/A: not applicable since new detectors were not installed on this test.

Several interesting observations can be made as a result of this testing.

- If the detection system activated, it typically did so within the proposed pre-burn times. However, in some cases, the detection system did not activate and this occurred primarily for tests with the fan running, which provides some convective cooling to the linear heat detectors and may also affect the fire size and shape for the optical detectors.
- The average discharge time of the 2-nozzle (high pressure) dry chemical system is 2 seconds. The average discharge time of the 4-nozzle (low pressure) dry chemical system is 11 seconds. An interesting difference is

seen with the extinguishment times between the 2-nozzle and 4-nozzle systems.

    - For the 4-nozzle system (similar in design to Vendor A), typically, if extinguishment is to be observed, it occurs within 3 seconds. This is the time period that the system has the most momentum to penetrate obstructed fires and if the fire cannot be extinguished quickly, it tends to not be extinguished at all.
    - However, for the 2-nozzle system, since the discharge is so fast, it takes a few additional seconds to observe extinguishment in some of the fire scenarios.

- The most challenging fire appears to be the distributed pool fire scenario with the fan running.

5.6.3 Vendor C Test Results

Vendor C conducted two test sessions. The first test session was conducted July 22-23, 2014, and the second session was conducted on August 19-20, 2014. In total, 26 tests were conducted in the engine compartment test fixture.

Suppression System Description

Vendor C did not test with a detection system. The suppression system design was a hybrid between compressed air foam (CAF) and water mist. The suppression agent was CAF, but two different types of nozzles were utilized; one more typically found on commercial pre-engineered CAF systems and one more typically found in commercial pre-engineered water mist systems.

Table 7 provides a summary of the tests conducted and the suppression devices used for each test.

Table 7. Summary of Vendor C Tests and Suppression System.

Test No.	Fire Scenario	Suppression System Description
1	PSF Spray without Fan	10-nozzle System (5 CAF and 5 Water Mist)
2	PSF Spray without Fan	10-nozzle System (5 CAF and 5 Water Mist)
3	Diesel Spray without Fan (low position)	10-nozzle System (5 CAF and 5 Water Mist)
4	Diesel Spray with Fan (low position)	10-nozzle System (5 CAF and 5 Water Mist)
5	Diesel Spray with Fan (low position)	Same nozzle array, plugged half the nozzles to evaluate change in rate of application
6	Diesel Spray with Fan (low position)	Same nozzle array, plugged half the nozzles to evaluate change in rate of application
7	Plastics Fire without Fan	Same nozzle array, plugged half the nozzles to evaluate change in rate of application
8	Battery Compartment Fire without Fan	Same nozzle array, plugged half the nozzles to evaluate change in rate of application
9	Diesel Spray without Fan (high position)	12-nozzle System (7 CAF, 3 Water Mist, 2 Smaller Water Mist)
10	Diesel Spray with Fan (high position)	12-nozzle System (7 CAF, 3 Water Mist, 2 Smaller Water Mist)
11	Diesel Spray with Fan (high position)	12-nozzle System (7 CAF, 3 Water Mist, 2 Smaller Water Mist) – Adjusted positions
12	Diesel Spray with Fan (high position)	12-nozzle System (7 CAF, 3 Water Mist, 2 Smaller Water Mist) – Adjusted positions
13	Diesel Spray without Fan (low position)	12-nozzle System (7 CAF, 3 Water Mist, 2 Smaller Water Mist) – Adjusted positions
14	PSF Spray without Fan	Same as Test 13
15	PSF Spray with Fan	Same as Test 13 and 14
16	Pool Fires with Fan	Same as Tests 13-15
17	Pool Fires with Fan	Adjusted nozzle positions
18	Pool Fires with Fan	Changed CAF nozzles to a different model number, same configuration as Test 17
19	Pool Fires with Fan	Same nozzles as Test 18, adjusted position
20	Pool Fires with Fan	Changed CAF nozzles to a different model number, same configuration as Test 19
21	Pool Fires with Fan	Changed CAF nozzles to a different model number, same configuration as Test 19-20
22	Diesel Spray with Fan (low position)	Same as Test 21

Table 7. Summary of Vendor C Tests and Suppression System (continued).

Test No.	Fire Scenario	Suppression System Description
23	Diesel Spray with Fan (low position)	Changed CAF nozzles to different model number, same configuration as Test 22
24	Diesel Spray without Fan (low position)	Same as Test 23
25	Plastics Fire without Fan	Same as Tests 23-24
26	Plastics Fire with Fan	Same as Tests 23-25

Test Results

Table 8 provides a summary of the fire tests and the extinguishment time observed. Temperature data in the engine compartment for each test can be referenced in Appendix G.

Table 8. Summary of Vendor C Test Results.

Test No.	Fire Scenario	Extinguishment Time (s)
1	PSF Spray without Fan	No extinguishment
2	PSF Spray without Fan	No extinguishment
3	Diesel Spray without Fan (low position)	No extinguishment
4	Diesel Spray with Fan (low position)	No extinguishment
5	Diesel Spray with Fan (low position)	No extinguishment
6	Diesel Spray with Fan (low position)	No extinguishment
7	Plastics Fire without Fan	No extinguishment
8	Battery Compartment Fire without Fan	3
9	Diesel Spray without Fan (high position)	2
10	Diesel Spray with Fan (high position)	No extinguishment
11	Diesel Spray with Fan (high position)	2
12	Diesel Spray with Fan (high position)	2
13	Diesel Spray without Fan (low position)	2

Table 8. Summary of Vendor C Test Results (continued).

Test No.	Fire Scenario	Extinguishment Time (s)
14	PSF Spray without Fan	2
15	PSF Spray with Fan	3
16	Pool Fires with Fan	No extinguishment
17	Pool Fires with Fan	No extinguishment
18	Pool Fires with Fan	No extinguishment
19	Pool Fires with Fan	No extinguishment
20	Pool Fires with Fan	No extinguishment
21	Pool Fires with Fan	No extinguishment
22	Diesel Spray with Fan (low position)	No extinguishment
23	Diesel Spray with Fan (low position)	3
24	Diesel Spray without Fan (low position)	3
25	Plastics Fire without Fan	49
26	Plastics Fire with Fan	No extinguishment

Several interesting observations can be made as a result of this testing.

- In general, the CAF/mist system was challenged by the fire scenarios and in particular the heavily obstructed fires. This is likely due to this type of technology typically being used for local applications, rather than a total flooding application, which is more representative of an engine compartment.
- The average discharge time of the CAF/mist system was 1–1.5 min. Similar to the Vendor A and B test results, if the fire is not extinguished within the first few seconds of application, typically the fire will not be extinguished at all.
- The most challenging fire appears to be the distributed pool fire scenario with the fan running.

5.7 Engine Compartment Fire Detection System Discussion

This section provides a summary of how fire detection in engine compartments is typically addressed in the field currently and discusses how detection is to be integrated into the proposed test procedure, but also requires further research.

<u>Types of detectors</u>

A number of detectors can and are being used in engine compartments. They include:

- Linear Thermal Detectors (LTDs) – these are a pair of wires covered in insulation with a specific melting point. When the plastic insulation melts, the two wires short and this provides an alarm signal.
- Spot detectors – these devices measure the temperature at a point. They are usually set to signal at a specific temperature – similar to a bi-metallic strip.
- Thermocouple detectors – these are also “point” detectors. The temperature is measured continuously, and the trigger temperature can be programmed into the software.
- Rate of rise detectors – These are sensitive to the rate of change of temperature rather than its actual value. The detector could be the same as a thermocouple detector. The software can be programmed to trigger at a specific rate or rise.
- Optical detectors – these detect temperature or a flame by monitoring the radiation intensity in one or two bands of the spectrum of light. Multi-channel detectors may have a lower false alarm rate. These detectors are sensitive to a size and shape of a fire.
- A good summary of various detection technologies can be referenced in Appendix A [5].

<u>Quantity and Location of detectors</u>

It normally takes several detectors to cover an entire engine compartment. Most electronic boxes can accept several independent inputs. Many detectors can also be “daisy-chained” together in series.

Detectors are usually installed after conducting a hazard analysis of the engine compartment. Most engines have a “cold side” for the air intake and fuel injectors, and a “hot side” where the exhaust manifold, exhaust gas recirculator (EGR) valve, turbocharger, and emissions control canisters are located. The alternators and starter motor can be on either side of the engine and are usually down low. The engine block effectively separates the cold and hot side – so detectors are needed on both sides. To protect high current electrical cables, such as from the alternators or to the starter motor, LTDs are sometimes attached directly to the cables with cable ties.

In principle, one could cover the entire engine compartment with LTDs or other detectors. But both the OEMs and operators want to minimize the objects that must be removed and replaced in order to perform maintenance on other engine compartment components. Thus there are practical limitations on where detectors can be placed.

Since heat rises, there is a rationale for installing detectors near the top of the engine compartment. If there is no airflow, a detector directly over the fire will usually detect it. The heat will flow upward by convection. But if there is airflow, the fire plume will be displaced to the side, and the fire may not be detected. All inspected motorcoaches had the engine radiator located on the driver’s side of the engine compartment with the airflow toward the passenger’s side. The air exits through louvers on the rear engine compartment door or small louvers on the passenger side, or via the bottom of the engine compartment. None of the engine compartments inspected had floor pans, but the downward airflow area is limited by the presence of the engine block, the emissions control equipment, and the lavatory holding tank. The downward airflow area is limited to about 40–50% of the available footprint. Thus the airflow will tend to displace the fire plume toward the passenger side.

Vendors A and B primarily used LTDs for detection. Vendor C did not test any detectors. Both vendor A and B had optical sensors available and Vendor B also tested a TLSE.

The LTD material comes with different temperature ratings – most of the motorcoach installations use LTDs designed to provide a signal at 180 °C (356 °F). Vendor B also tested a LTD set to activate at 232 ºC. Based on the results of this testing, it seems that the LTDs work well if they are close to the fire and get heated. But for distant fires, or situations with the radiator fan on, they may not detect the fire.

It was originally planned to use the automatic detection system to trigger the release of the fire suppression agent. However, the detection system was not always successful, so manual suppression system activation was elected with a specific pre-burn time. This allowed the test procedure to evaluate both the detection and suppression components.

The hot surface re-ignition test simulates an overheated turbocharger. It is represented by a flat steel plate heated from behind by two quartz heaters. It was found that the LTD routed high in the engine compartment activated relatively quickly and radiation may have been the primary mode of heat transfer in this case.

<u>Summary</u>

The details of the test procedures evolved as more tests were performed. As expected, it was observed that fires were detected when they were close to the detector. A failure to activate was typically related to proximity to the fire source or ventilation effects, rather than specific detector technology.

Further research is recommended to determine quantitatively how each type of detector responds to a fire at a given distance and view angle. This will provide the data on how many detectors are needed and where to optimally locate them. It may not be necessary to use the large engine compartment test fixture to evaluate single detector types.

The final test procedures allowed for a simplified evaluation of the detection systems installed in an engine compartment. This is reflected in the recommended test criteria in Section 5.8. However, it is also recommended that future research be conducted with respect to detection in engine compartments to further refine the optimal test methods.

5.8 Engine Compartment Test Procedure and Test Criteria

The following test criteria have been developed for evaluating detection and suppression systems in motorcoach engine compartments.

- The detection and suppression system is installed per manufacturer direction and/or specifications.
- The installation remained unchanged for the twelve fire tests. In other words for a given single system configuration, all the tests are conducted with the same detector and suppression system (nozzle) locations. If the system design/configuration is changed, all tests will be conducted again for that new design/configuration.
- For all of tests described in Section 5.5 of this report, with the exception of the hot surface re-ignition test, the design fire must be extinguished.
- For all of tests described in Section 5.5 of this report, with the exception of the hot surface re-ignition test, the detection system must have activated prior to the end of the pre-burn time of the design fire.

- For the hot surface re-ignition test, the installed system must prevent re-ignition for a minimum of 150 seconds. This time limit is derived from a recent Volpe Center report, which discusses egress times from a full motorcoach after an accident [13].
- It is typical that detection and suppression systems that meet this test criterion also meet testing requirements for their individual system components. This is a common requirement of active fire protection systems. Successful fire testing is an important aspect of a good system, but the fire testing on its own does not address the robustness of the system design, with respect to individual component reliability. An example of this type of component testing method is FM 5320, *Approval Standard for Dry Chemical Extinguishing Systems, December 2013*.
- Additional details about the recommended test procedure and criteria can be referenced in Appendix H.

6.0 WHEEL WELL FINAL DESIGN, FIRE SCENARIO DEVELOPMENT AND TESTING

6.1 Wheel Well Fire Scenario Development and Final Design

The project team has determined, based on the literature and discussions with stakeholders (manufacturers, carriers, etc.), that the major heat sources for tire fires are (in order of importance):

1. Dragging brakes;
2. Failed bearings (these are becoming less frequent with the new "maintenance free" bearings which do not require addition of lubricant oil). However, there still are a significant number of coaches on the road with the older style bearings that fail more readily without good maintenance
3. Underinflated tires (especially the inner tire of a set of dual drive axle tires). The National Transportation Safety Board (NTSB)/Greyhound track tests were not able to cause a fire this way (they stopped the test at thread separation) [12]. However, NTSB has implicated underinflated tires in another motorcoach fire investigation, and most experts still believe that under inflation can cause fires;

The most vulnerable tires to overheat are on the tag axle (un-driven axle), followed by the drive axle, and then the steering tires. An early warning sensor system would have a higher likelihood of success than an active detection and suppression system in the wheel well area. This is due to the fact that the wheel well is an extremely challenging fire area, due to its relatively open geometry, harsh environment, and the aggressive nature of a tire fire. If an impending fire event can be detected prior to heating the tire to its ignition temperature, then it should be possible to avoid the event before it starts. A wheel well fire early warning system test procedure has been developed, which evaluates sensors and algorithms that can detect a hot wheel in advance of a tire fire.

This test procedure is based on a single tag axle that is supported at one end with a bearing structure and driven by an electric motor connected to the wheel lug nut assembly. The wheel is heated by partially engaging the brakes on the tag axle, causing heat to be transferred through the rotor and wheel assembly and into the tire. There is also direct radiative heat transfer from the hot brake components to the inside of the wheel. The goal is to show that some quantity can be measured and used to predict an abnormal wheel heating condition, and to warn the driver before a tire fire would develop.

Based on the work conducted by NIST, tires are estimated to ignite at approximately 400 °C [3]. Currently available Tire Pressure Monitoring System (TPMS) sensors measure the temperature and pressure of the air inside the tire. These existing sensors can be set to issue a high temperature alarm at a specific temperature (adjustable by user). This alarm temperature can be considerably higher than what is encountered during hard braking and thus should not result in excessive false alarms.

It is important to show that the heat stored in the metal components is not enough to exceed the ignition temperature and allow a fire to start even after the wheel (motorcoach) has stopped. Therefore, two extended tests were conducted until a tire fire/blowout was observed. This demonstrated that the test fixture is sufficient to add enough heat into the system for a dangerous event, and also allow the study of the temperature distributions up to that point. Finally, this information can be used analytically to quantify the margins between false alarms and an actual tire fire. Figure 37 provides several views of the final wheel well test fixture design. Appendix I provides detailed drawings of the wheel well test fixture.

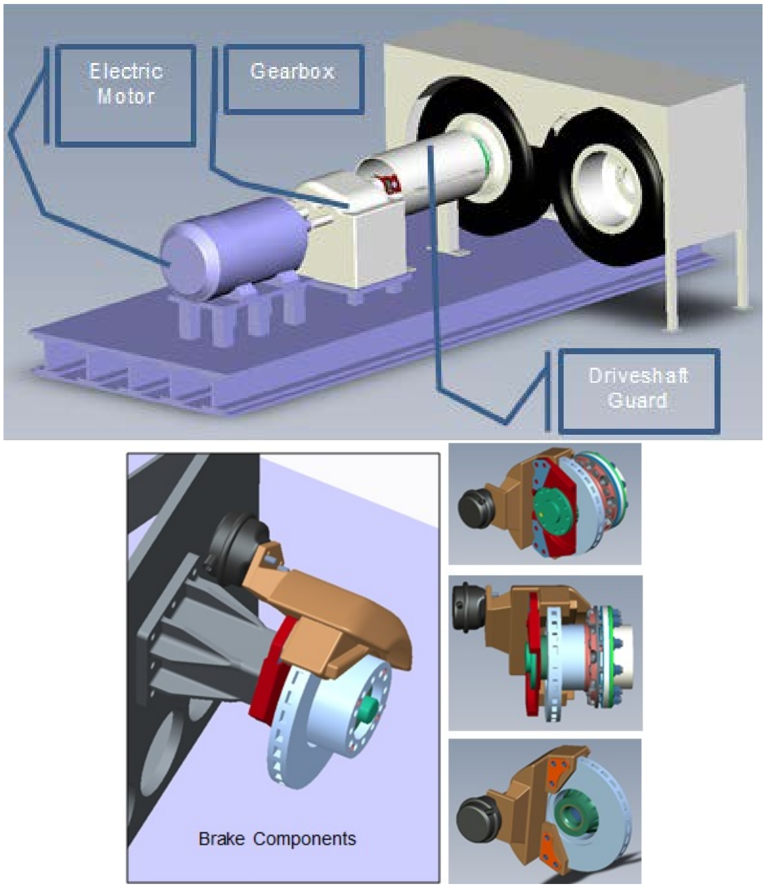


Figure 37. Motorcoach Wheel Well Test Fixture Final Design.

6.2 Wheel Well Test Fixture Fabrication

Figure 38 and Figure 39 show selected photographs of the fabricated wheel well early warning device test assembly.


Figure 38. Wheel Well Mockup Test Fixture (Overall Plan View).


Figure 39. Wheel Well Mockup Test Fixture (Ground Level View).

6.3 Wheel Well Test Fixture Instrumentation

Several measurements were taken during baseline and vendor testing in this fixture. Two DAQs were used; one for stationary measurements and one for rotating measurements.

On the stationary DAQ, 5 voltage output devices were used to measure pressure, speed, frequency and amperage. In addition, 14 thermocouples were used to measure temperature at various locations. Table 9 summarizes the channel layout on the stationary DAQ. Figure 40 depicts selected stationary thermocouples that were important to the development of the fixture test procedure. Additional information is provided about the brake pad temperature measurements in Section 6.5 of this report.

On the rotating DAQ, 6 thermocouples were used to measure temperature at various locations. Figure 41 shows a photograph of the rotating DAQ transmitter. Thermocouples were hard-wired between this module and the measurement location. This module then transmitted the temperature data to a receiver, which was connected to a laptop where the data was stored. Table 10 summarizes the channel layout on the rotating DAQ. Figure 42 and Figure 43 depict the six rotating thermocouple locations.

Table 9. Summary of Stationary Wheel Well Test Fixture Instrumentation.

Device No.	Device Identification	Device Units	Comments
1	Brake Pressure	psig	Use to measure pressure applied to brake caliper piston
2	Oil Pressure	psig	Used to measure pressure in gearbox
3	Tachometer	RPM	Used to measure rotational speed of test tire
4	VFD Frequency	Hz	Used to measure the rotational speed of the electric motor
5	VFD Current	Amps	Used to measure the current draw of the electric motor
6	Rear Rim *	°C	Aimed at inner part of rear side of test rim
7	Front Rim *	°C	Aimed at inner part of front side of test rim
8	Rear Rim Near Tire Bead *	°C	Aimed at rear side of test rim, close to the tire bead intersection
9	Rotor *	°C	Aimed at brake rotor
10	Top of Caliper Housing	°C	This is the component that the brake caliper bolts to – top
11	Top of Torque Plate	°C	This is the component that the brake caliper bolts to – middle
12	Bottom of Torque Plate	°C	This is the component that the brake caliper bolts to – bottom
13	Weld Pad Spindle	°C	Used to measure heat transferred out of test apparatus
14	ABS Sensor Location	°C	A thermocouple probe was inserted into the ABS sensor port
15	Brake Pad	°C	A thermocouple was inserted into the brake pad material
16	Wheel Well: Above Non-Test Tire (Drive Axle)	°C	Air temperature 1-in. above non-test tire
17	Wheel Well: Middle Between Tires	°C	Air temperature 1-in. above tire elevation, between tires
18	Wheel Well: Above Test Tire (Tag Axle)	°C	Air temperature 1-in. above test tire
19	Wheel Well: Above Test Tire (1-in below Housing)	°C	Air temperature 1-in. below wheel well housing over test tire

* These devices are optical thermometers – they were used to determine if some of the rotating measurements could be taken with stationary devices. Most of these data are not provided in this report, since it was determined that the measurements are greatly affected by the hot rotor and since the heat exposure is being cycled, the emissivity of the rotor fluctuates greatly, which makes it difficult to tune the optical thermometer to the correct range. Based on this testing, it is recommended to use a DAQ and instrumentation similar to what is described in Table 10 if rotating data is desired.

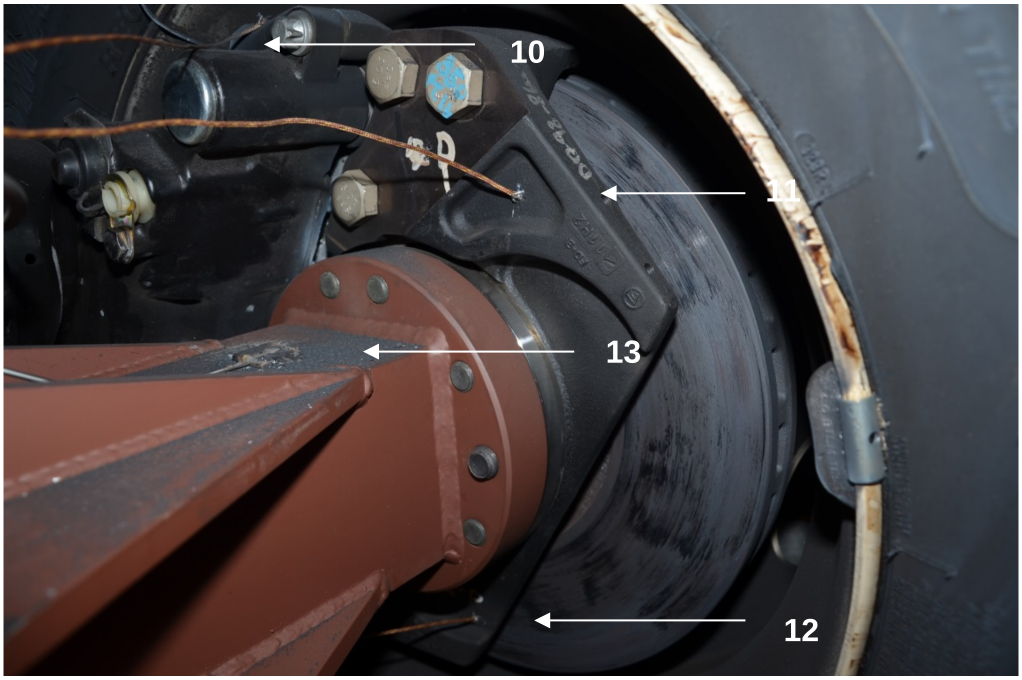


Figure 40. Selected Stationary Temperature Measurement Locations.

Table 10. Summary of Rotating Wheel Well Test Fixture Instrumentation.

Device No.	Device Identification	Device Units	Comments
1	Front Rim – Tire Bead	°C	Located close to the tire bead on the front of the rim
2	Front Rim – Middle	°C	Located closer to the middle of the rim on the front
3	Hub	°C	Located on coupling to universal joint that drives tire – measures heat that is lost through the front of fixture
4	Back Rim – Middle	°C	Located closer to the middle of the rim on the back (opposite No. 5)
5	Back Rim – Middle	°C	Located closer to the middle of the rim on the back (opposite No. 4)
6	Back Rim – Tire Bead	°C	Located close to the tire bead on the back of the rim

Figure 41. Rotating DAQ Transmitter.

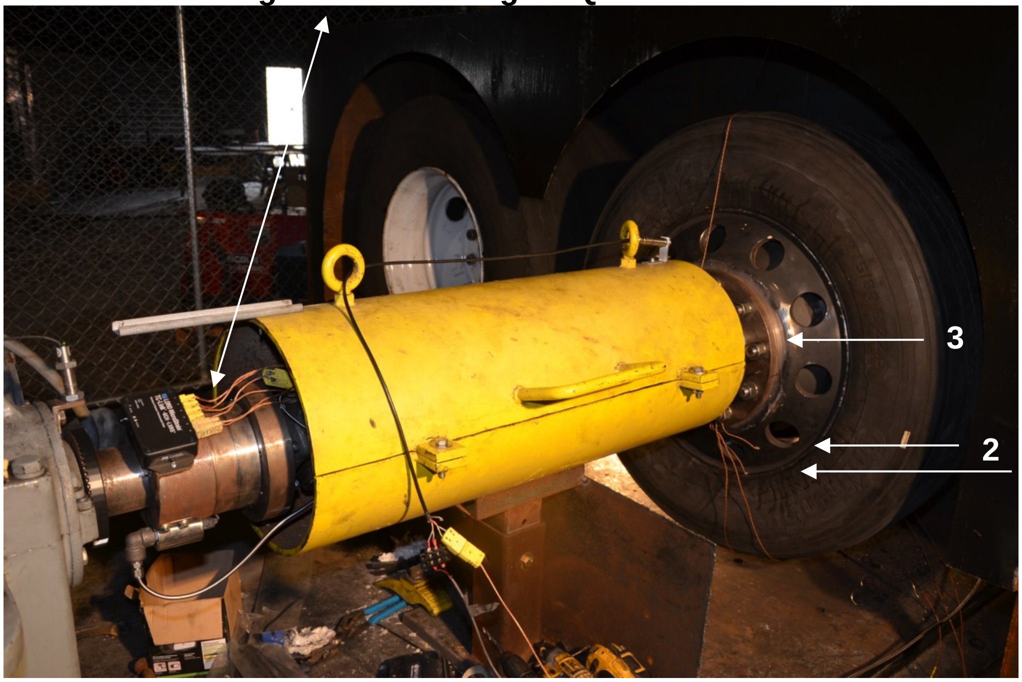


Figure 42. Rotating Temperature Measurement Locations (Front of Rim).

Figure 43. Rotating Temperature Measurement Locations (Back of Rim).

6.4 Wheel Well Test Fixture Baseline Testing

After the fabrication and installation of the final test fixture was complete, a series of baseline tests were conducted to checkout instrumentation and to map the current drawn from the motor to the applied torque to the system.

The applied torque was measured with a torque meter as a function of the current draw from the motor and applied brake pressure for a variety of wheel speeds. This allowed for the development of a calibration curve that correlates amperage and brake pressure to applied torque. Figure 44 and Figure 45 shows the relationship between torque, motor current draw and applied brake pressure.

Subsequent to these baseline tests, the torque meter was removed from the system and replaced with a shear coupling that occupied the same physical space. The shear coupling limits the torque that can be applied to the wheel and thus adds a measure of safety to the system.

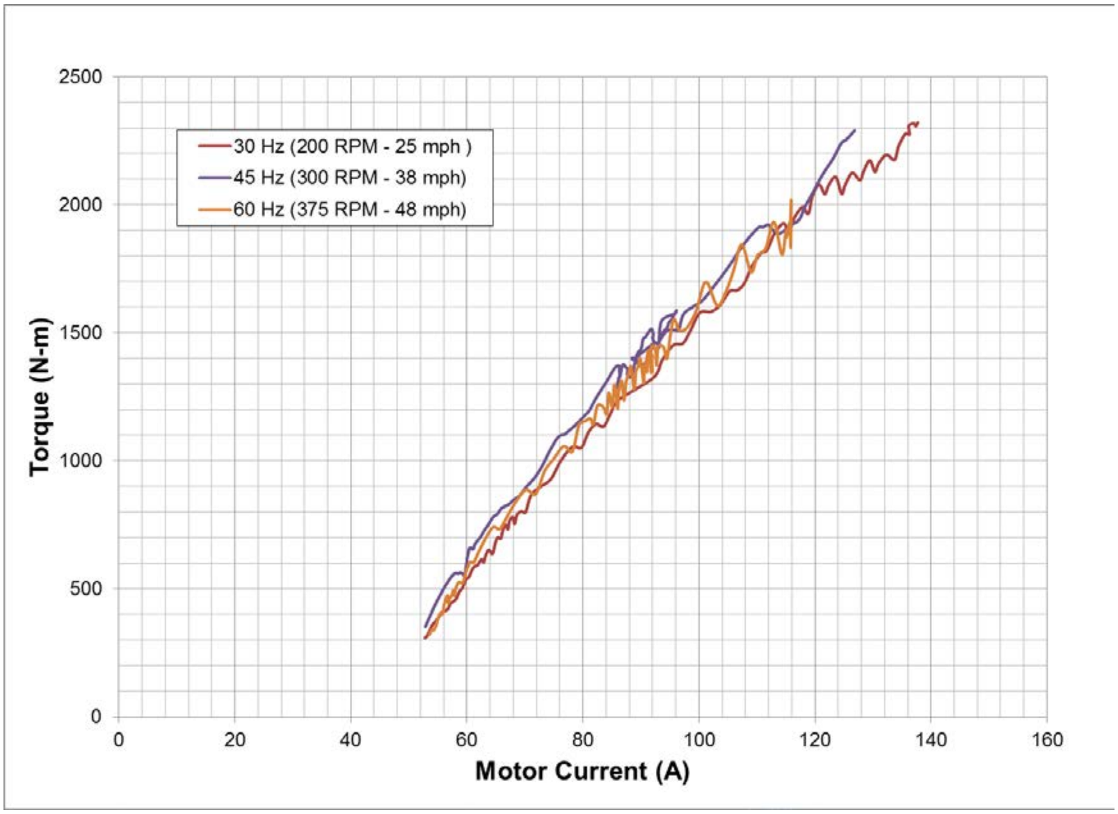


Figure 44. Torque as a Function of Motor Current Draw.

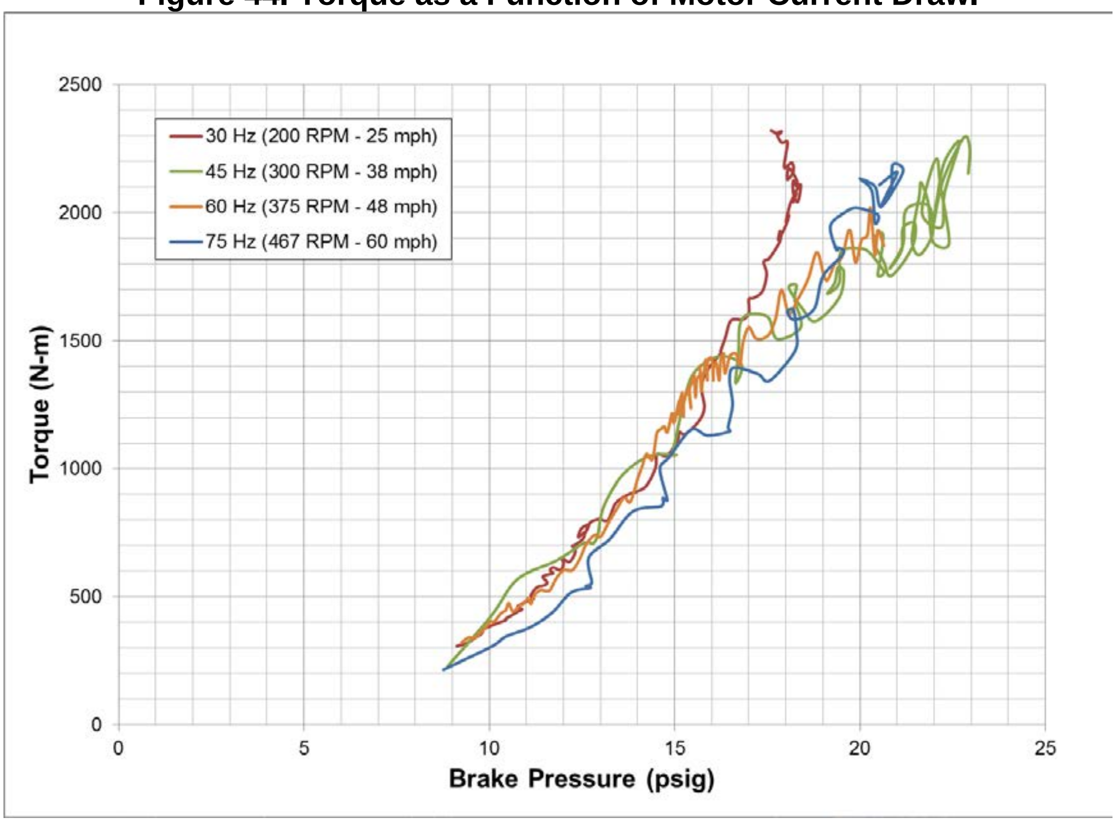


Figure 45. Torque as a Function of Applied Brake Pressure.

A baseline test was performed without a vendor sensor to determine how the wheel assembly heats up when a nominal 2000 N-m of torque was applied. During this baseline test, a phenomenon called ‘brake fade,’ or ‘brake glazing’ was observed. This phenomenon occurs when the brakes are brought to a significantly elevated temperature without any burnishing, or breaking-in, of the brake pads.

Figure 46 shows the brake pad installation location and a photographic comparison of brake pads that have and have not been glazed. As a result of this observation during the first test, the brake pads were burnished in advance, the heating rate was modified and the final test procedure includes a cycling heat exposure, rather than a constant exposure.

Figure 46. Left: Brake Pad Installation, Right: Brake Pad Comparison (Left: Glazed, Right: New).

An additional baseline test was taken to tire failure and subsequent fire. In this test, instead of attempting to apply maximum torque for maximum duration, maximum torque was applied for shorter durations and the entire assembly was brought to an elevated temperature more slowly and brake fade was avoided. This allowed the development of a much higher temperature of the overall wheel assembly than observed in the first test.

At the end of this test, while the wheel was coasting to a stop, a catastrophic blowout of the test tire was observed, which led to a small fire as a result of the tire being blown onto the hot components of the brake assembly, as well as the grease from the failed bearing. This fire was immediately suppressed and not allowed to develop. This event provides input to the development of a reasonable upper limit to observe sensor activation. Figure 47 provides a photograph of the stationary thermocouple locations on the torque plate and also various photographs of the wheel well test fixture components after this event. Figure 48 and Figure 49 provides selected data from this test.

Figure 47. Wheel Well Test Photographs: Top Left: Torque Plate Thermocouple Locations, Top Right: Just After Blowout, Bottom Left: Wheel Removed, Note Sheared Rotor Hub Assembly, Bottom Right: Rotor Hub Removed, Note Failed Bearing.

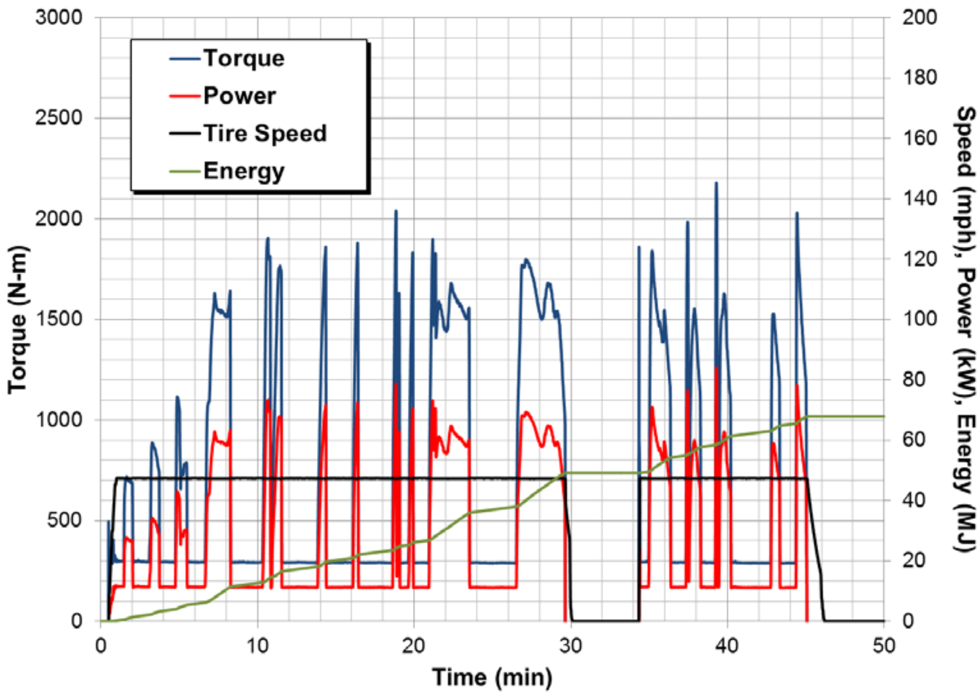


Figure 48. Heat Input Data from Tire Blowout/Fire Test.

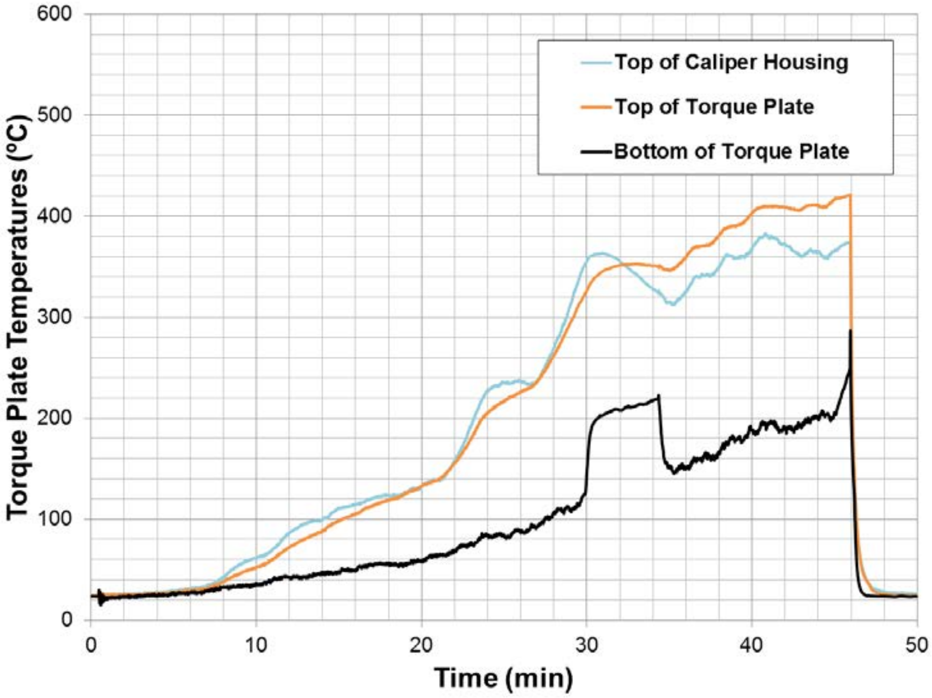


Figure 49. Selected Temperature Data from Tire Blowout/Fire Test.

6.5 Brake Glazing and Recommended Burnishing Procedure

After brake glazing was observed in initial baseline and vendor testing, the topic was investigated to determine a way to burnish the brake pads that would allow their extended use during this testing. The objective is to provide the best chance to supply maximum torque through the system. If possible, it would be a simpler test procedure to apply maximum torque until sensor activation or fire. However, this might not be a realistic objective.

Several options were considered for burnishing (or breaking–in) of the brake pads. Most brake pad manufacturers have recommendations for an abbreviated burnishing procedure. In addition, it was determined that there is a DOT precedent for burnishing pads in FMVSS 121D, *Laboratory Test Procedure for Air Brake Systems – Dynamometer, TP-121D-01.* This is an approval test procedure for evaluating air brake systems on a dynamometer.

There is a burnishing procedure in Section 12 of this document. An excerpt of this procedure is as follows:

> *Place the brake assembly on an inertia dynamometer and adjust the brake as recommended by the brake manufacturer. Make 200 stops from 40 mph at a deceleration of 10 ft/s/s, with an initial brake temperature on each stop of not less than 315 °F and not more than 385 °F. Make 200 additional stops from 40 mph at a deceleration of 10 ft/s/s, with an initial brake temperature on each stop of not less than 450°F and not more than 550°F.*

The proposed test fixture in this project is not a commercial dynamometer, however, it is possible to follow this basic procedure and provide this standardized burnishing. This procedure requires the use of a brake pad thermocouple. This is briefly described in Section 6.3 of this report, but additional detail is provided here. A single Type K thermocouple is installed in the nominal center of the brake pad material of the brake pad on the piston side of the disk brake assembly. Figure 50 provides a photograph array of the brake pad thermocouple location and installation.

Figure 50. Brake Pad Thermocouple Location and Construction.

This full burnishing procedure was followed prior to the first test for Vendor B. An abbreviated burnishing test was carried out prior to the second test for Vendor B. The abbreviated procedure was the same as the full procedure, except the number of cycles at each temperature range was changed from 200 to 20. Figure 51 – Figure 54 shows the heat input and stationary temperatures measured during these two burnishing tests.

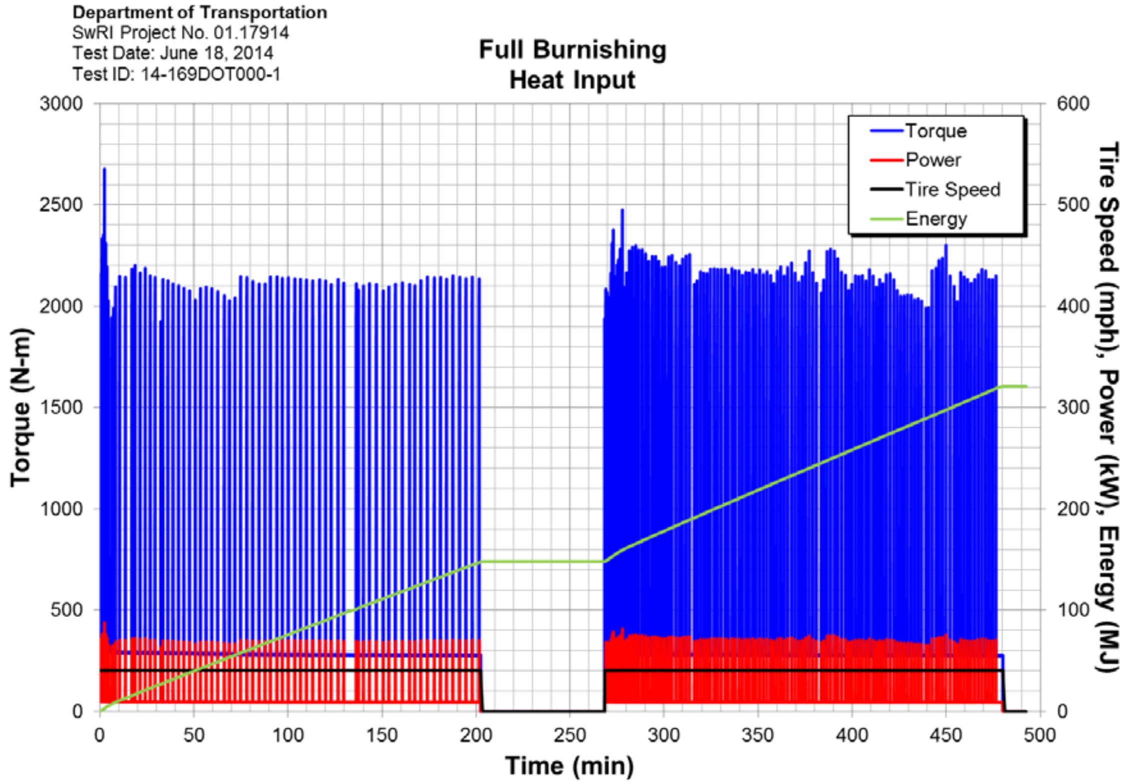


Figure 51. Full Burnishing – Heat Input.

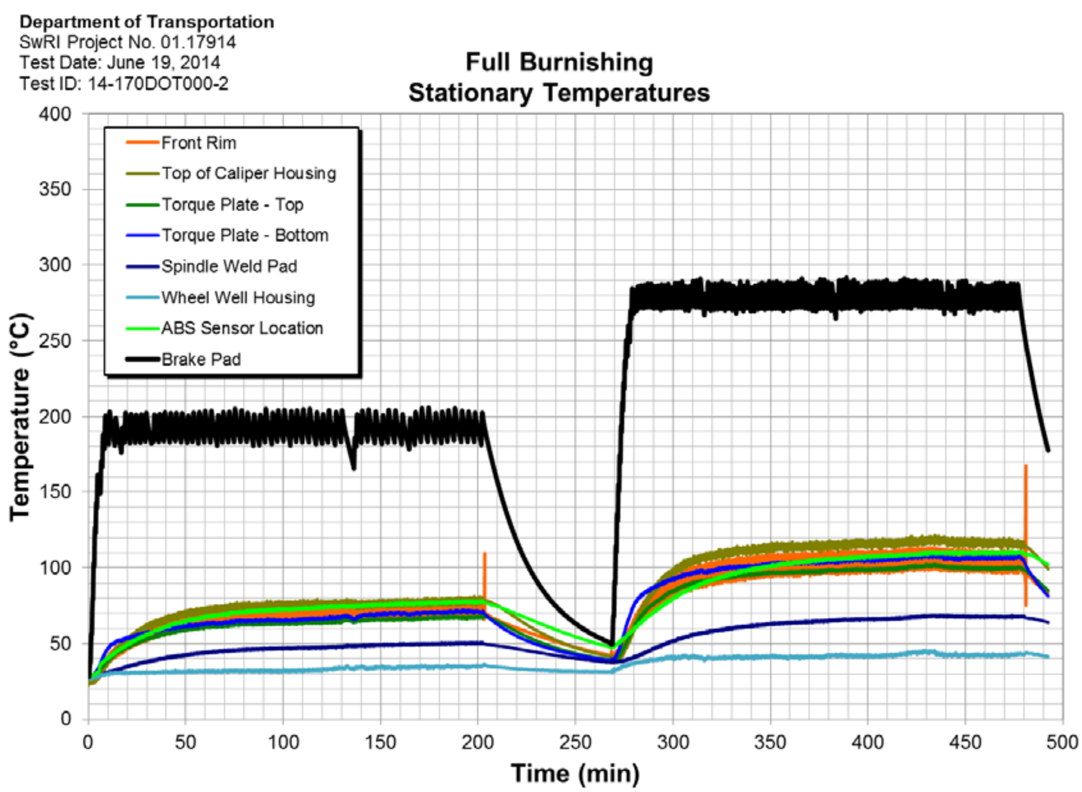


Figure 52. Full Burnishing – Stationary Temperatures.

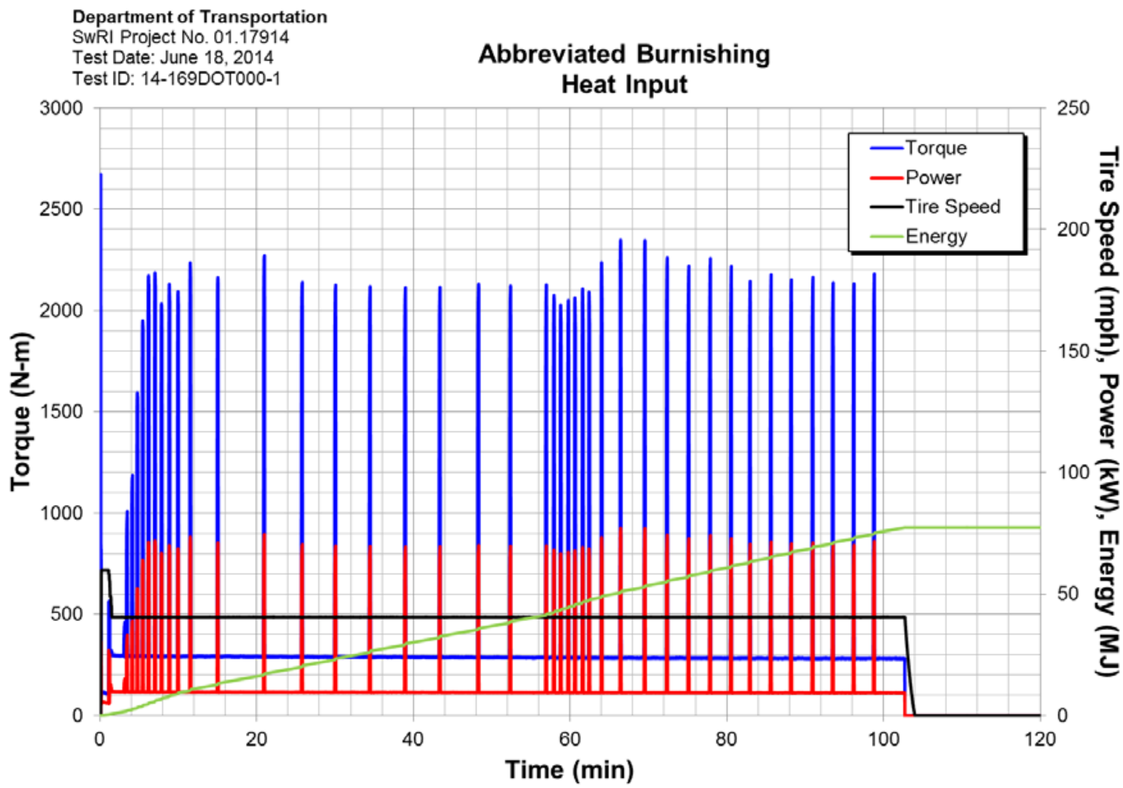


Figure 53. Abbreviated Burnishing – Heat Input.

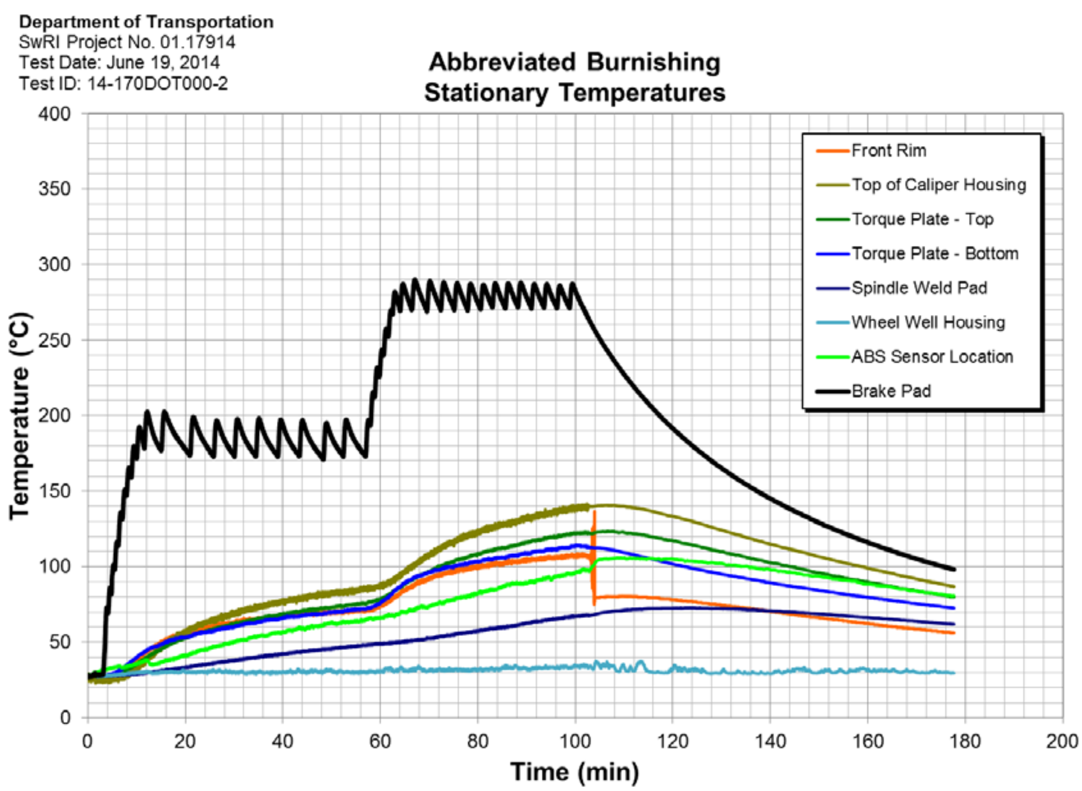


Figure 54. Abbreviated Burnishing – Stationary Temperatures.

In the first test for Vendor B, it was attempted to apply maximum torque for an extended period and observe whether brake glazing still occurred. Although, these brake pads were fully burnished, brake glazing was still observed after approximately 10 min, as can be observed in Figure 61.

For the second test for Vendor B, an abbreviated burnishing procedure was utilized and a cycling approach to the heat input as show in Figure 48. Since it did not appear that brake glazing could be completely avoided, it would be beneficial to show that an abbreviated burnishing procedure could still be useful in an aggressive cycling approach. In addition, burnishing the brake pads in some standardized way prior to each sensor evaluation test should add repeatability and reproducibility to the test procedure.

As can be seen in Figure 55 and Figure 56, the heat was able to be continuously added to the system through several cycles until a maximum stationary temperature (top of torque plate) was achieved that indicates a tire fire was imminent, at which point, the test was aborted.

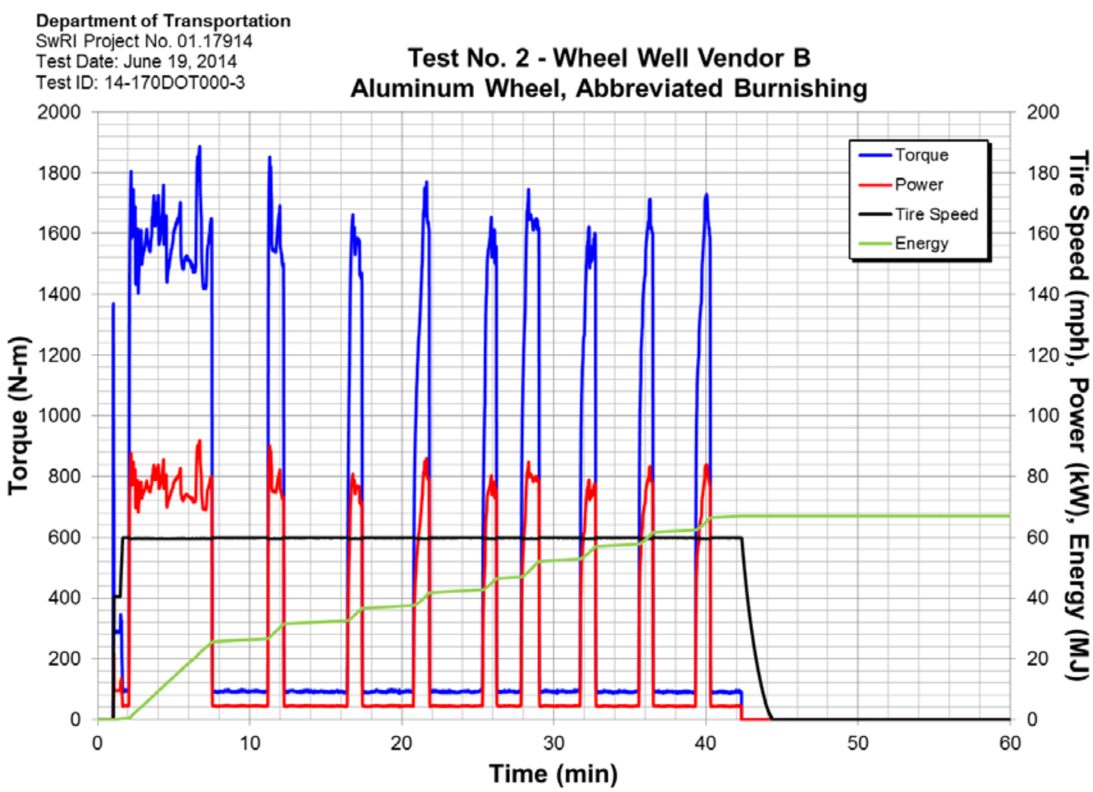


Figure 55. Vendor B: Test 2 – Abbreviated Burnishing – Heat Input.

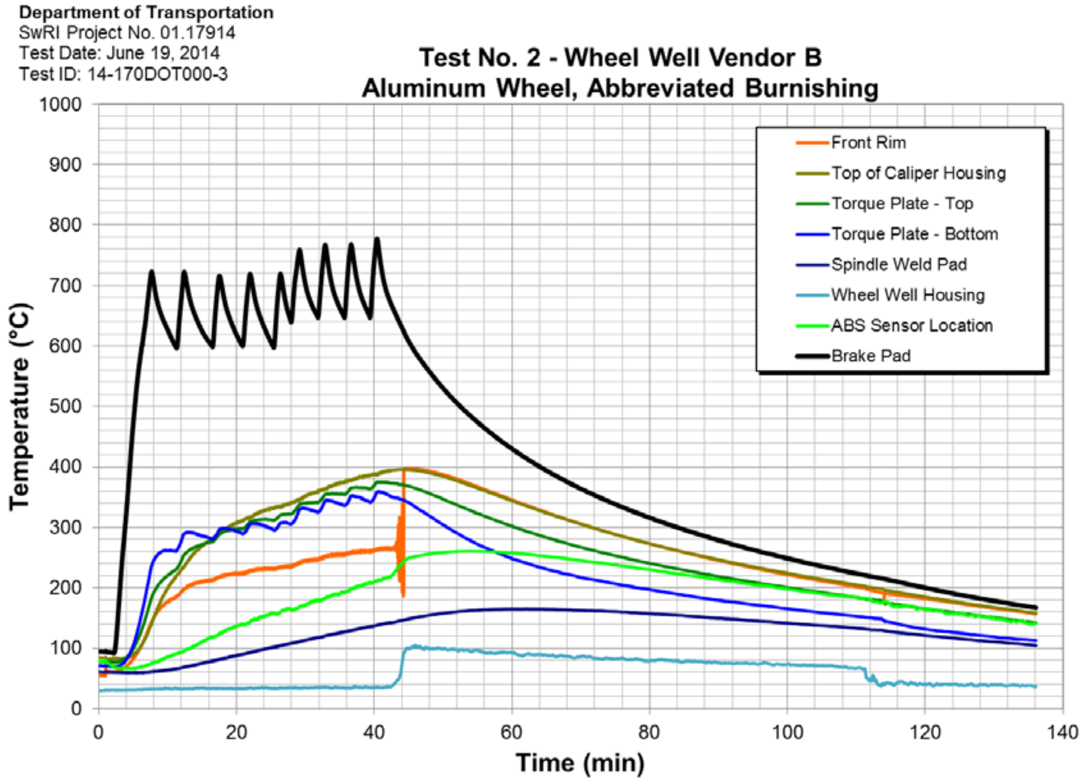


Figure 56. Vendor B: Test 2 – Abbreviated Burnishing – Stationary Temperatures.

Based on this testing and the discussion above, it will be recommended to perform the abbreviated burnishing procedure prior to each sensor evaluation test and the heat input procedure will be cyclical, rather than constant.

6.6 Aluminum versus Steel Wheels

Both aluminum and steel wheels were tested. For vendor A only steel wheels were used. For the other vendors both steel and aluminum wheels were tested.

To show the difference in the temperature response of aluminum vs. steel wheels both short duration and long duration tests were conducted. Short duration tests had heat input for about 20 minutes and dissipated about 40 MJ of energy. Figure 57 shows that the aluminum wheel heated somewhat faster than the steel wheel, but the difference is small. Due to the smaller amount of energy dissipated (compared to a longer test), the peak temperatures were less than 270 °C, which is well below the nominal tire ignition temperature.

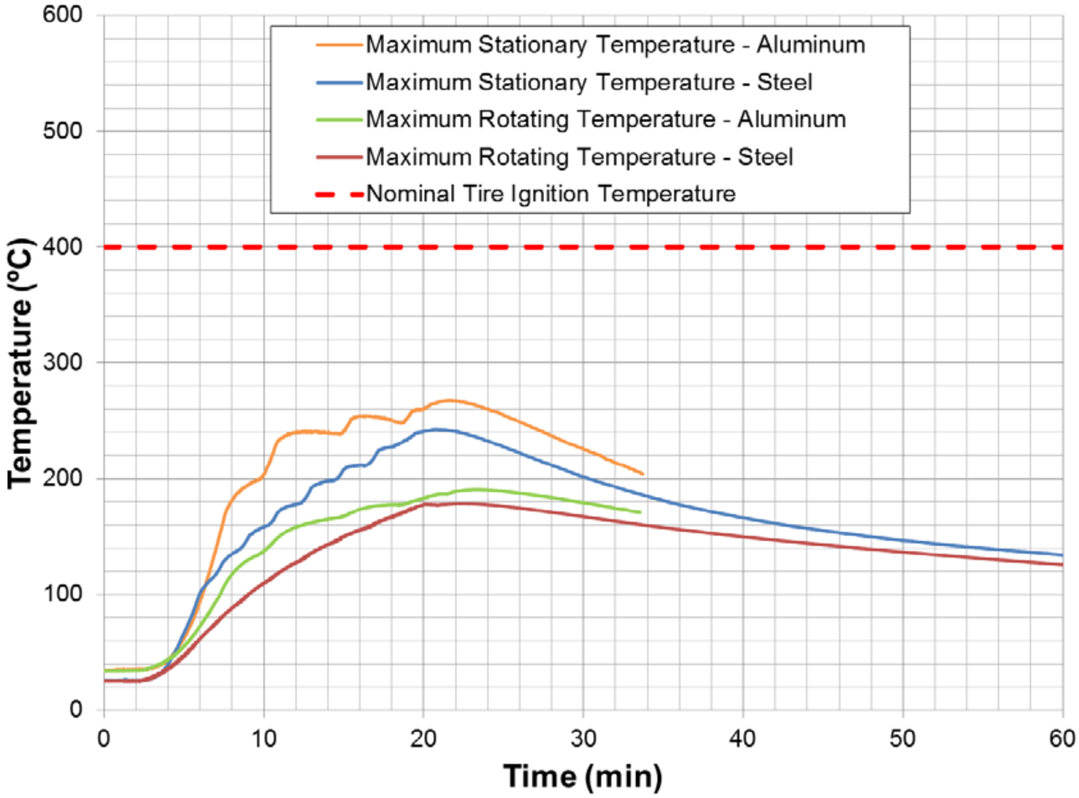


Figure 57. Comparison of Steel and Aluminum Wheel Temperatures in Short Test.

Figure 58 shows the long duration tests where the heat input was applied for up to 46 minutes and the total heat input was 70 MJ. The stationary temperatures for steel and aluminum were about the same with only about a minute of time difference. These temperatures reached 400 °C, however, the tire was not in contact with the stationary parts, so no ignition would have occurred. The rotating temperatures only got to about 260 °C, which is well below the ignition temperature. For these tests the rotating temperatures were determined by an optical IR sensor. These signals are noisier because the sensor saw the hot disk brake rotor through the holes in the wheel. This is especially noticeable when the wheel RPM is slowing down and stopping.

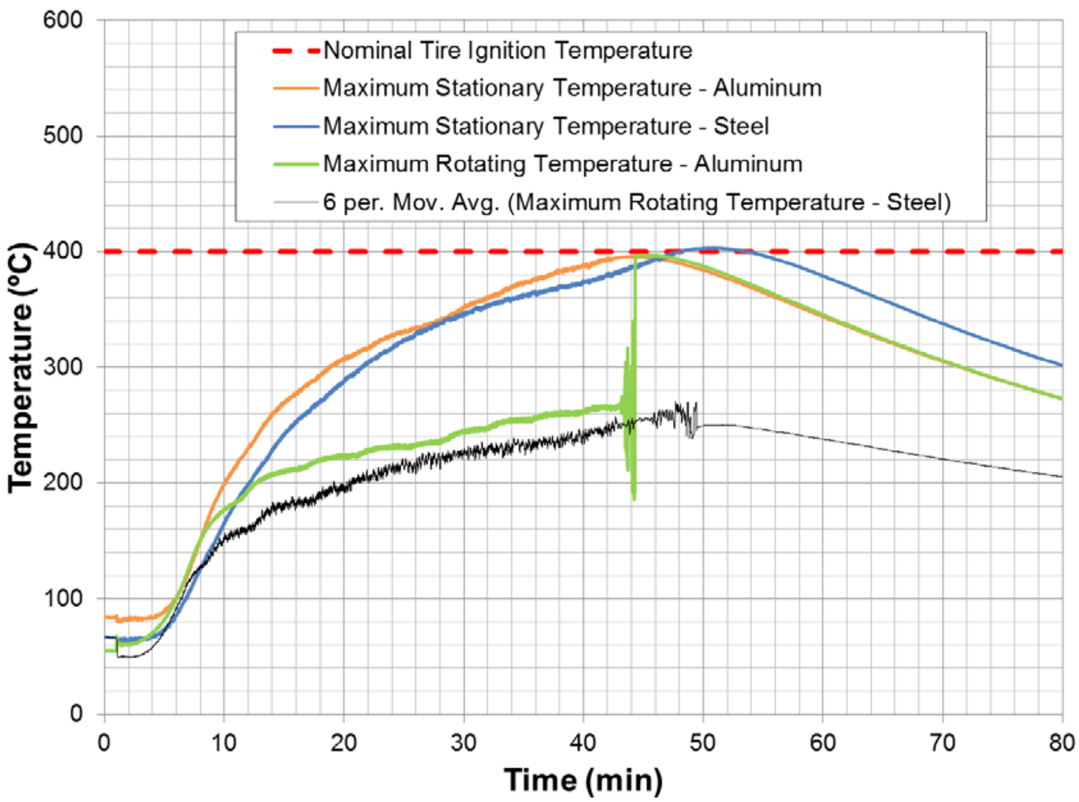


Figure 58. Comparison of Steel and Aluminum Wheel Temperatures in Long Test.

Based on these results and the majority use of aluminum wheels on motorcoaches, it is recommended in the final procedure to conduct tests with aluminum wheels.

6.7 Wheel Well Vendor Testing

This section provides a detailed summary of one representative test for each vendor, followed by an overall summary of all the tests conducted. The three wheel well vendors are completely different companies from the three engine compartment detection and suppression system vendors.

For each of the tests 4 major quantities were reported:

(1) Tire speed)MPH) (computed for wheel RPM – usually 60 MPH);

(2) Torque (N-m) (computed from motor alibration curves)

(3) Power (kW) (rate of heat dissipation – computed from torque and wheel RPM); and

(4) Energy (MJ) (total heat dissipated – integral of power versus time).

6.7.1 Vendor A Test Results

Test Device Description

The Tire Pressure Monitoring System (TPMS) sensor was mounted on the valve stem. The sensor has short spacers ("feet") on the bottom so that it doesn't directly contact the metal rim. This partially isolates the sensor from the temperature of the metal parts, and allows the sensor to measure the tire air temperature – which is what is needed for the TPMS compensated tire pressure measurement. There may be some conduction of heat to the sensor from the valve stem. There was a radio frequency (RF) connection to the electronic control unit (ECU). Several RF receiving antennas were attached to the safety cage about 15 feet from the tire being tested. The software was programmed to issue a hot wheel warning at 80 °C. The software was also programmed to issue a warning if there is a rapid pressure loss of more than 0.483 bar/min.

<u>Test Results</u>

The test was performed on May 20, 2014. The ambient temperature was 27 °C. All the tests for this vendor were done with steel wheels. Data recording and tire rotation was begun. See Figure 59. The tire rotation rate was equivalent to 60 MPH on the road. The air disk brake pressure was increased until the motor current was approximately 150 Amps. This occurred at approximately 20 psig. This corresponds to a torque of about 2700 N-m. The heat dissipation rate by the brake was approximately 135 kW. The total heat input during the test was approximately 35 MJ.

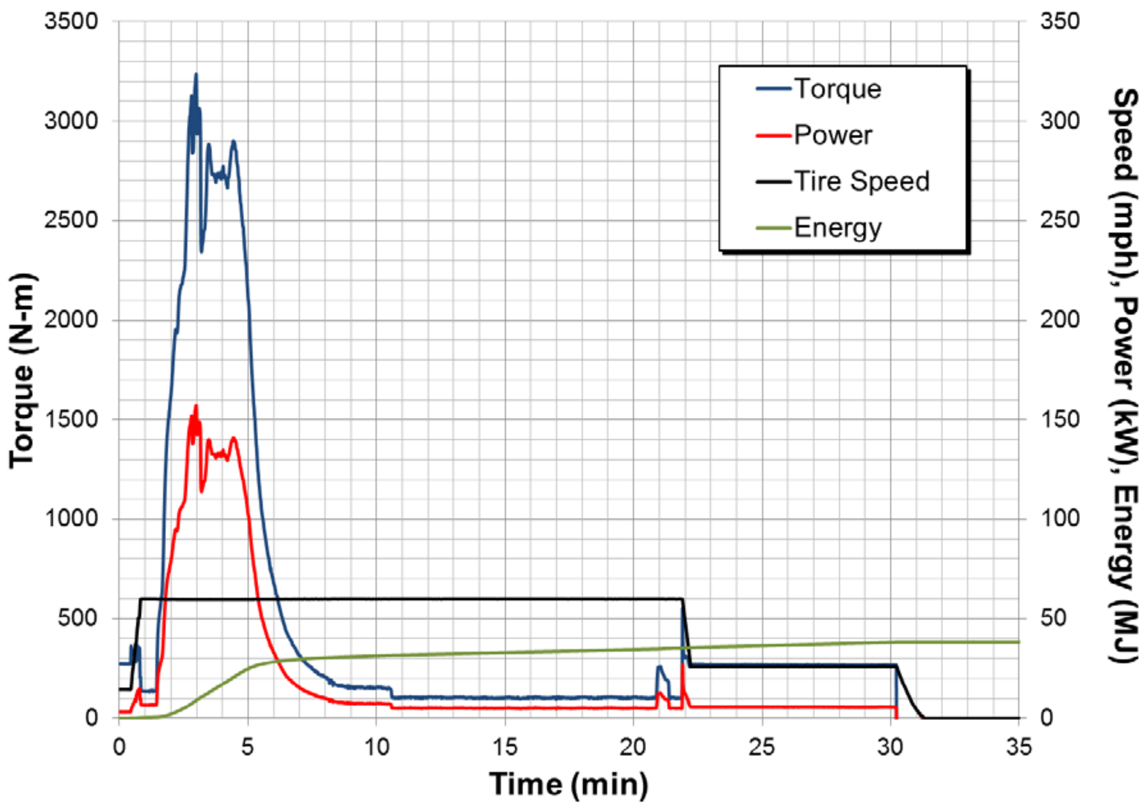


Figure 59. Vendor A Heat Input Data.

After about 5 minutes of heat input, the torque dropped to near zero because of brake pad glazing. Therefore the subsequent heat input power was near zero. A subsequent test showed that the torque could not be maintained under glazing conditions even at a brake pressure of 100 psig.

See Figure 60 for the summary of performance results. Plotted is the maximum stationary temperature measured (at the top of the torque plate) and the maximum rotating temperature (measured on the back of the wheel rim closest to the hot rotor). Also plotted in green are the temperature measurements from the Vendor A sensor.

Note that they lag the temperature measurements mounted on stationary and rotating metallic parts closer to the brake pad heat source. This implies that the sensor was measuring the temperature of the air in the tire and not the metal rim. It can be seen that the sensor output ramps up in a staircase fashion. This is because the sensor only reports to the ECU once a minute until an alarm code is received. Then it increases to a 1 Hz scan rate.

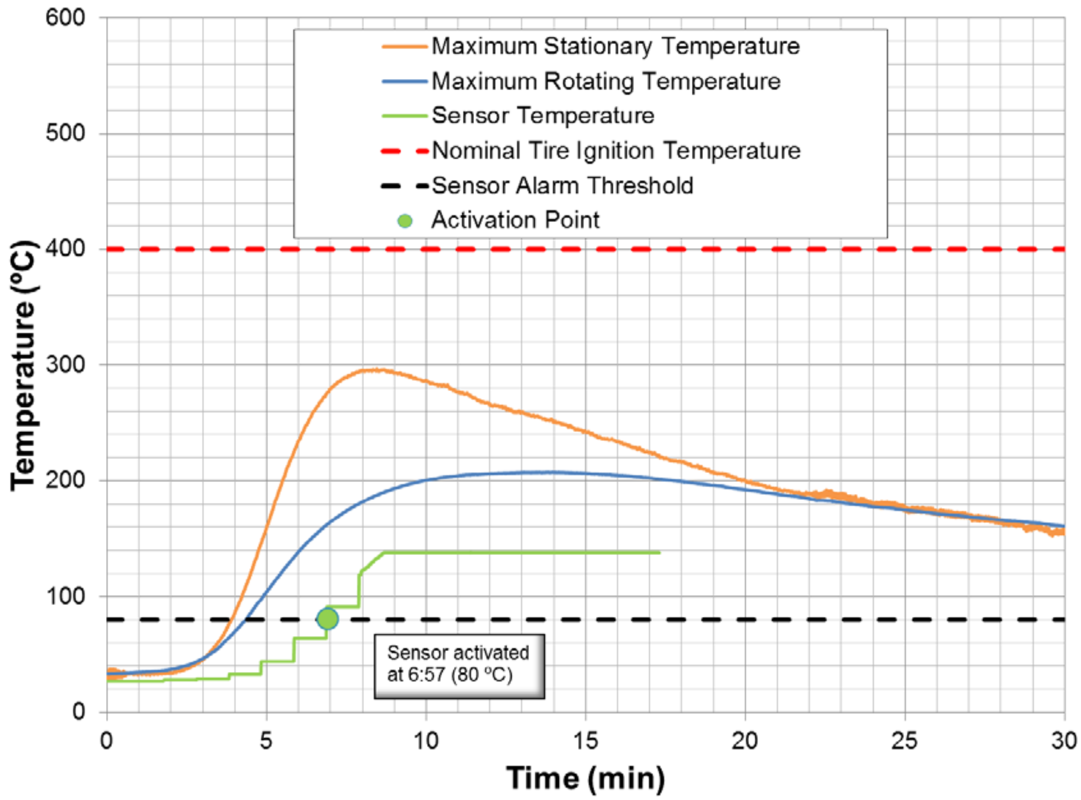


Figure 60. Vendor A Temperature Data.

The alarm was activated at approximately 7 min into the test. At this time the temperature of the stationary sensor was 290 °C, and the temperature of the rotating sensor was 160 °C. These temperatures are well below that of the tire ignition temperature of 400 °C. The temperature rise of the vendor sensor was rapid, and if the alarm set temperature was 100 °C (20 C above the nominal set point) the alarm time would only increase by about one minute.

This test shows that the Vendor A system can adequately warn the driver in advance of a tire fire. But it is important that the driver act quickly to stop the motorcoach and let the wheel cool. Appendix J can be referenced for additional summary plots for Vendor A.

6.7.2 Vendor B Test Results

Test Device Description

The TPMS tested is still under development and not yet available commercially. The sensor is embedded in a round rubber casing about the size of a hockey puck. It is designed to be adhesively mounted on the inside tread surface of the tire. An RF link sends the data to a Central Control Unit (CCU) which contains the receiving antenna and the receiver. An additional antenna/receiver unit can be installed for axles that are far to the rear. The electronic output signal is transmitted to a dedicated driver's display. The driver's display can be toggled between a display of tire pressure and a display of tire temperature. A preset high temperature alarm was set for 115 °C. If activated, the display provides an audible and flashing light alarm.

Test Results

The test was conducted on June 18, 2014. To prevent brake pad glazing the brake pads were burnished. The test duration was about 50 min with heat applied in two segments – the first about 20 min long, and the second about 3 min long. Figure 61 shows that the tire speed was 60 mph, the max torque was about 1500 N-m, and the heat input was about 75 kW.

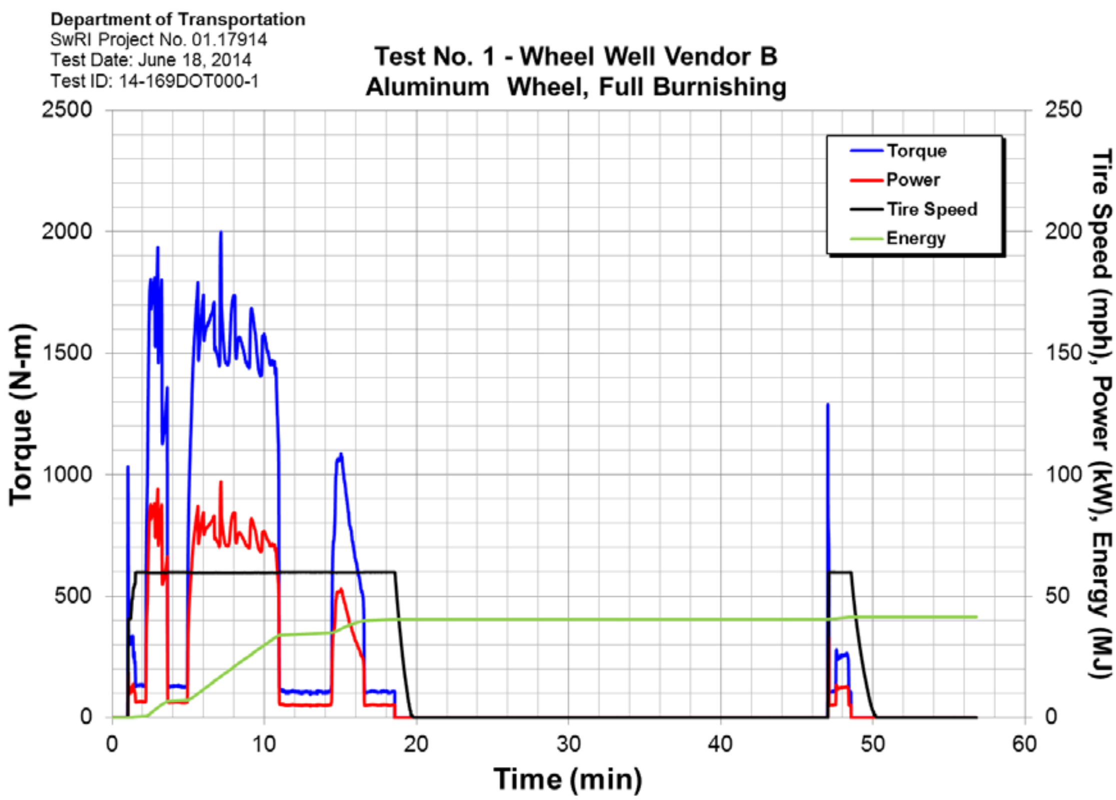


Figure 61. Vendor B Heat Input Data.

Figure 62 shows the maximum stationary and rotating temperatures as well as the vendor sensor temperature as a function of time. The vendor sensor display readings were videotaped and subsequently transcribed into Excel to provide this plot.

For this test, an alarm was not received before the test was terminated. The stationary temperature was 330 °C, and the maximum rotating temperature was 245 °C. At the time of the peak temperatures experienced in this test (approximately 17 minutes) the vendor temperature sensor was reading only 30 °C. The highest temperature the sensor recorded near the end of the test was approximately 68 °C.

If the alarm sensor was set to a lower temperature, e.g., 60 °C, then an alarm would have been received. But this temperature may be so low that the false alarm rate would be unacceptably high. It is likely that the tread of the tire is just too far away from the heat source (the hot rim), and has a lot of air-cooling from the tire rotation. This result in no way detracts from the primary function of this sensor, which is compensated tire pressure monitoring. Appendix K can be referenced for additional summary plots for Vendor B.

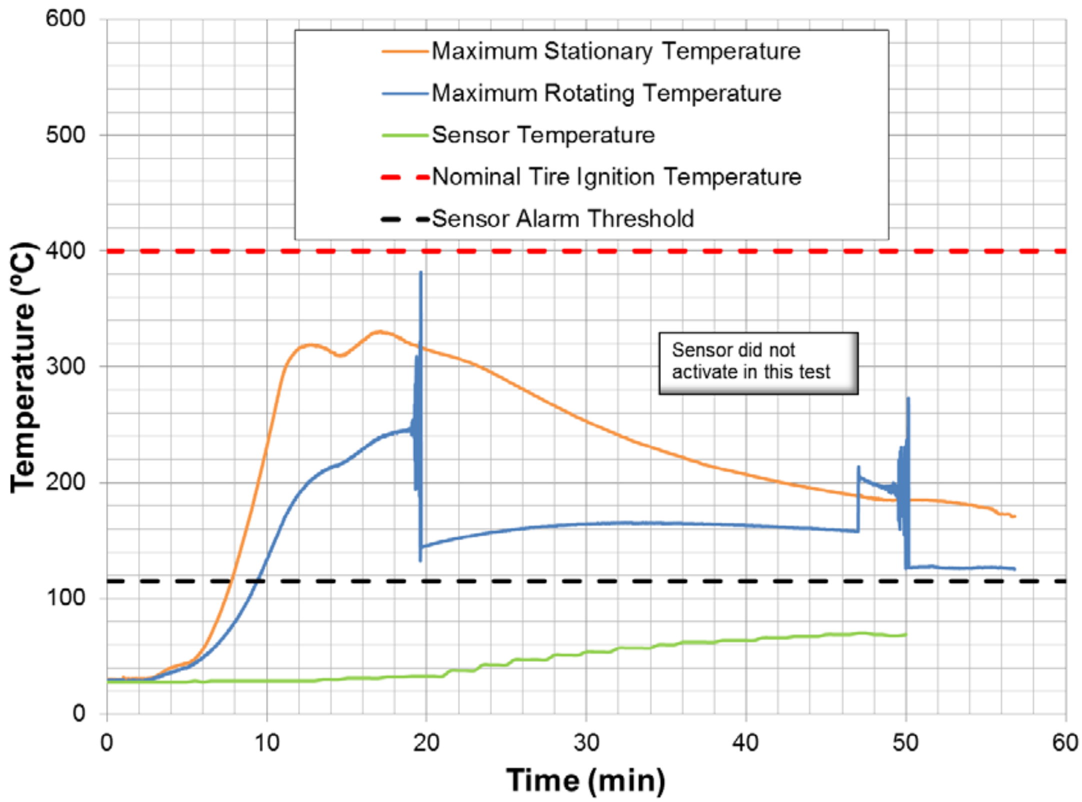


Figure 62. Vendor B Temperature Data.

6.7.3 Vendor C Test Results

Test Device Description

This TPMS is mounted on the part of the wheel closest to the wheel hub and bearing. It is held in place by a long stainless steel strap (like a long radiator hose clamp) and tightening device. The sensor has short spacers (“feet”) on the bottom so that it doesn’t directly contact the metal rim. This partially isolates the sensor from the temperature of the metal parts, and allows the sensor to sense the tire air temperature – which is what is needed for the TPMS compensated tire pressure measurement. There was an RF connection to the Electronic Control Unit (ECU). The RF receiving antennas were located approximately 15 feet from the tire being tested. The software was programmed to issue a hot wheel warning at 85 °C.

Test Results

Three tests were performed on June 24 – June 26, 2014. Test 1 is reported in this section. Figure 63 shows the test inputs. You can see that there were four periods of heating. The first was about 5 minutes in duration – followed by three small heat input bursts of about 1 min each. The tire rotation was equivalent to 60 MPH. The torque was about 1600 N-m and the input power was about 75 kW. The total energy released in the test was about 39 MJ.

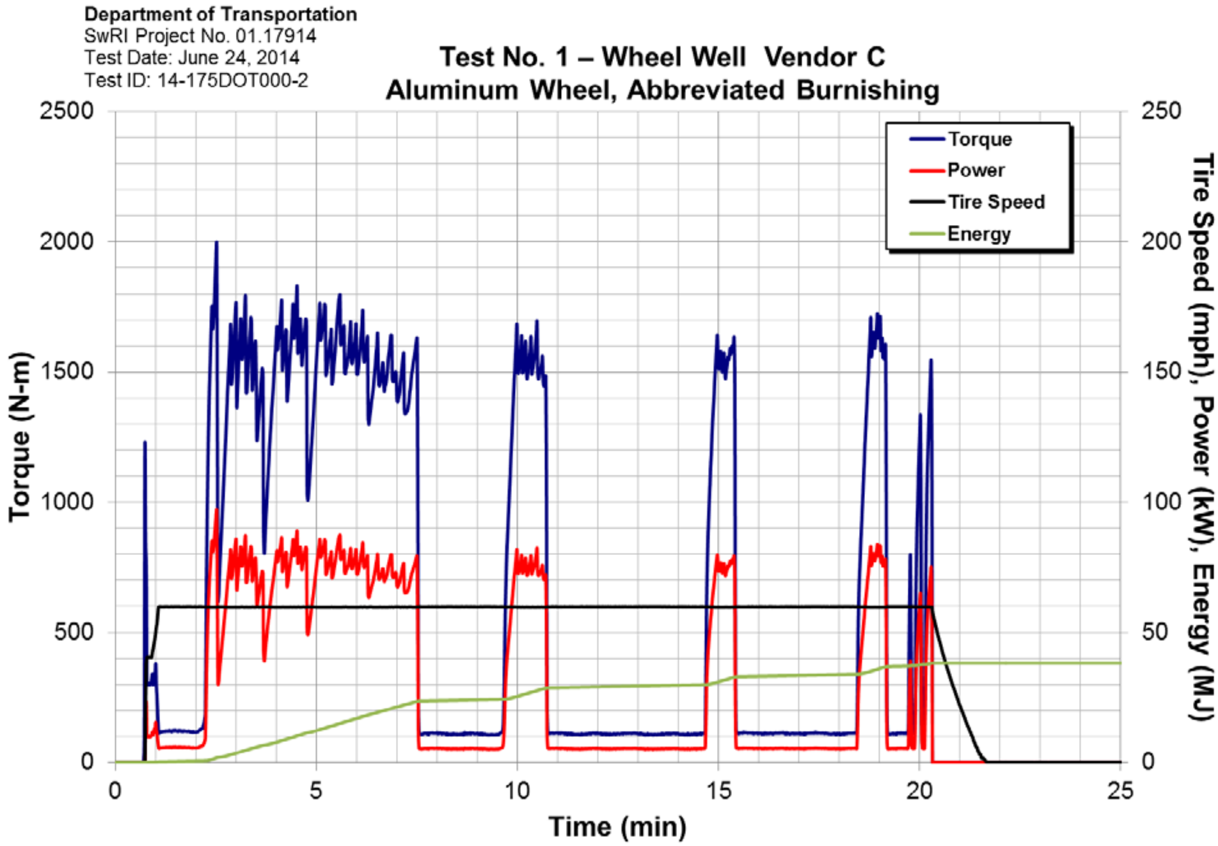


Figure 63. Vendor C Heat Input Data.

The temperature results are shown in Figure 64. Two different vendor sensors were tested. Sensor 1 is the commercial sensor which has higher “feet” under it, and thus is less coupled to the metal wheel. Sensor 2 is a device under development which has shorter feet and thus responds more quickly to wheel heating. The temperature alarm set point was 85 °C. You can see that sensor 1 triggered at approximately 18 minutes, and sensor 2 at approximately 11 minutes. At the time of the sensor 1 alarm, the max stationary and rotating temperatures were 250 °C and 180 °C, respectively. At the time of the sensor 2 alarm the stationary and rotating temperatures were 240 °C and 150 °C, respectively.

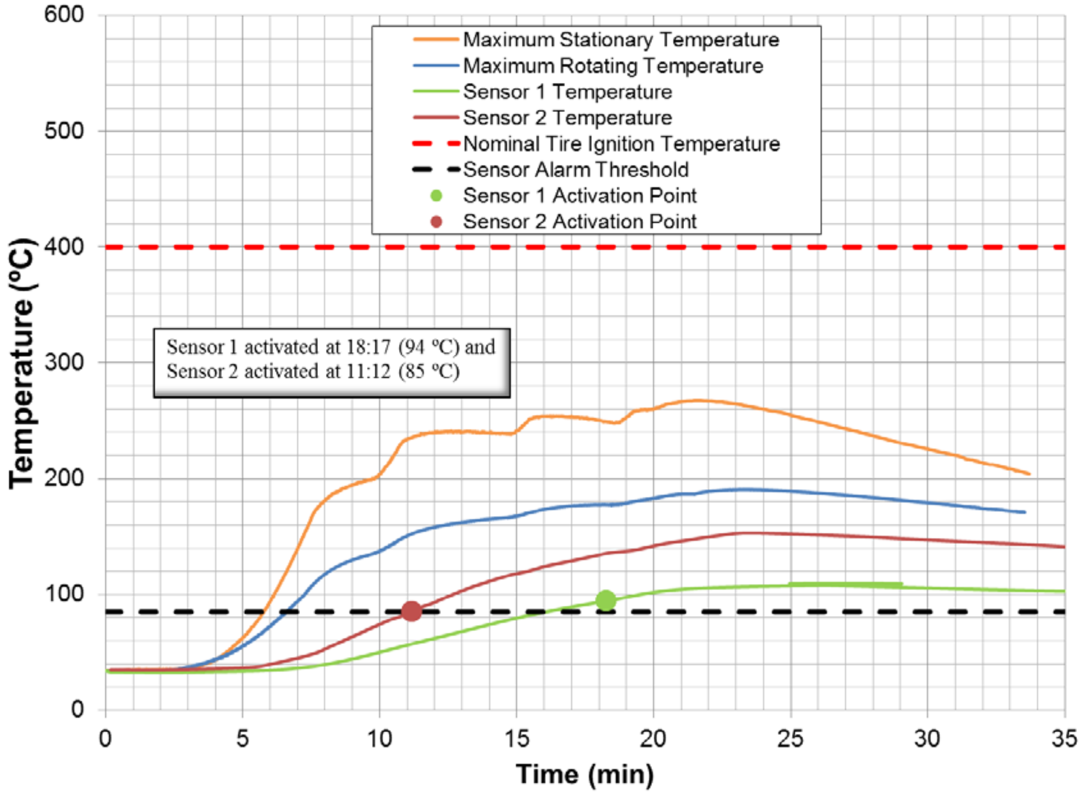


Figure 64. Vendor C Temperature Data.

Note that the temperatures continued to rise after each heat cycle. Sensor 2, with the shorter feet, triggered about 7 min earlier than Sensor 1, and thus would provide more warning time to the driver. Note that the stationary temperatures are well below the nominal tire ignition temperature – so either sensor should be adequate to provide warning. Appendix L can be referenced for additional summary plots for Vendor C.

6.7.4 Summary

Table 11 shows a summary of the heat input characteristics for all tests. The test procedure slowly evolved to an initial heat input of approximately 3 to 6 minutes, followed by a series of nominal one minute cycles of heat input. Some of the tests were "short" about 20 min, and others long about 40 min, depending on the response of the sensor under test. The max torque was about 1600 N-m, and the max power dissipated was from 75 to 80 kW, with the exception of the first calibration and Vendor A test with extreme brake glazing. The total energy dissipated was about 40 MJ for the shorter tests and 70 MJ for the longer tests.

Table 11. Summary of Heat Input during Wheel Well Testing.

Test	Test number	Type of wheel	Duration to end of heat input (min)	Number of heating pulses	Duration of pulses (min)	Max Torque (N-m)	Max Power (kW)	Total Energy Dissipated (MJ)	Comments
Baseline - Checkout and Calibration	1	Steel	5	1	5	3100	150	43	The brake pads glazed on this test and the applied torque dropped to near zero after less than 6 minutes of exposure
Baseline - Checkout and Calibration	2	Aluminum	45	24	3,2,then 22 cycles of 1 min each	1600	87	95	Brake pads started glazing at 45 minutes and the test was ended at 50 minutes.
Vendor A	1	Steel	5	1	4	2800	154	39	Brake pads glazed, no burnishing
	2	Steel	45	16	1 or 2 min.	1700	70	68	No burnishing, tire burst at end when bead separated from rim
Vendor B	1	Aluminum	19	3	1,3,1	1600	75	42	Full burnishing
	2	Aluminum	40	9	6,then 8 cycles of 1 min each	1600	80	68	Abbreviated burnishing
	3	Steel	46	16	4,then 15 cycles of 1-min each	1700	80	73	Abbreviated burnishing
Vendor C	1	Aluminum	21	5	5,1,1,1,1	1600	75	39	Abbreviated burnishing
	2	Steel	20	9	3,1,1,1,1 ,1, 1,1,2	1600	80	36	Abbreviated burnishing
	3	Aluminum	18	14	3,then 13 cycles of 1-min each	1500	75	40	Abbreviated burnishing

Table 12 shows a summary of the selected vendor test results. Two of the three systems provided alarms in advance of dangerous temperatures near the rubber tire. In most cases the rate of temperature rise is rapid, which means that a higher set temperature will not substantially increase the time to alarm. This result can be used to reduce the rate of false alarms.

Table 12. Summary of Selected Wheel Well Vendor Test Results.

	Vendor A	Vendor B	Vendor C (Sensor 1)	Vendor C (Sensor 2)
Hot Wheel Alarm Activated?	Yes	No	Yes	Yes
Sensor Set Point (°C)	80	115	85	85
Maximum Rotating Temperature at Alarm (°C)	160	245	180	150
Maximum Stationary Temperature at Alarm (°C)	280	330	250	240
Vendor Sensor Temperature at Alarm (°C)	80	30	94	85
Nominal Time at Alarm (min)	7	No Alarm	18	11
Nominal Time at Alarm + 10 °C (min)	8	No Alarm	20	12
Nominal Time at Alarm + 20 °C (min)	8	No Alarm	No Alarm	13

6.8 Wheel Well Test Procedure and Test Criteria

The following test procedure and test criteria were developed for evaluating hot wheel early warning systems in motorcoach wheel wells.

- The early warning system is installed per manufacturer specifications.
- The test utilizes an aluminum wheel (Size: 22.5 × 8.25) and either a new or used tire (Size: 315/8OR22.5). The tire is pressurized with air to 30 psig (for safety reasons).
- The test is conducted at a tire rotation speed equivalent to 60 mph.
- The brake pads are burnished per the abbreviated procedure discussed in Section 6.5 of this report.
- The brakes are applied in order to input heat into the system until the brake pad temperature reaches 750 °C. Subsequent cycles from 650 – 750 °C are administered until sensor activation or until the maximum stationary temperature reaches 400 °C.
- If the sensor does not activate prior the maximum stationary temperature reaching 400 °C, the test is aborted and the sensor considered to have failed this evaluation.

- If the sensor activates, one additional heating cycle is performed, the wheel stopped, and the final observations made of additional heating and final sensor temperature.
- During the final cool down period, the fixture is monitored and during this time, if the maximum stationary temperature exceeds 400 °C, the sensor is considered to have failed this evaluation. If the stationary temperature remains below 400 °C during the cool down period, the sensor is considered to have passed this evaluation.
- Additional details about the test procedure and criteria are referenced in Appendix M.

7.0 FIRE HARDENING EVALUATION METHOD DEVELOPMENT

The objective of this topic is to develop test methods and performance criteria to assess effectiveness of fire-hardening materials in preventing or delaying fire propagation from the engine compartment or a wheel well into the passenger compartment.

7.1 Fire Hardening Background

A significant amount of research has been conducted on this topic by NIST [3], including large/full-scale tests on a motorcoach assembly and measurement of the time it takes for fire to penetrate into the passenger compartment from a wheel well fire (tire fire). In this research, several hardening materials were tested to see how the time was affected.

In their project, NIST looked at replacement of combustible motorcoach siding material above the wheel well and below the windows of the passenger compartment (fender and additional exterior siding panel). The replacement materials or modifications included steel, intumescent fire protection schemes (where a carbon foam is created to provide thermal insulation), and a fire plume deflector. While steel and the intumescent coating were effective at preventing or delaying fire spread into the passenger compartment, the fire plume deflector that would ideally direct the flame out and away from the bus was not.

One missing piece from the NIST work was a way to relate the times to fire penetration in full-scale to a laboratory-scale test method, so that new products and materials could be evaluated for this application.

The focus of this task is to recommend a standard fire test method that can be used to evaluate fire hardening materials and can also be related to the original NIST work.

7.2 Fire-Hardening Fire Test Methods

Several test methods were considered to evaluate suitability of materials for motorcoach fire hardening. The elements of the test methods that were considered in selecting a suitable test method included: cost of setup and/or to conduct test, scalability of test method, and the ability of the test method to be related to conditions seen in full scale tests.

One intermediate-scale test method was chosen and one bench-scale test method were chosen for this purpose. The same nominal materials that were tested by NIST were tested in these two apparatuses/procedures and the results are compared to obtain a relationship between small, intermediate and full-scale test data.

Additional details about these methods are provided below and the full test matrix and results from the data analysis are provided in subsequent sections of this report.

7.2.1 General Approach

For organic solids, liquids, and gases, a nearly constant net amount of heat is released per unit mass of oxygen consumed for complete combustion. An average value for this constant of 13.1 MJ/kg of O2 can be used for practical applications and is accurate with very few exceptions to within ±5%. Therefore, measurements of the oxygen consumed in a combustion system can be used to determine the net heat released. This technique, generally referred to as the “oxygen consumption technique”, is now the most widely used and accurate method for measuring heat release rate (HRR) in experimental fires.

The HRR of the NIST experiments was measured with the oxygen consumption technique and so this is the same method used in the two standard test procedures discussed below. It was expected that this particular quantity would able to be scaled between the NIST data and the standard test method data.

7.2.2 Cone Calorimeter Test Method

The Cone Calorimeter is a bench-scale test apparatus, which measures the rate of heat release of materials and products under a wide range of conditions using the oxygen consumption technique. A schematic of the instrument is shown in Figure 65. Other useful information obtained from Cone Calorimeter tests includes time to ignition, mass loss rate, smoke production rate, and effective heat of combustion.

In the Cone Calorimeter, a square sample measuring 100 × 100 mm (4 × 4-in.) is exposed to the radiant flux of an electric heater. The heater is in the shape of a truncated cone and is capable of providing heat fluxes to the specimen in the range of 0–100 kW/m². An electric spark igniter is used for piloted ignition of the pyrolysis gases produced by the radiant heater.

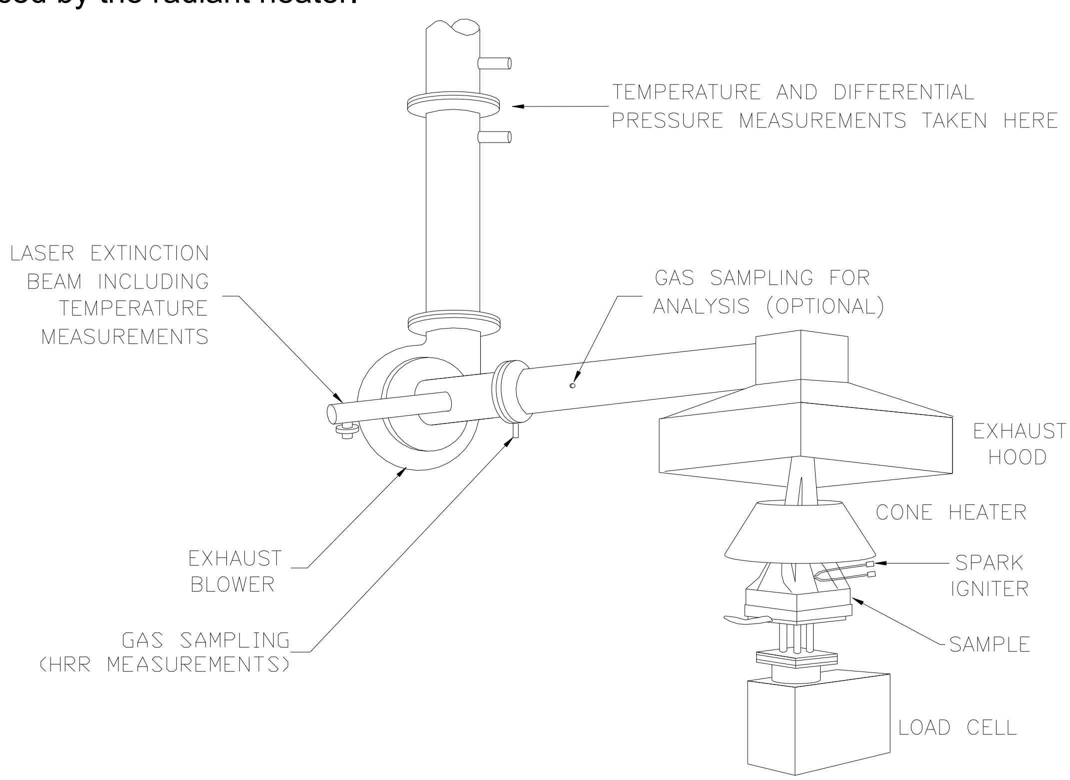


Figure 65. Schematic of the Cone Calorimeter Apparatus.

Test specimens are to be representative of the product's end use and can have a maximum thickness of 50 mm (2 in.). Specimens with a thickness of less than 6 mm are to be tested using a substrate that is representative of end-use conditions. Prior to testing, the test specimen is wrapped in aluminum foil, backed with a layer of low-density refractory fiber blanket, and placed in a standard specimen holder. An optional edge frame can be used to retain the sample within the specimen holder during testing. A load cell is used to measure the mass loss of the specimen throughout the duration of the test.

At the start of a test, the specimen (in the appropriate holder) is placed on the load cell, which is located below the heater. The top edge of the specimen is typically positioned 25 mm below the base plate of the heater. The electric spark igniter is located 13 mm above the center of the specimen. Four seconds after the pyrolysis gases released by the specimen ignite; the electric spark igniter is removed.

The products of combustion and entrained air are collected in a hood and extracted through an exhaust duct by a fan. A gas sample is drawn from the exhaust duct and analyzed for oxygen concentration. The gas temperature and differential pressure across an orifice plate are used for calculating the mass flow rate of the exhaust gases. Smoke production is determined based on the measured light obscuration in the duct using a laser photometer located close to the gas sampling point.

The Cone Calorimeter apparatus, calibration procedure, and test protocol are standardized in the United States as ASTM E 1354-13 and NFPA 271:2009, *Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter* and internationally as ISO 5660-1:2002, *Fire Tests—Reaction to Fire—Part 1: Rate of Heat Release from Building Products—(Cone calorimeter method)*. ASTM E 1354 and NFPA 271 are functionally identical. SwRI's Cone Calorimeter is capable of performing tests in accordance with the ASTM, NFPA, and ISO standards.

The following terms and abbreviations are used in the Cone Calorimeter test results:

- t_{ig} — time to ignition/sustained flaming (flame over specimen surface for at least 4 s)
- Test Duration — total test duration (time from the start of test until any flaming or other signs of combustion cease, the average mass loss over a 1-min period has dropped below 150 g/m², or until 60 min have elapsed)
- C-Factor — calibration constant for oxygen consumption analysis ($m^{1/2}$ -$kg^{1/2}$ -$K^{1/2}$)
- HRR_{peak} — maximum value of the heat release rate per unit area (kW/m²)
- THR — total amount of heat released per square meter (MJ/m²)
- HRR_{60s} — average heat release rate over the first 60 s (1 min) after ignition
- HRR_{180s} — average heat release rate over the first 180 s (3 min) after ignition
- HRR_{300s} — average heat release rate over the first 300 s (5 min) after ignition
- $HRR_{30s,\ max}$ — the maximum 30-s sliding average of the heat release rate per unit area (kW/m²)
- Initial Mass — the initial mass of the test specimen, prior to testing (g)
- Mass at Ignition — the mass of the test specimen at the time of sustained ignition (g)

- Final Mass the mass of the test specimen at the end of the test (g)
- Mass Loss total specimen mass loss over the test (g/m^2)
- MLR average specimen mass loss rate per unit area ($g/m^2 \cdot s$) computed over the test duration
- 10-90 MLR average specimen mass loss rate per unit area ($g/m^2 \cdot s$) computed over the period starting when 10% of the specimen mass loss occurred and ending when 90% of the specimen mass loss occurred
- EHC effective heat of combustion (the ratio of heat release rate to mass loss rate–MJ/kg) averaged over the test duration or the entire test if ignition does not occur
- $S_{A,1}$ smoke production per unit area of exposed specimen (m^2/m^2) prior to ignition
- $S_{A,2}$ smoke production per unit area of exposed specimen (m^2/m^2) from ignition until flameout or the end of the test; equal to zero if ignition does not occur
- S_A total smoke production per unit area of exposed specimen during the test duration ($S_{A,1} + S_{A,2}$)
- SEA specific smoke extinction area (the ratio of smoke production to specimen mass loss–m^2/kg) averaged over the test duration.

7.2.3 Parallel Panel Test Method

The Parallel Panel test method is standardized in *Section 4.0 of ANSI/FM 4910, American National Standard for Cleanroom Materials Flammability Test Protocol (October 2013)*. This specific standard is applicable to materials in cleanrooms, but the same basic parallel panel approach is also used in FM 4880, which is applicable to exterior wall systems. The derivation of the method is discussed in detail by FM Research [14]. The method was developed to relate intermediate-scale test results to full-scale fire test performance, in terms of material flammability (ignition and flame spread).

The 8-ft Parallel Panel Fire Test exposes two 2 × 8-ft (w × h) samples placed 1 ft apart to the effects of a 1 × 2-ft propane gas sand burner with an output of 60 kW for a 10-min duration followed by a 2 min observation period. The panel assembly is located on a load cell capable of measuring mass loss throughout the test. The test is performed under a calorimeter in order to measure heat release and smoke release rates during the test. Additionally, heat flux is measured at a height of 4 ft on the surface of one panel at the vertical centerline. In these specific tests, the backside temperature of the test assembly was also measured, although this is not required. Visual measurements of the flame height are recorded using digital video and still photographs.

The heat release rate is measured using the oxygen consumption technique. The gas temperature and differential pressure across a bi-directional probe are measured for calculating the mass flow rate of the exhaust gases. The smoke release rate is determined by the measured light obscuration in the exhaust duct using a vertically-oriented, white-light extinction photometer located close to the gas sampling point. Figure 66 shows a schematic of the parallel panel test apparatus.

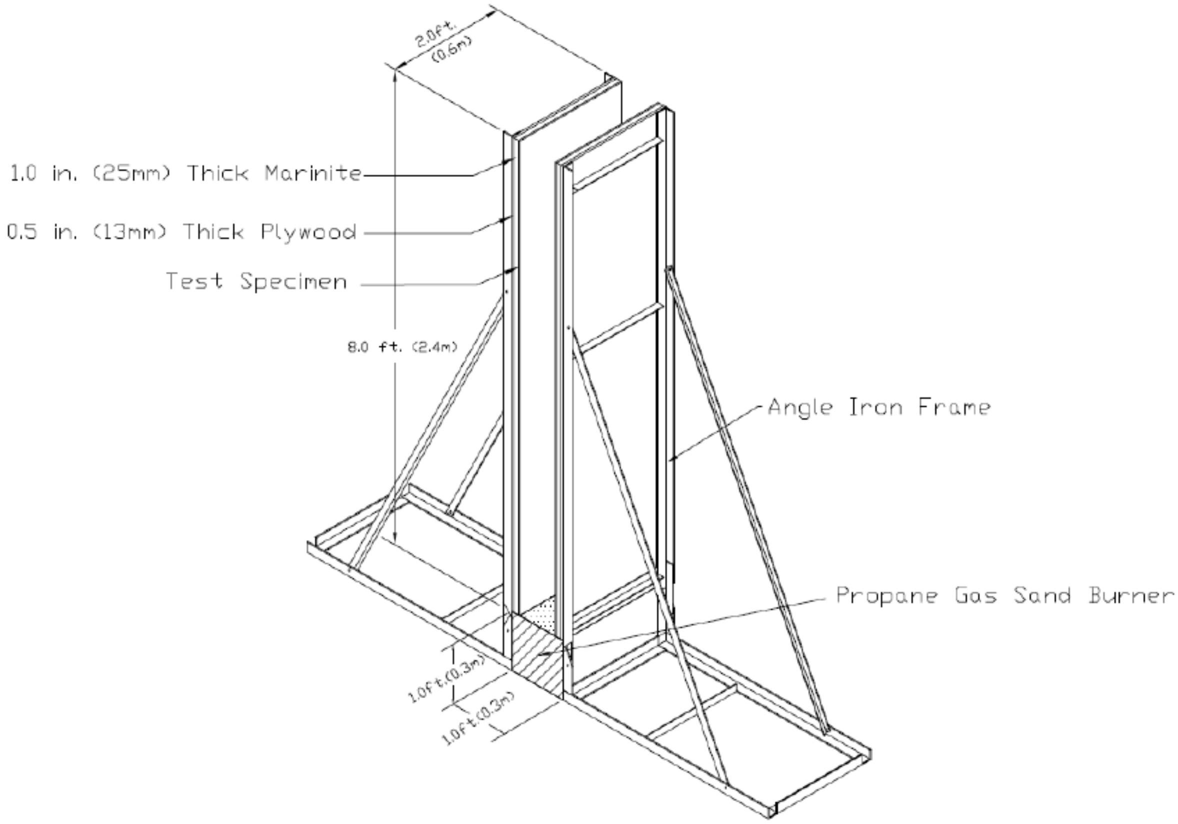


Figure 66. Schematic of the Parallel Panel Apparatus.

7.3 Fire Hardening Test Plan

Several materials were tested in both the Cone Calorimeter and the Parallel Panel test apparatus. NIST performed four tests that utilized glass-reinforced plastic (GRP) exterior paneling. They conducted an additional test with the GRP coated with Pitt Char XP and an additional test with a sheet steel panel, instead of a combustible material, like the GRP panel. For this project, the same nominal materials used in the NIST work were tested, along with a few additional materials.

The following materials were used for fire hardening testing:

- GRP Sandwich Panel – donated by motorcoach OEM
  - Nominal thickness: 8.85 mm
  - Color: gray outer with white foam core
- Galvanized Sheet Metal Panel – donated by motorcoach OEM
  - Nominal thickness: 1.28 mm
  - Color: Silver with Green primer paint
- Gypsum Wallboard – obtained locally
  - Nominal thickness: 16 mm
  - Color: pink paper face
- Red Oak Plywood – obtained locally
  - Nominal thickness: 18.72 mm

- Color: natural wood (brown/tan)

- Pitt Char XP – obtained locally from a PPG, Industries, Inc. distributer
    - Each of the four materials above was tested with and without a Pitt Char XP coating.
    - PPG application instructions for troweling on the coating were followed and a nominal 150-200 mil (4-5 mm) coating thickness was applied to each material.

7.4 Fire Hardening Test Results

7.4.1 Cone Calorimeter Testing

Cone calorimeter heat release rate testing was performed at an incident heat flux of 50 kW/m^2. Additional ignition testing was conducted to determine the critical heat flux for ignition (CHF) and the material's thermal response parameter (TRP).

The TRP is a measure of the thermal inertia of a material (product of thermal conductivity, density, and specific heat). It is calculated by plotting the inverse square root of the ignition time versus the external heat flux and fitting a line through the data points. The inverse of the slope of this line is defined as the TRP. The fire propagation index (FPI) is a measure of full-scale flame spread propensity and is calculated based on ignition data (TRP) and HRR data (peak HRR). In general, fire performance is inversely proportional to the FPI. In other words, products with bad fire performance (high flame spread) typically have high FPI values. The FPI is calculated based on the following equation:

$$FPI = \frac{1000(0.042 \cdot Q_{peak})^{1/3}}{TRP}$$, where

Q_{peak} = peak heat release rate in cone at 50 kW/m^2 (kW/m^2);

TRP = thermal response parameter (kW-s$^{1/2}$/m^2);

Figure 67 – Figure 70 provide the TRP plots for each material tested in the cone calorimeter.

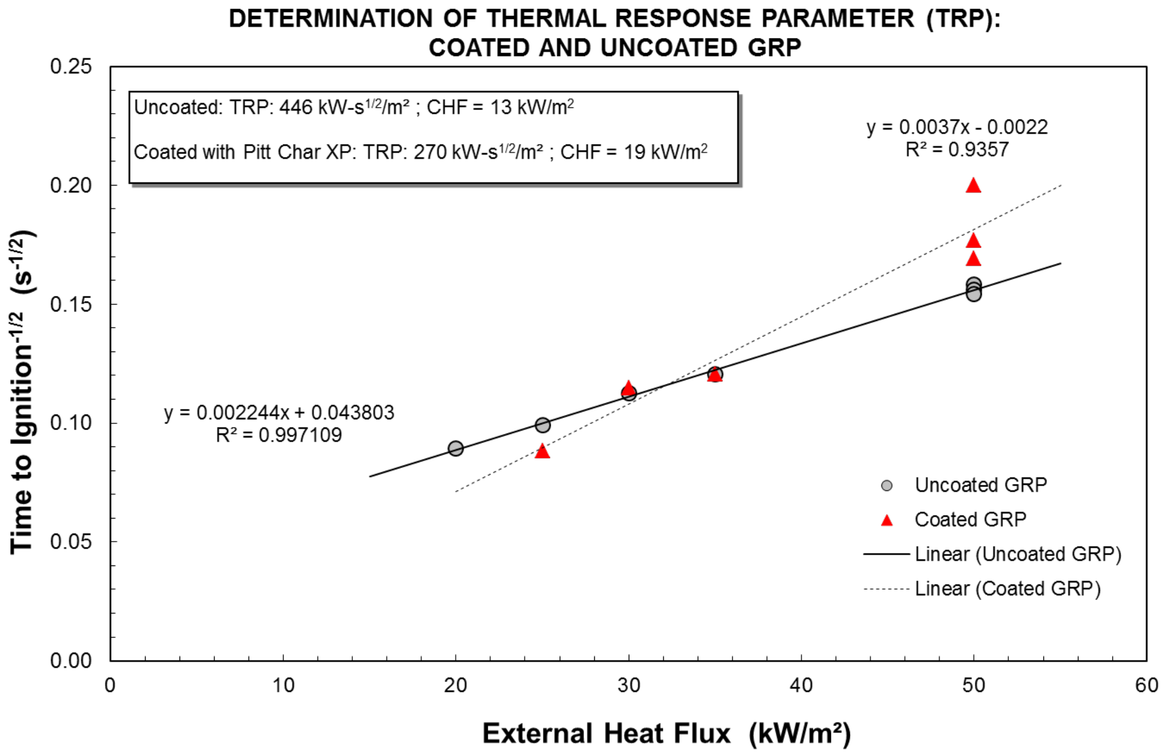


Figure 67. TRP Plot for GRP.

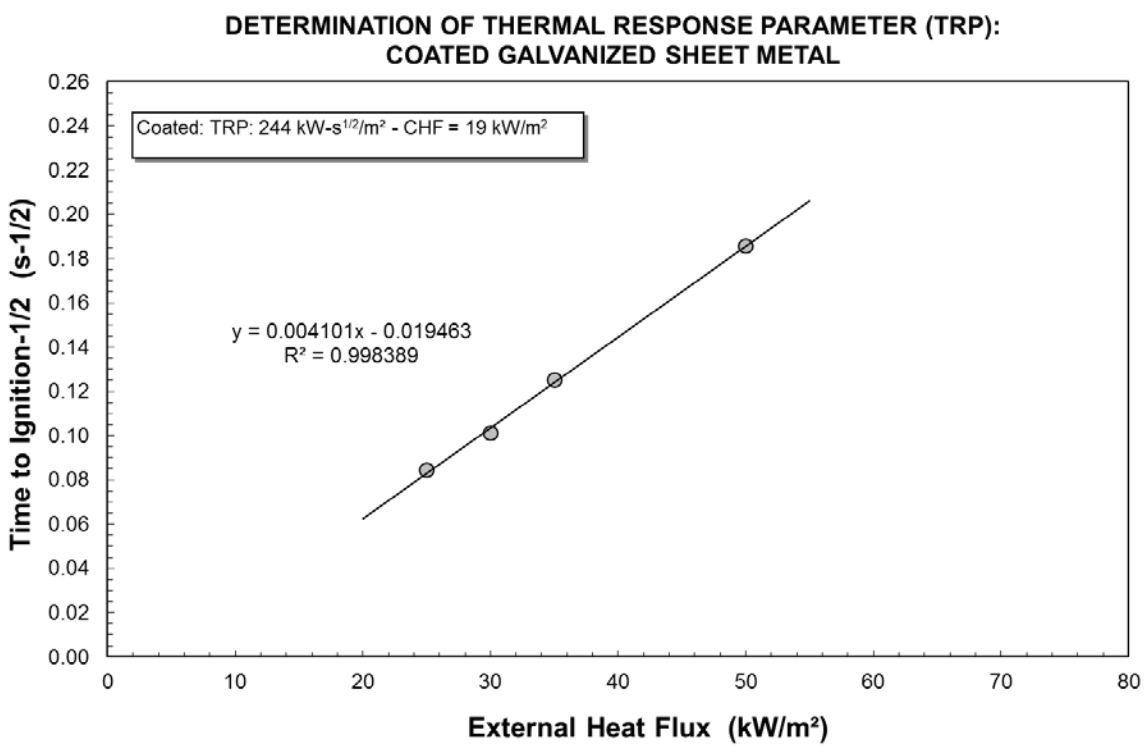


Figure 68. TRP Plot for Coated Galvanized Sheet Metal.

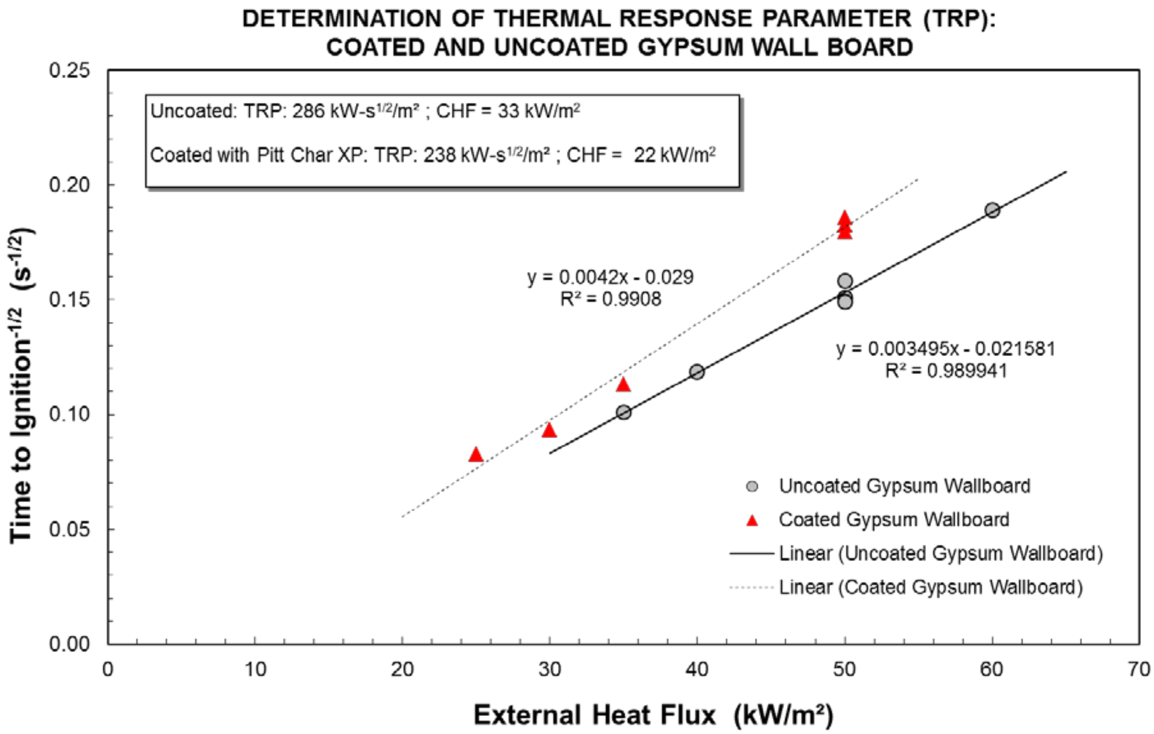


Figure 69. TRP Plot for Gypsum Wallboard.

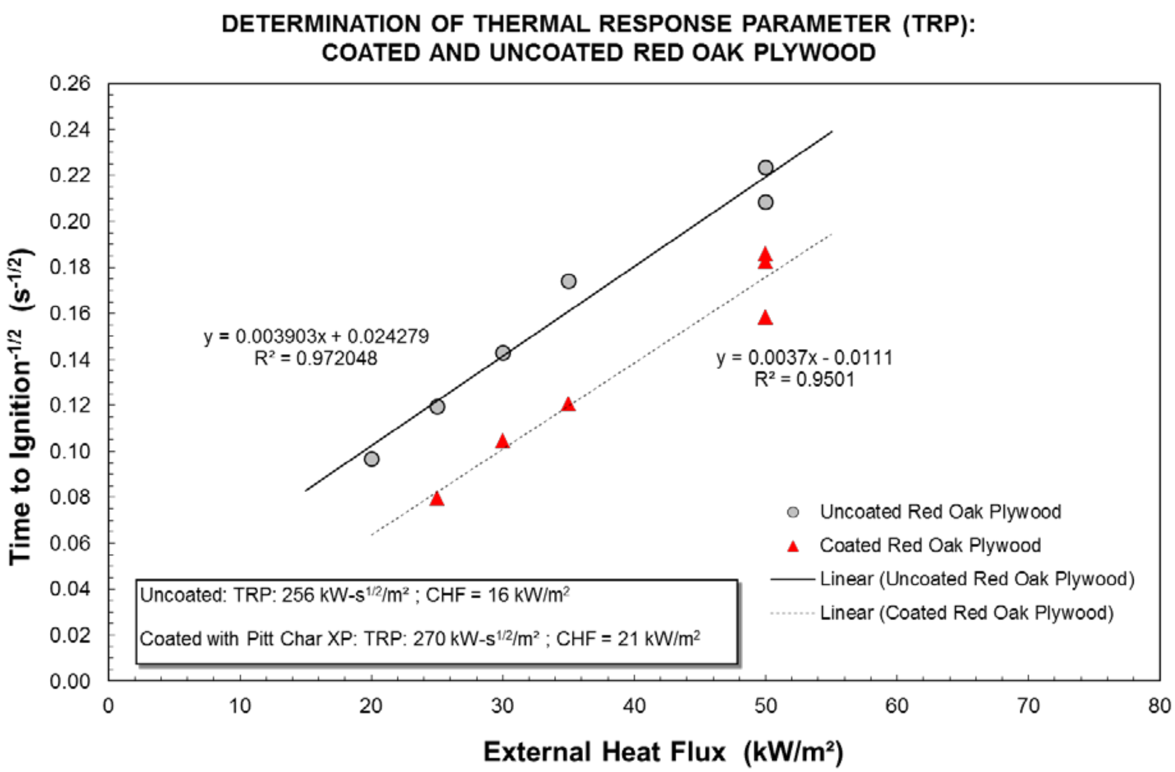


Figure 70. TRP Plot for Red Oak Plywood.

Table 13 provides a summary of the cone calorimeter test results.

Table 13. Summary of Cone Calorimeter Fire Hardening Test Results.

Test Material		CHF (kW/m^2)	TRP ($kW\text{-}s^{1/2}/m^2$)	HRR_{peak} (kW/m^2)	FPI ($m^{5/3}/kW^{2/3}\text{-}s^{1/2}$)
Uncoated	GRP Panel	13	446	342	5.45
	Galvanized Sheet Metal	ND	ND	9	ND
	Gypsum Wallboard	33	286	101	5.66
	Red Oak Plywood	16	256	300	9.09

ND: not determined, this material is noncombustible, so these parameters cannot be calculated for the uncoated specimens.

Table 13. Summary of Cone Calorimeter Fire Hardening Test Results (continued).

Test Material		CHF (kW/m^2)	TRP ($kW\text{-}s^{1/2}/m^2$)	HRR_{peak} (kW/m^2)	FPI ($m^{5/3}/kW^{2/3}\text{-}s^{1/2}$)
Coated with Pitt Char XP	GRP Panel	19	270	156	6.93
	Galvanized Sheet Metal	19	244	151	7.59
	Gypsum Wallboard	22	238	153	7.81
	Red Oak Plywood	21	270	148	6.81

It can be noted from Table 13 that the Pitt Char XP coating is able to reduce the peak heat release rate for all the materials that have some combustibility. The sheet metal and gypsum wallboard peak heat release rate actually increases with the Pitt Char XP coating application since these materials are inherently non-combustible (with exception to the paper face on the gypsum wallboard and very thin primer paint coat on the sheet metal).

It can be observed that for this data set, the FPI term does not seem to be a good indicator of better fire performance. This is primarily due to the fact that the Pitt Char XP coating is combustible and will ignite and spread flame. This skews the data slightly as the TRP typically goes down for the coated materials, but not as much as the heat release rate goes down, which inflates the FPI term.

A greater benefit of the Pitt Char XP coating in this data set can be seen for combustible materials, such as the GRP and red oak plywood. In the case of these materials, the peak heat release rate can be reduced by a factor of 2. Based on these observations, further analysis of the peak heat release rate is used to compare to full-scale fire spread data.

Full sets of cone calorimeter data can be referenced in Appendix N.

7.4.2 Parallel Panel Testing

Parallel Panel testing was conducted in general accordance with FM 4910. All samples were installed against a calcium silicate substrate and plywood backing. Heat flux was measured 4 ft from the bottom of one of the panels under test and an additional thermocouple was installed on the backside of the test assembly 4 ft from the bottom of the same panel.

Table 14 provides a summary of the parallel panel test results.

Table 14. Summary of Parallel Panel Fire Hardening Test Results.

Test Material		**HRR_{peak} (kW)**	**Time to HRR_{peak} (s)**	**Peak Heat Flux (kW/m^2)**	**Peak Backside Temperature (°C)**
Uncoated	GRP Panel	1196	146	111	100
	Galvanized Sheet Metal	6	95	4	54
	Gypsum Wallboard	5	96	5	44
	Red Oak Plywood	365	113	60	72
Coated with Pitt Char XP	GRP Panel	82	184	41	65
	Galvanized Sheet Metal	72	187	28	62
	Gypsum Wallboard	106	193	35	87
	Red Oak Plywood	66	148	22	38

It can be noted from Table 14 that the Pitt Char XP coating has a similar effect on the materials in intermediate-scale. It increases the peak heat release rate for mostly noncombustible materials, but reduces it dramatically for combustible materials. Full sets of parallel panel data can be referenced in Appendix O. Figure 71 – Figure 73 show a few selected photographs from the fire hardening testing in the Parallel Panel test apparatus.

Figure 71. Parallel Panel Test – Left: Setup, Right: Peak HRR (Uncoated GRP Material Shown).

Figure 72. Parallel Panel Test – Left: Setup, Right: Peak HRR (Uncoated Sheet Metal Material Shown).

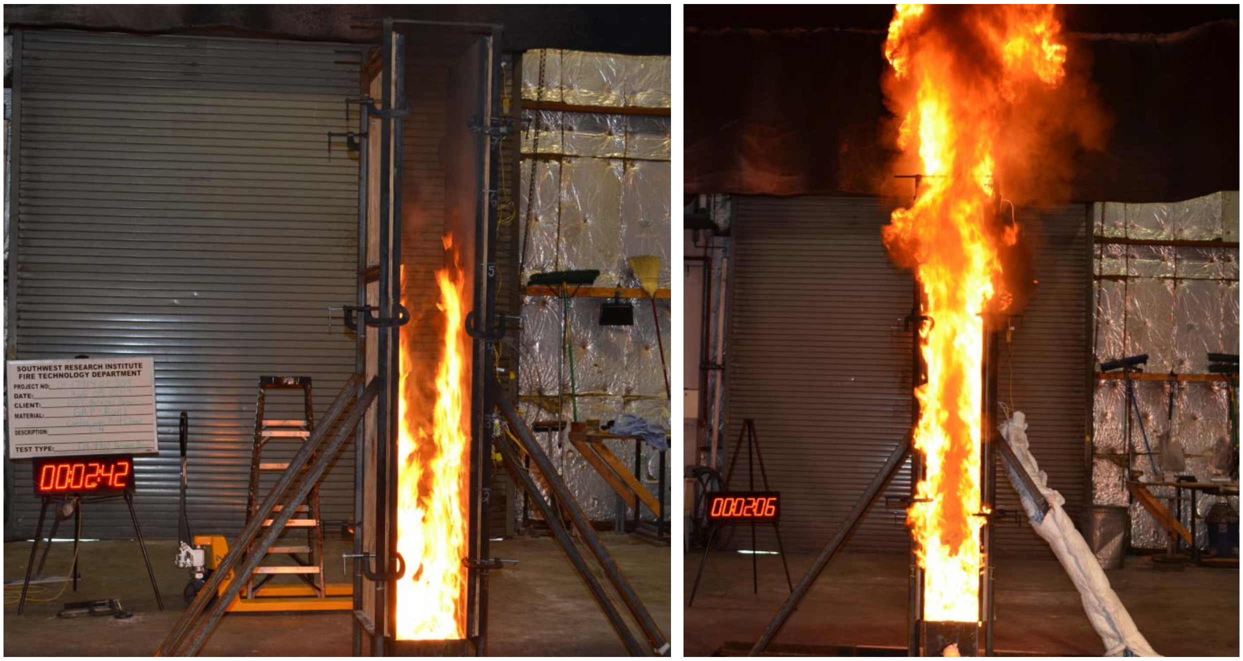


Figure 73. Parallel Panel Test – Left: Coated GRP, Right: Uncoated GRP.

7.5 Fire Hardening Data Analysis

7.5.1 NIST Testing

Table 6 provides a summary of the tests that NIST conducted and the results.

Table 15. Summary of NIST Test Results.

Test No.	Test Material	HRR_{peak} (kW)	Time to HRR_{peak} (s)	HRR / Time to Peak (kW/s)
1	GRP Panel (Tag Axle)	1175	280	4.2
2	GRP Panel (Drive Axle)	1480	363	4.1
3	Galvanized Sheet Metal	391	2464	0.2
4	GRP Panel Coated with Pitt Char XP	1043	1946	0.5

Table 15. Summary of NIST Test Results (continued).

Test No.	Test Material	HRR_{peak} (kW)	Time to HRR_{peak} (s)	HRR / Time to Peak (kW/s)
5	GRP Panel with Steel Deflector above Fender	1136	588	1.9
6	GRP Panel (Tag Axle – Tenability Experiment)	950	679	1.4

Figure 74 plots the time to penetrate the passenger compartment versus heat release rate. It can be noted that there is not a clear demarcation in terms of heat release rate between good performers and bad performers, with respect to gaining time to penetration. However, Figure 75 plots the time to penetration versus the ratio of heat release rate to the time to penetration. In this plot it can be observed that there seems to be a demarcation between good and bad performers for an approximate ratio of HRR/time=1.

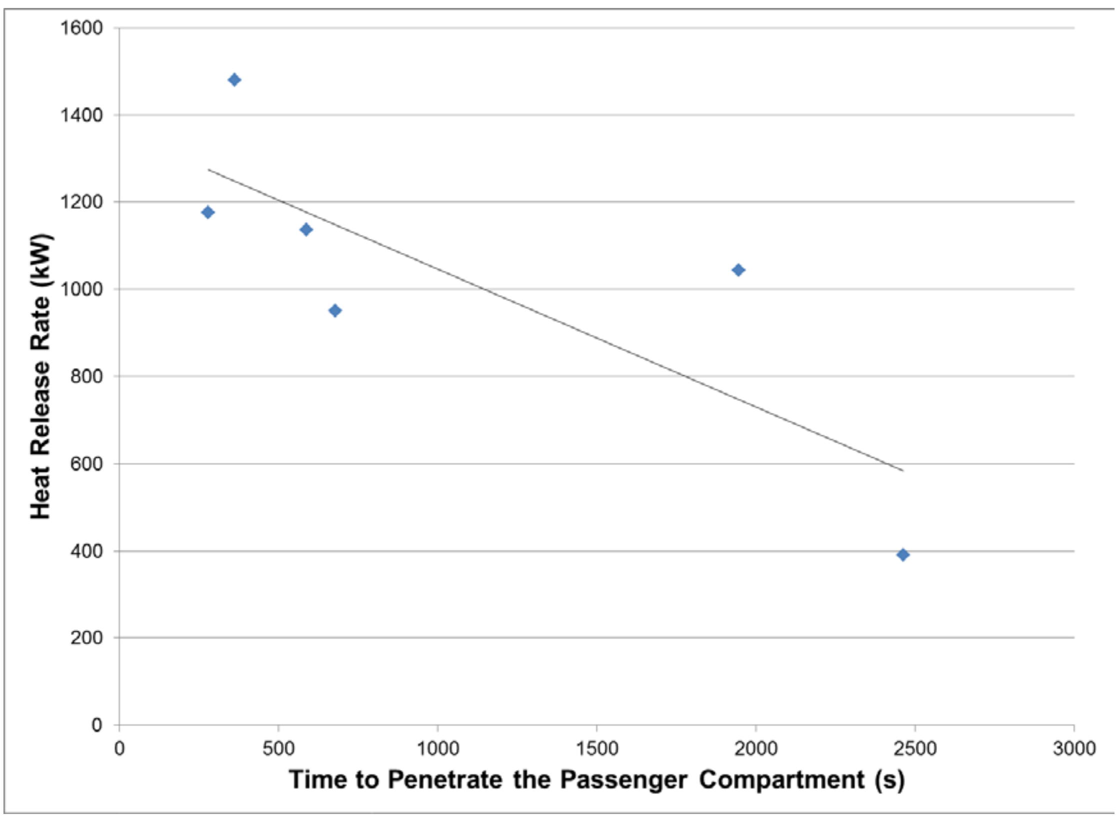


Figure 74. NIST Data Plot – Time versus HRR.

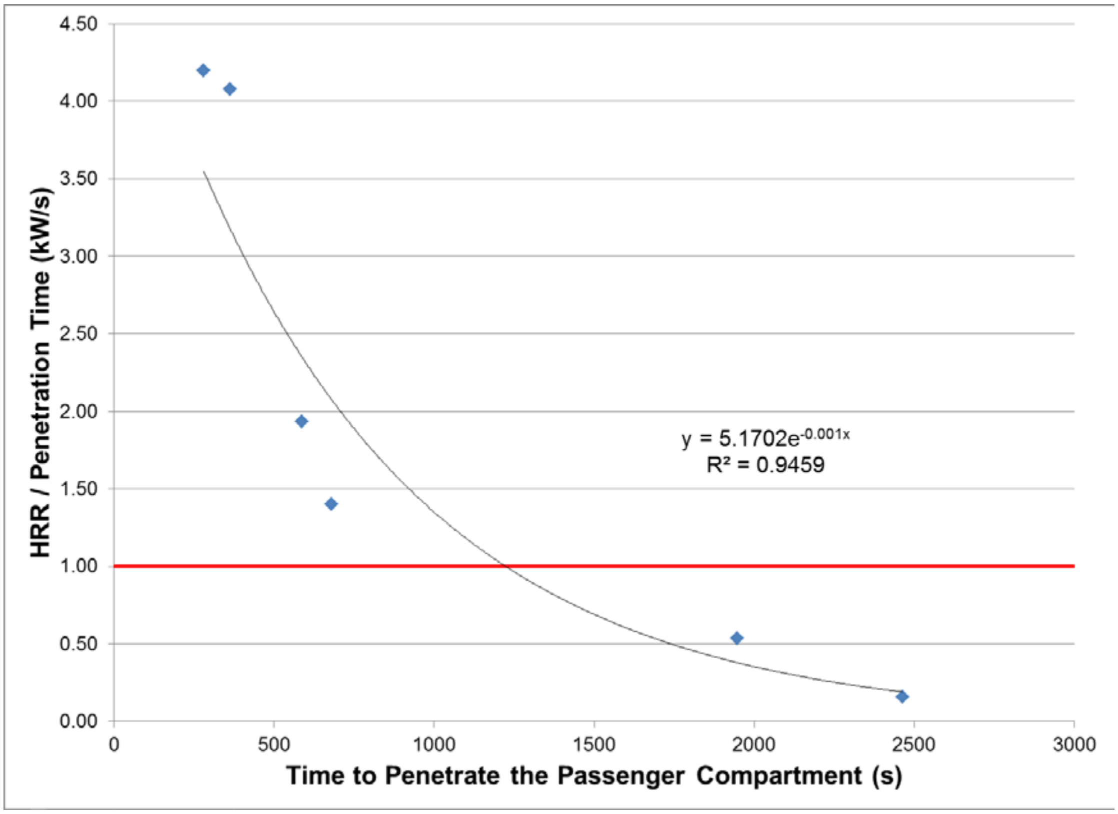


Figure 75. NIST Data Plot – Time versus HRR/Time.

7.5.2 Predicting Full-Scale Test Results (Time to Penetration)

Table 16 shows a comparison of data between the NIST results and testing in the cone calorimeter and parallel panel test apparatuses. Figure 76 and Figure 77 show plots of the parallel panel and cone peak heat release rate versus NIST time to penetration.

Table 16. Comparison of NIST, Parallel Panel and Cone Test Results.

Test Material	Parallel Panel HRR_{peak} (kW)	Cone Calorimeter HRR_{peak} (kW)	NIST Time to Penetration (s)
GRP Panel (Tag Axle)	1196	342	280
GRP Panel (Drive Axle)	1196	342	363

Table 16. Comparison of NIST, Parallel Panel and Cone Test Results (continued).

Test Material	Parallel Panel HRR_{peak} (kW)	Cone Calorimeter HRR_{peak} (kW)	NIST Time to Penetration (s)
Galvanized Sheet Metal	6	9	2464
GRP Panel Coated with Pitt Char XP	82	156	1946
GRP Panel with Steel Deflector above Fender	1196	342	588
GRP Panel (Tag Axle – Tenability Experiment)	1196	342	679

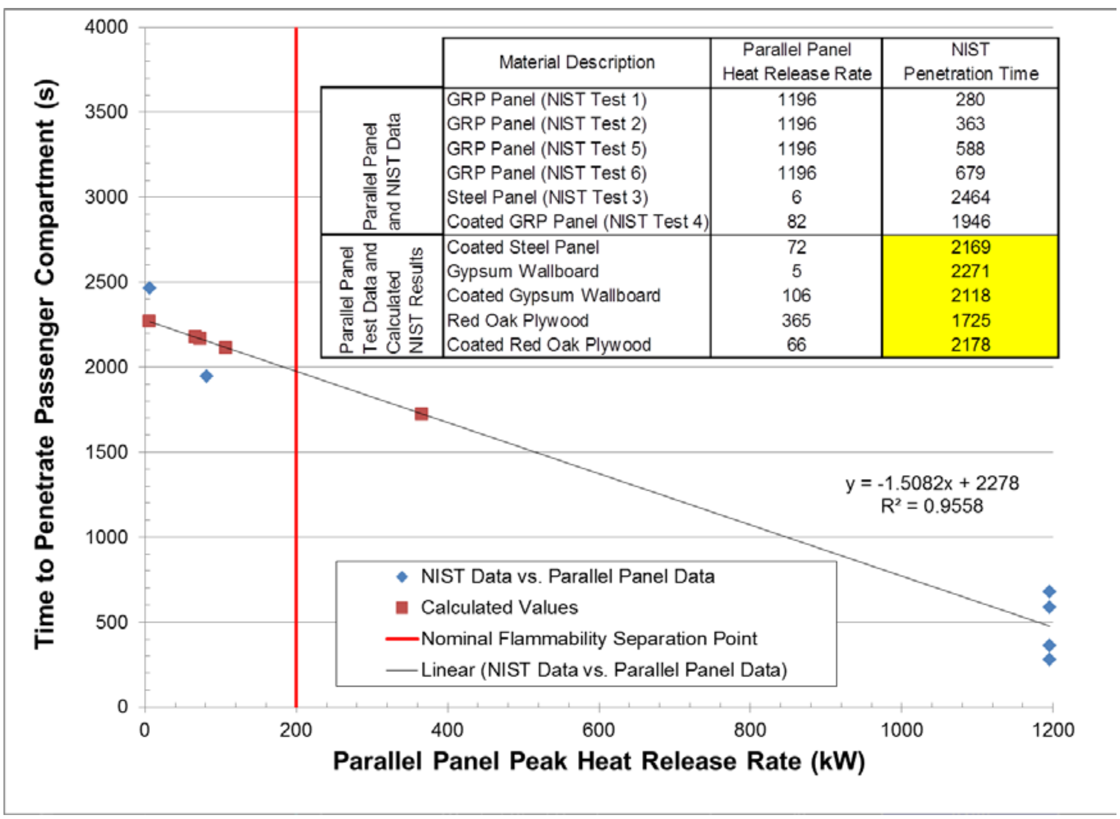
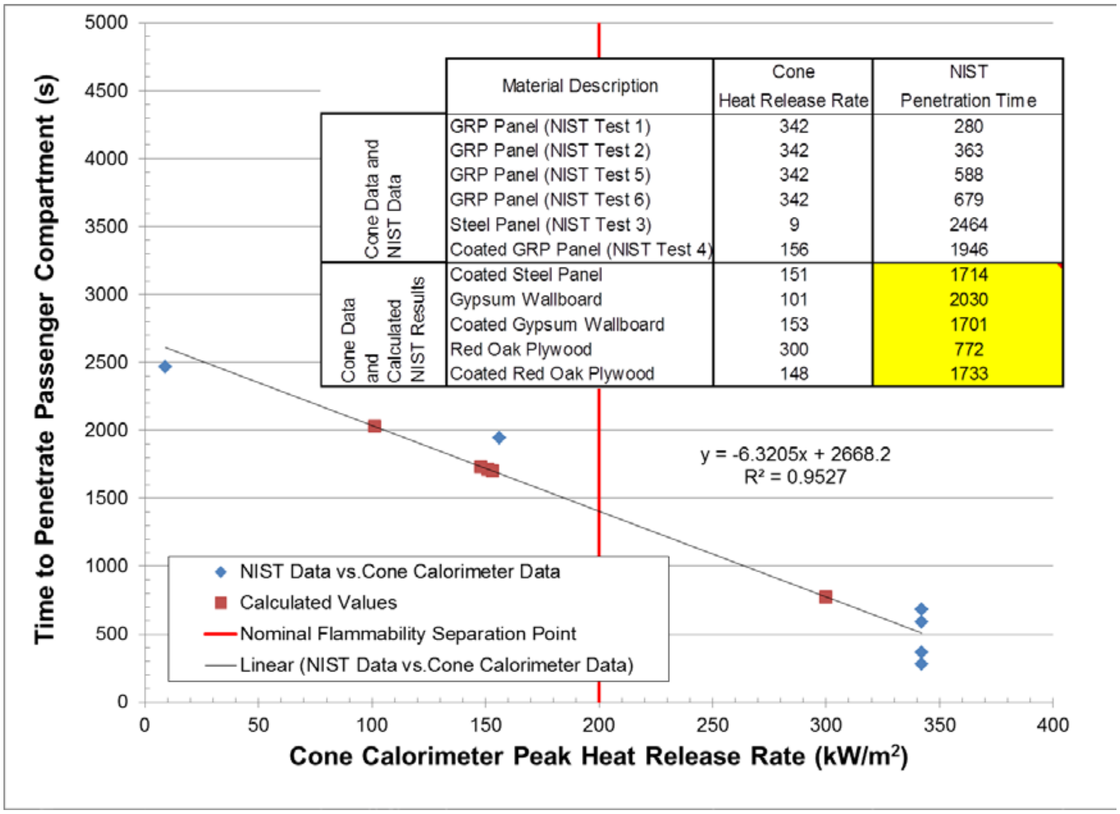


Figure 76. Parallel Panel Peak Heat Release Rate versus NIST Time to Penetration.



	Material Description	Cone Heat Release Rate	NIST Penetration Time
Cone Data and NIST Data	GRP Panel (NIST Test 1)	342	280
	GRP Panel (NIST Test 2)	342	363
	GRP Panel (NIST Test 5)	342	588
	GRP Panel (NIST Test 6)	342	679
	Steel Panel (NIST Test 3)	9	2464
	Coated GRP Panel (NIST Test 4)	156	1946
Cone Data and Calculated NIST Results	Coated Steel Panel	151	1714
	Gypsum Wallboard	101	2030
	Coated Gypsum Wallboard	153	1701
	Red Oak Plywood	300	772
	Coated Red Oak Plywood	148	1733

Figure 77. Cone Calorimeter Peak Heat Release Rate versus NIST Time to Penetration.

The blue diamonds in Figure 76 and Figure 77 represent direct comparison between NIST data and SwRI data either in the Parallel Panel test or in the Cone Calorimeter test. The red squares represent calculated data based on the linear regression of the blue data. These data are highlighted in yellow in each figure. These data could be used as a test for future additional full-scale test results in order to refine/validate the smaller-scale models.

There is a limited amount of full-scale data to rigorously evaluate this relationship between cone calorimeter and parallel panel test results with the results NIST obtained. However, it seems likely that a relationship does exist and could be refined if more full-scale data were made available.

As a screening tool, a limit between propagating and non-propagating performing materials may be on the order of 200 kW in the Parallel Panel test or 200 kW/m^2 in the Cone Calorimeter test.

7.6 Fire Hardening Recommended Test Criteria

It is likely that more research is necessary to recommend final test criteria. However, the following recommended screening criteria have been developed for evaluating fire hardening materials.

- Testing may be performed in general accordance with FM 4910 (Parallel Panel) or ASTM E1354 (Cone Calorimeter).
- If testing is performed in the Cone Calorimeter, the incident heat flux must be 50 kW/m^2.

- In order to evaluate a material as **'propagating'** and performing in a similar manner to typical exterior GRP materials in a tire fire, the peak heat release rate measured in the Parallel Panel test and Cone Calorimeter test will be **greater than 200 kW and 200 kW/m^2**, respectively.
- In order to evaluate a material as **'non-propagating'** and performing in a similar manner to typical exterior sheet metal materials in a tire fire, the peak heat release rate measured in the Parallel Panel test and Cone Calorimeter test will be **less than** or equal to **200 kW and 200 kW/m^2**, respectively.

8.0 FINAL OBSERVATIONS

8.1 Engine Compartment

8.1.1 Observations

The following observations can be made about the engine compartment test procedure and fixture used to evaluate detection and suppression systems.

- The SwRI team designed, fabricated, and commissioned a simulated motorcoach engine compartment fixture. It is representative of the motorcoaches currently sold in the United States.. It is larger than those used typically in Europe, but has comparable air flow.
- The fixture contains a substantial amount of obstructions to simulate the major components (including the engine) and various hoses, pipes, and electrical wires.
- The suppression systems of three vendors were tested. Two vendors tested both with detection systems and suppression systems. Linear Thermal Detectors were most frequently used, however, optical detectors were also used. The third vendor used a compressed air foam suppression system (no detection).
- It may be necessary to have a hybrid system with two different suppressants to extinguish all the fires as well as meet the re-ignition criteria.
- The distributed pool fire test with the fan running appears to be the most challenging test, based on vendor testing.
- Criteria are proposed for successfully completing this series of 12 engine compartment fire tests.

8.2 Wheel Well

8.2.1 Observations

The following observations can be made about the wheel well test procedure and fixture used to evaluate hot wheel early warning devices.

- The SwRI wheel well test fixture uses a dragging brake to deposit enormous amounts of heat into the wheel assembly. It is capable of raising both rotating and stationary parts of the wheel assembly to high temperatures.
- There are several commercially available TPMS's that are capable of detecting a hot wheel and alerting the driver before the tire catches fire.

- Most motorcoach OEMs that sell in the United States.. are now installing TPMS's as optional or standard equipment.
- The inside of the tire tread does not seem to be a good location to measure hot wheels for this simulated fire scenario.
- There are several locations where a simple thermocouple sensor on a stationary component can detect a hot wheel far in advance of a tire fire. But this solution does not provide high or low tire pressure warnings.
- It is important to train drivers to stop the motorcoach after receiving a hot wheel warning.

8.3 Fire Hardening

8.3.1 Observations

The following observations can be made about the fire hardening test procedures used to evaluate fire hardening materials.

- A relationship seems to exist between time to flame penetration into the passenger compartment in full-scale tests conducted by NIST [3] and data gathered in a bench-scale (Cone Calorimeter) and intermediate-scale (Parallel Panel) test apparatus.
- A screening heat release rate value of 200 kW or 200 kW/m^2 can be used to indicate a potential propagating or non-propagating fire hardening material in the Parallel Panel or Cone Calorimeter test apparatus, respectively.

APPENDIX A
REFERENCES
(CONSISTING OF 1 PAGE)

REFERENCES

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APPENDIX B
ENGINE COMPARTMENT TEST FIXTURE DRAWINGS
(CONSISTING OF 74 PAGES)

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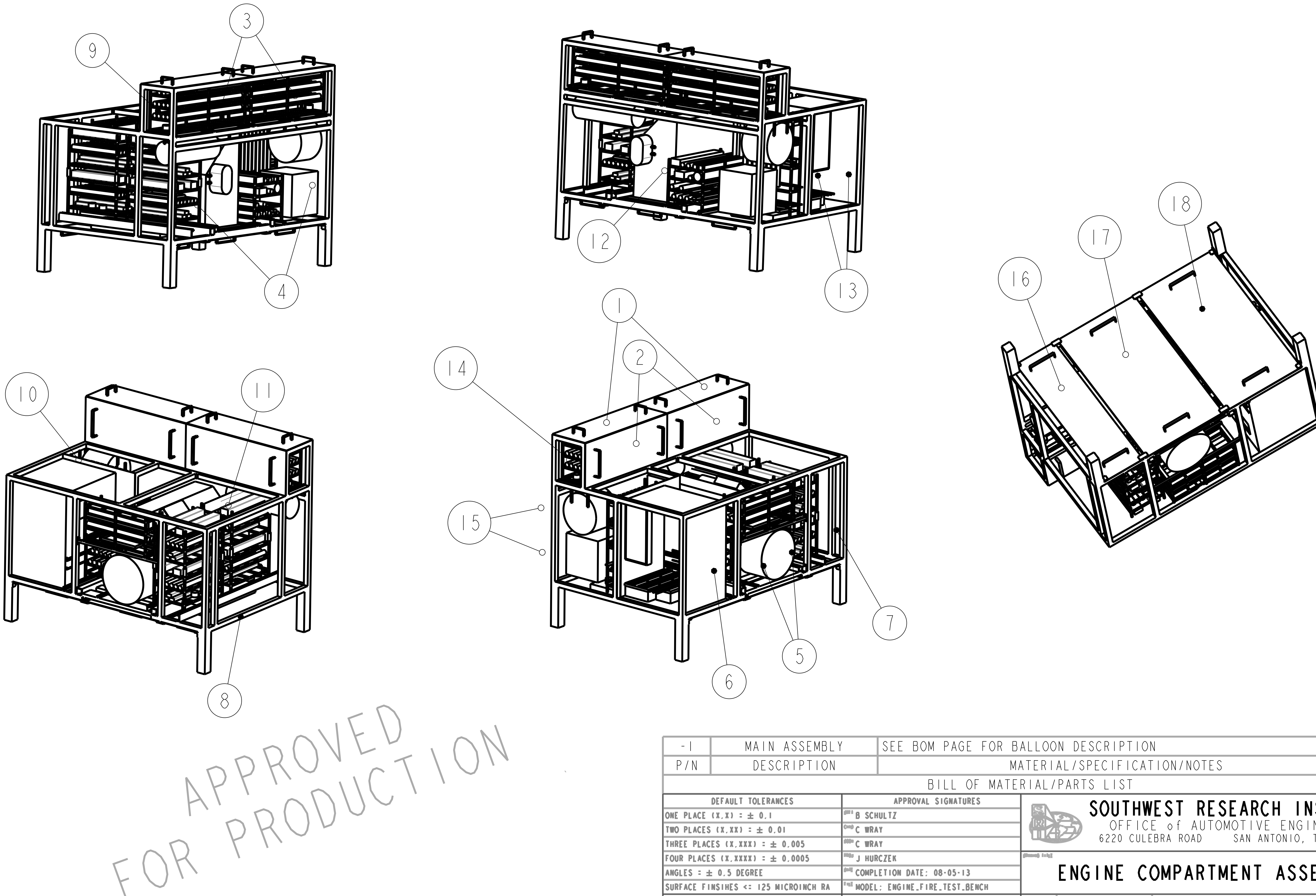

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TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HURCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 08-05-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: ENGINE_FIRE_TEST_BENCH

THIRD ANGLE PROJECTION

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ENGINE COMPARTMENT ASSEMBLY

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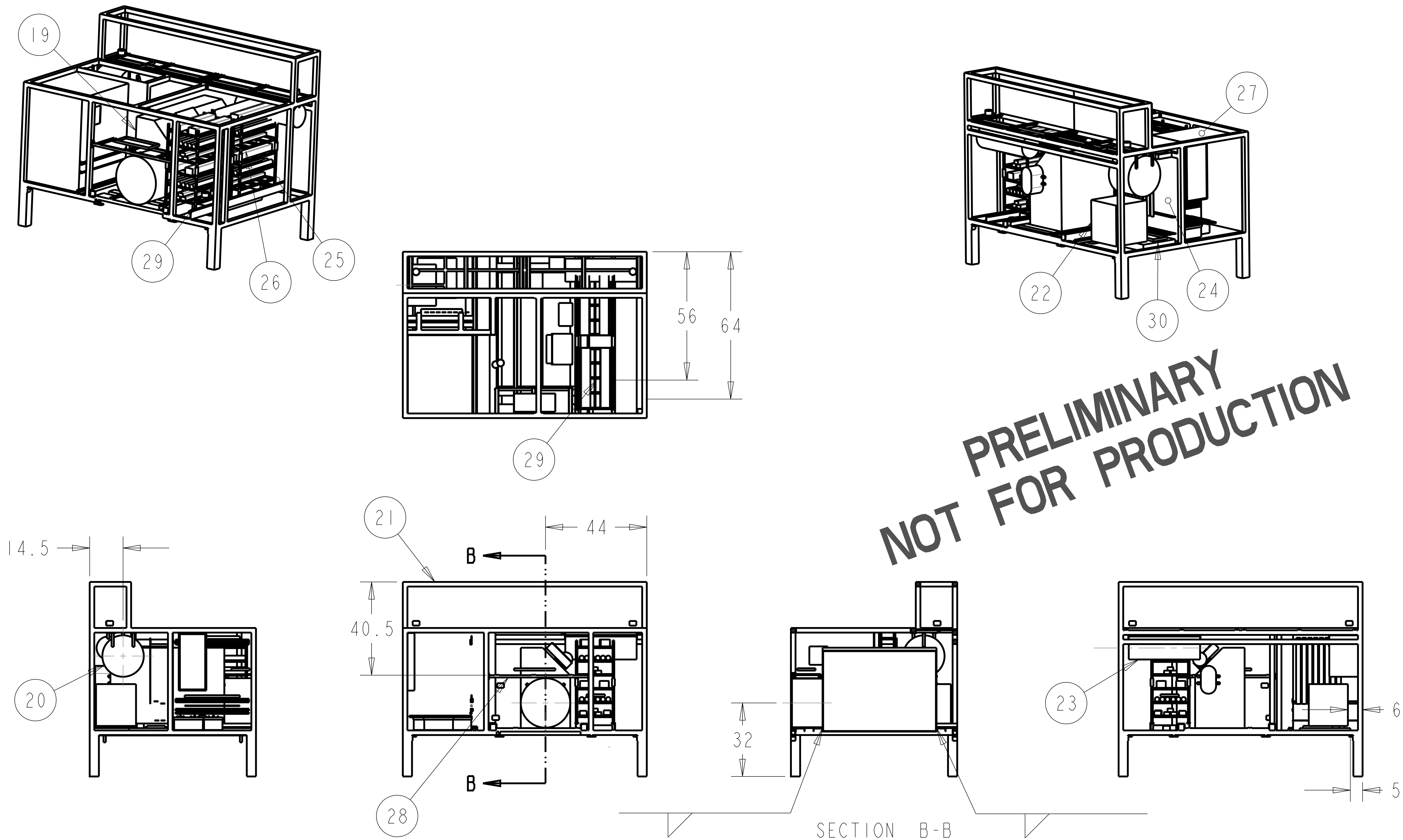

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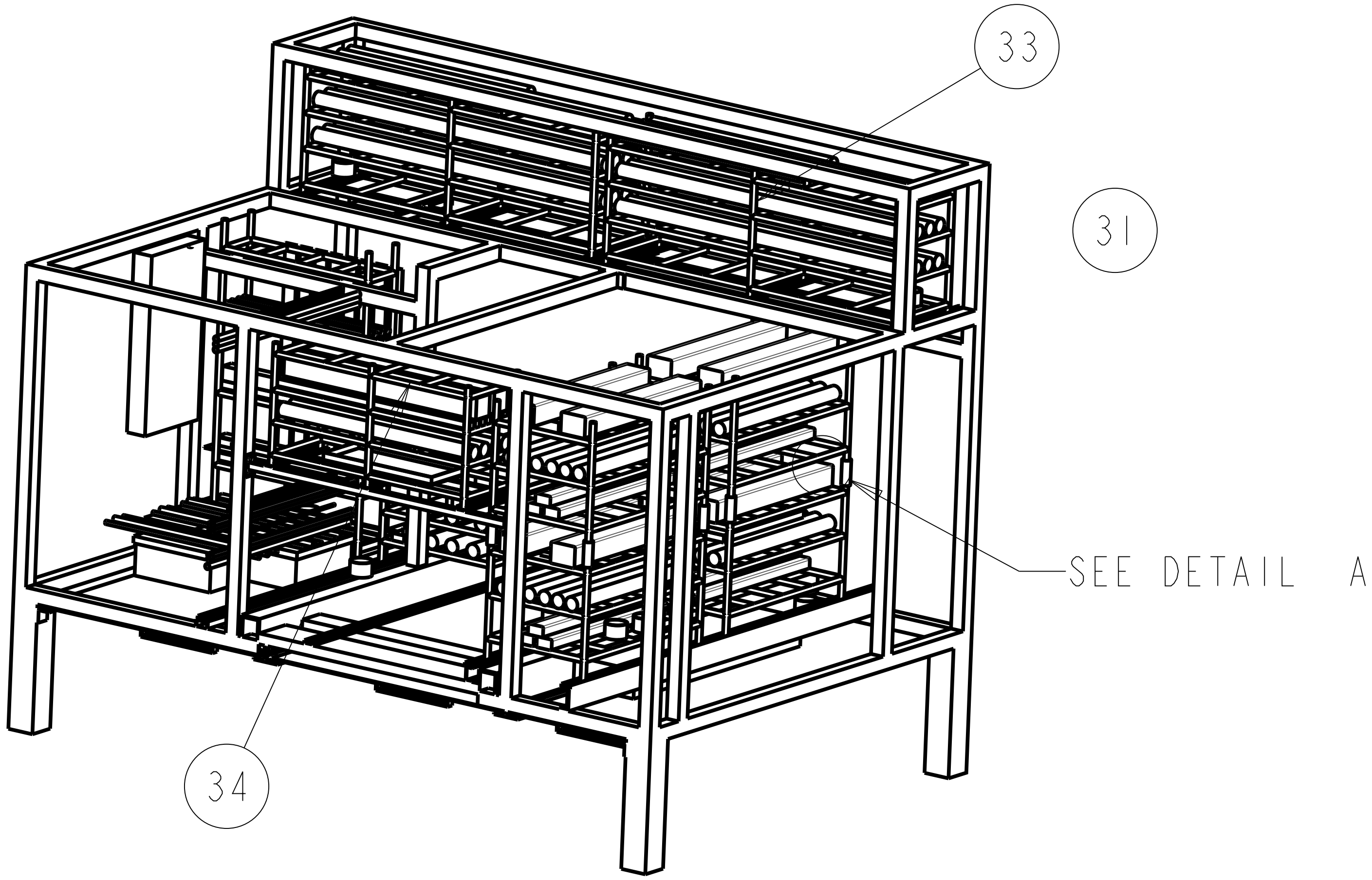
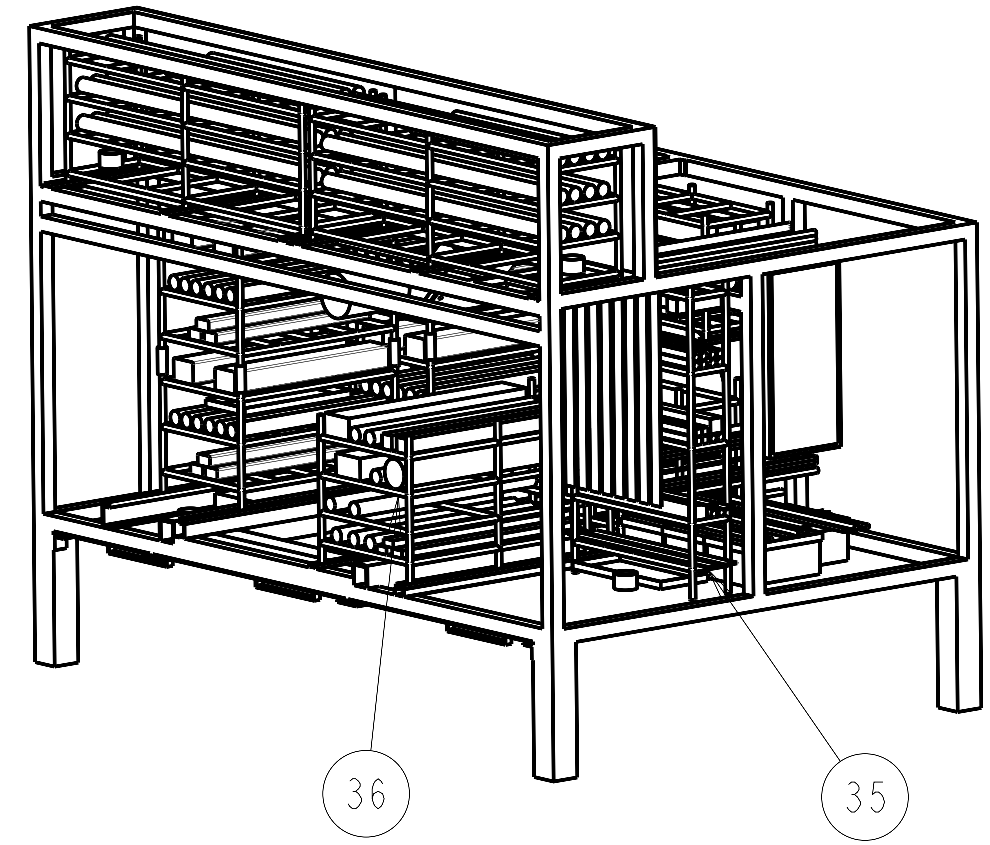
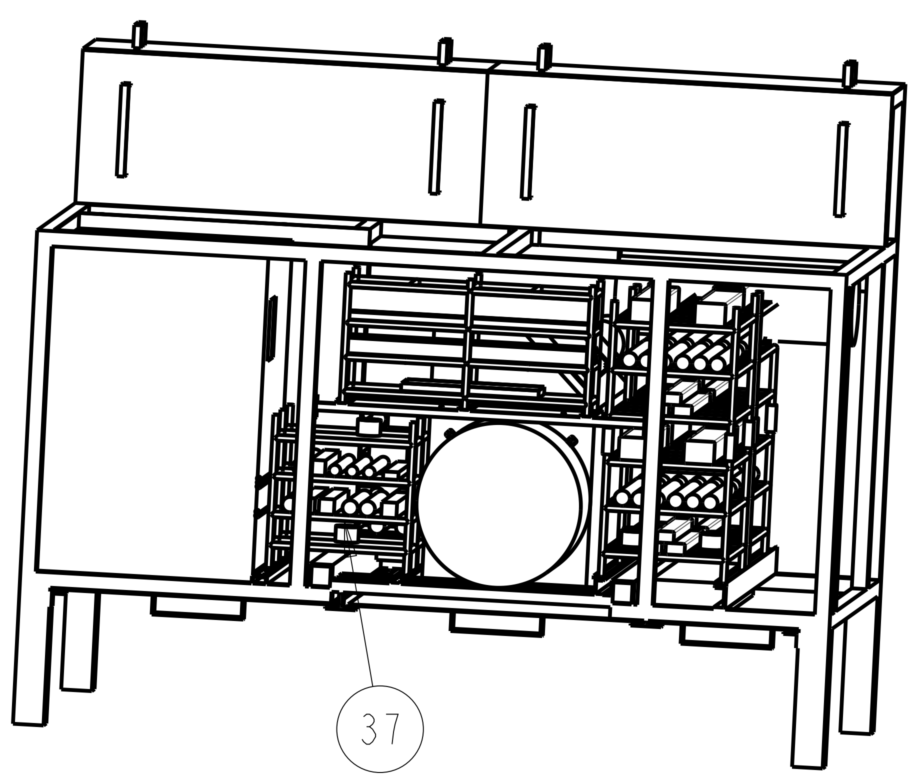
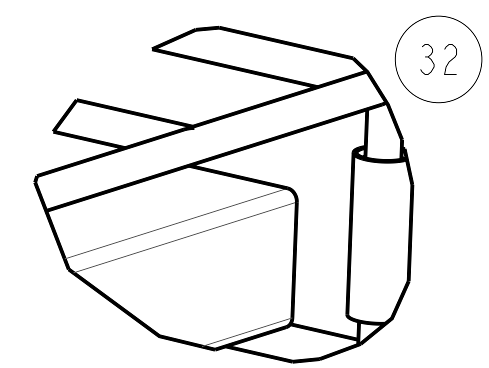
B-2









DETAIL A
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2 2 1

B B

A A

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1	MODULE 2	SEE DRAWING 17914-1000-200	35
1	MODULE 4	SEE DRAWING 17914-1000-400	34
2	MODULE 5	SEE DRAWING 17914-1000-500	33
8	STAND OFF CM 6	SEE DRAWING 17914-1000-602	32
4	MODULE 6	SEE DRAWING 17914-1000-600	31
1	SEWAGE TANK	SEE DRAWING 17914-900-100	30
1	DPF-SCR-SIMULATOR	SEE DRAWING 17914-700-100	29
1	BARCKET, CM-4	SEE DRAWING 17914-1000-401	28
1	STORAGE SPACE ASSEMBLY	SEE DRAWING 17914-200-000	27
1	LOUVERS	PURCHASED ITEM????	26
1	RADIATOR	SEE DRAWING 17914-800-100	25
1	WALL, DIVIDER	SEE DRAWING 17914-100-221	24
1	RQDIATOR SURGE TANK	SEE DRAWING 17914-500-100	23
1	AC COMPRESSOR	SEE DRAWING 17914-400-100	22
1	FRAME	SEE DRAWING 17914-100-201	21
1	AIR FILTER HOUSING	SEE DRAWING 17914-600-100	20
1	ENGINE ASSEMBLY	SEE DRAWING 17914-300-000	19
1	WALL, BOTTOM SIDE RIGHT	SEE DRAWING 17914-100-220	18
1	WALL, BOTTOM SIDE CENTER	SEE DRAWING 17914-100-219	17
1	WALL, BOTTOM SIDE LEFT	SEE DRAWING 17914-100-218	16
2	PLATE, VENT DAMPER	SEE DRAWING 17914-100-208	15
1	WALL, RIGHT VENT	SEE DRAWING 17914-100-207	14
2	WALL, STORAGE	SEE DRAWING 17914-100-223	13
1	WALL, REAR LOWER MID	SEE DRAWING 17914-100-204	12
1	WALL, MAIN TOP LEFT	SEE DRAWING 17914-100-212	11
1	WALL, MAIN TOP RIGHT	SEE DRAWING 17914-100-209	10
1	WALL, LEFT REAR	SEE DRAWING 17914-100-203	9
1	FAN	PURCHASED ITEM	8
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2	WALL, BACK LOWER SIDE	SEE DRAWING 17914-100-205	4
2	WALL, REAR TOP HAT	SEE DRAWING 17914-100-211	3
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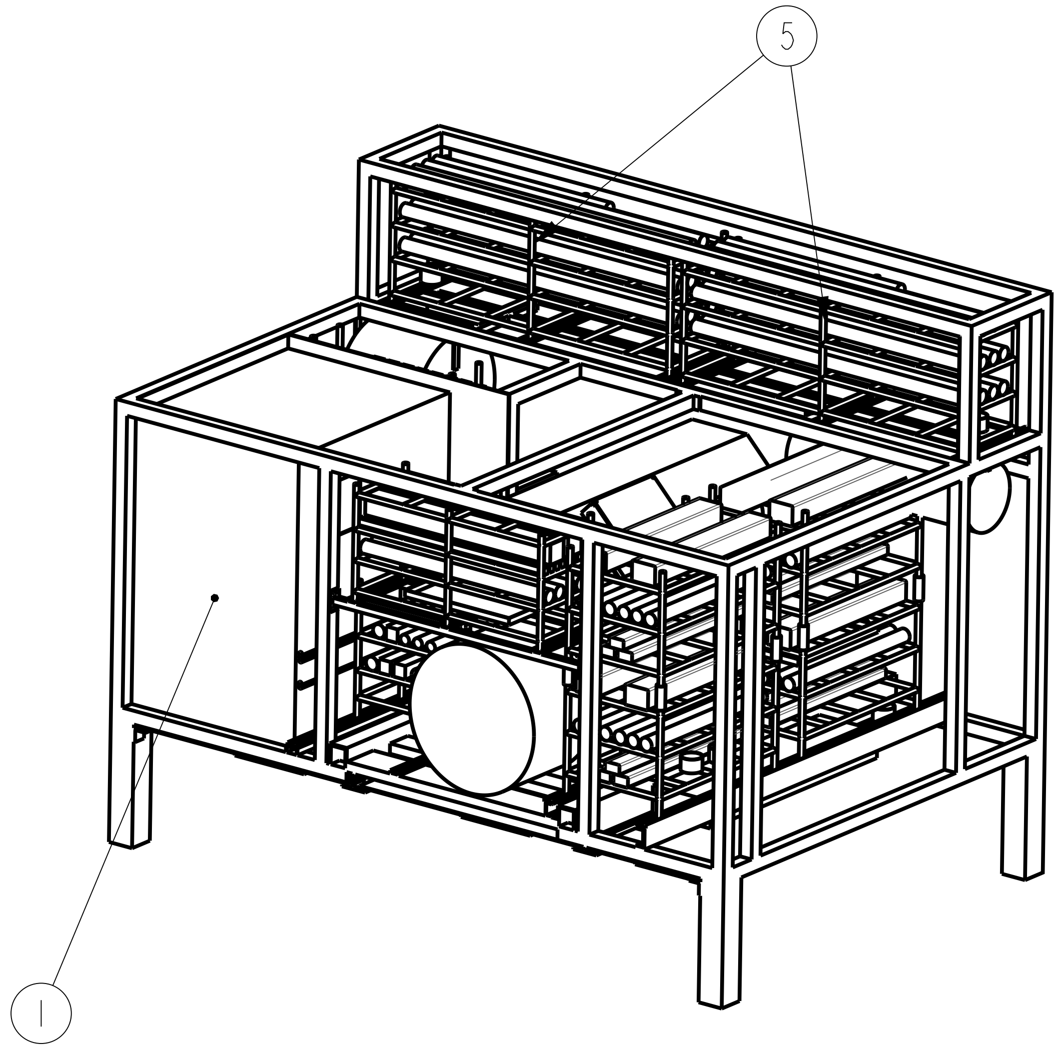

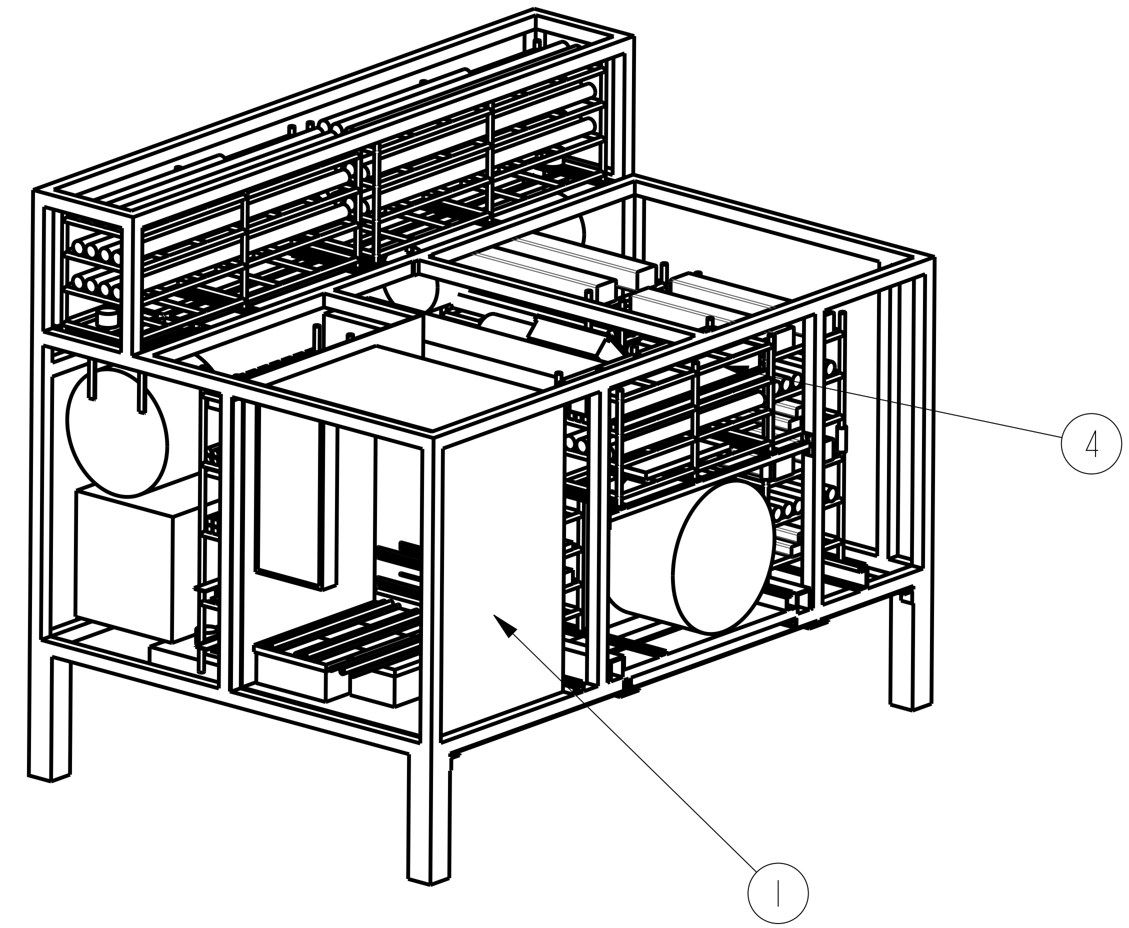

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TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 07-18-14
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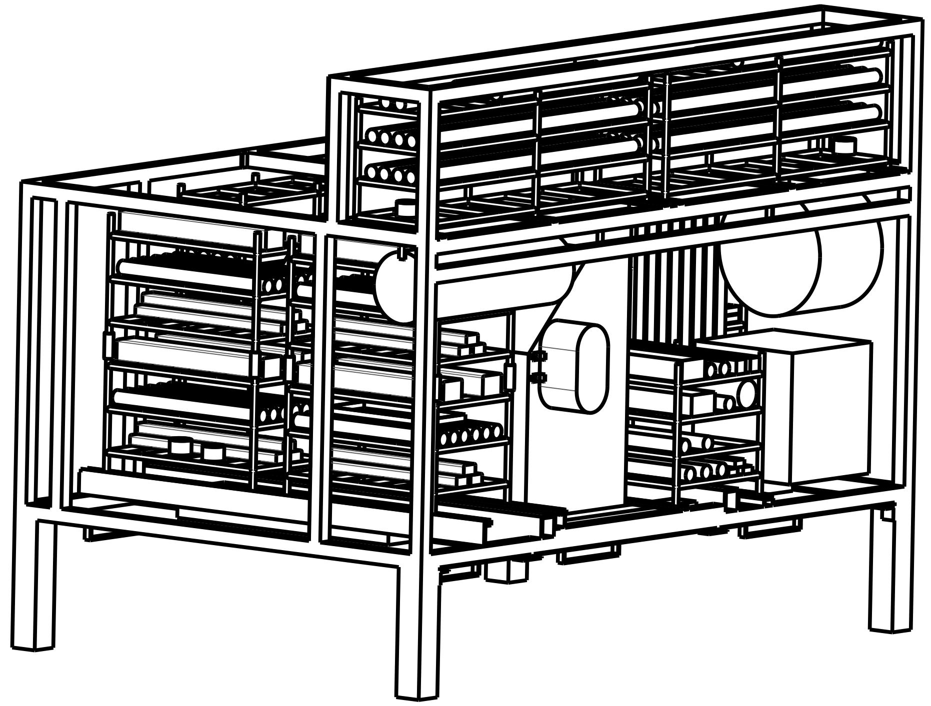

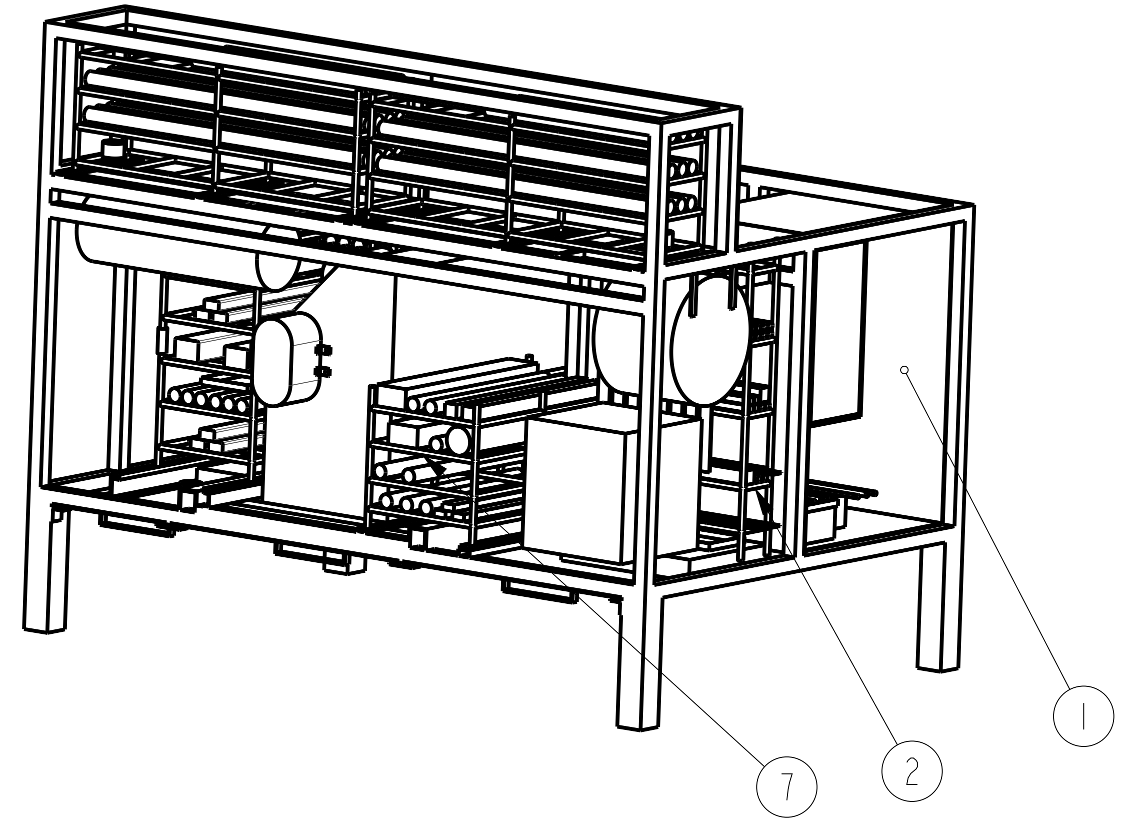

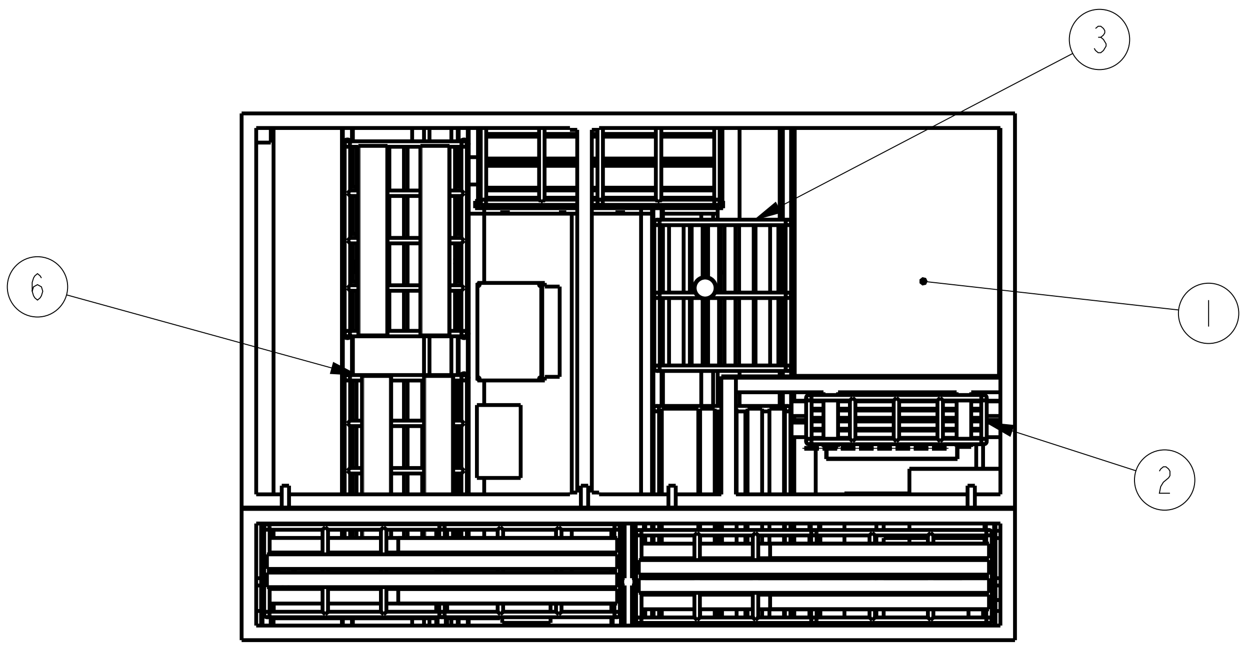

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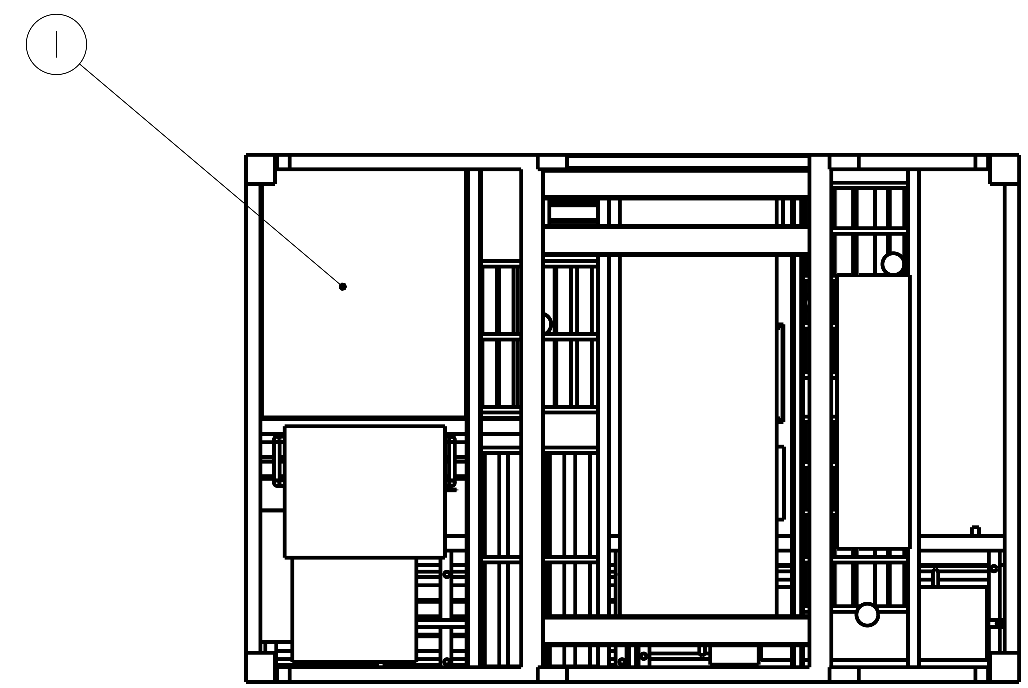

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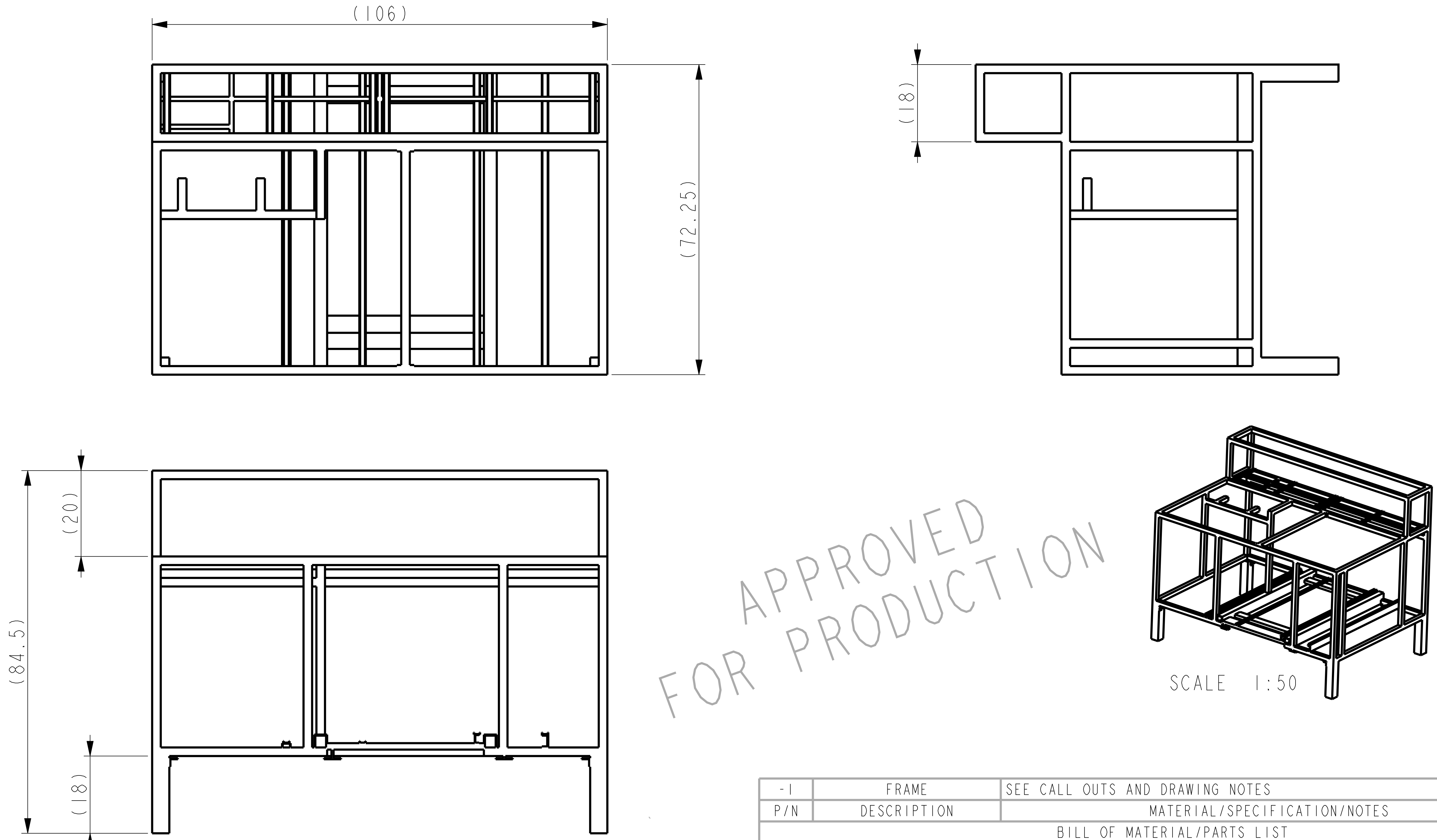

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b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
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TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 08-01-13
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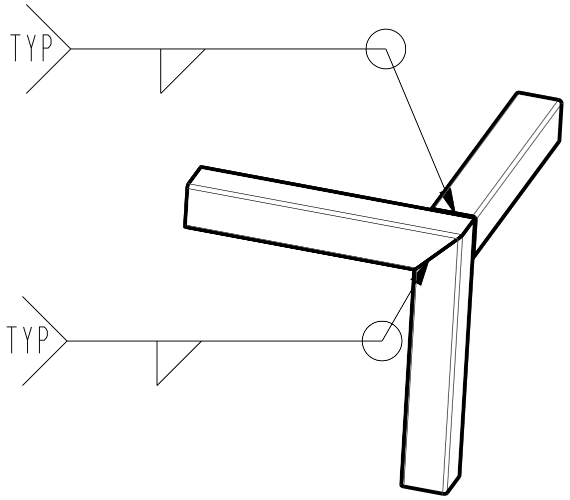

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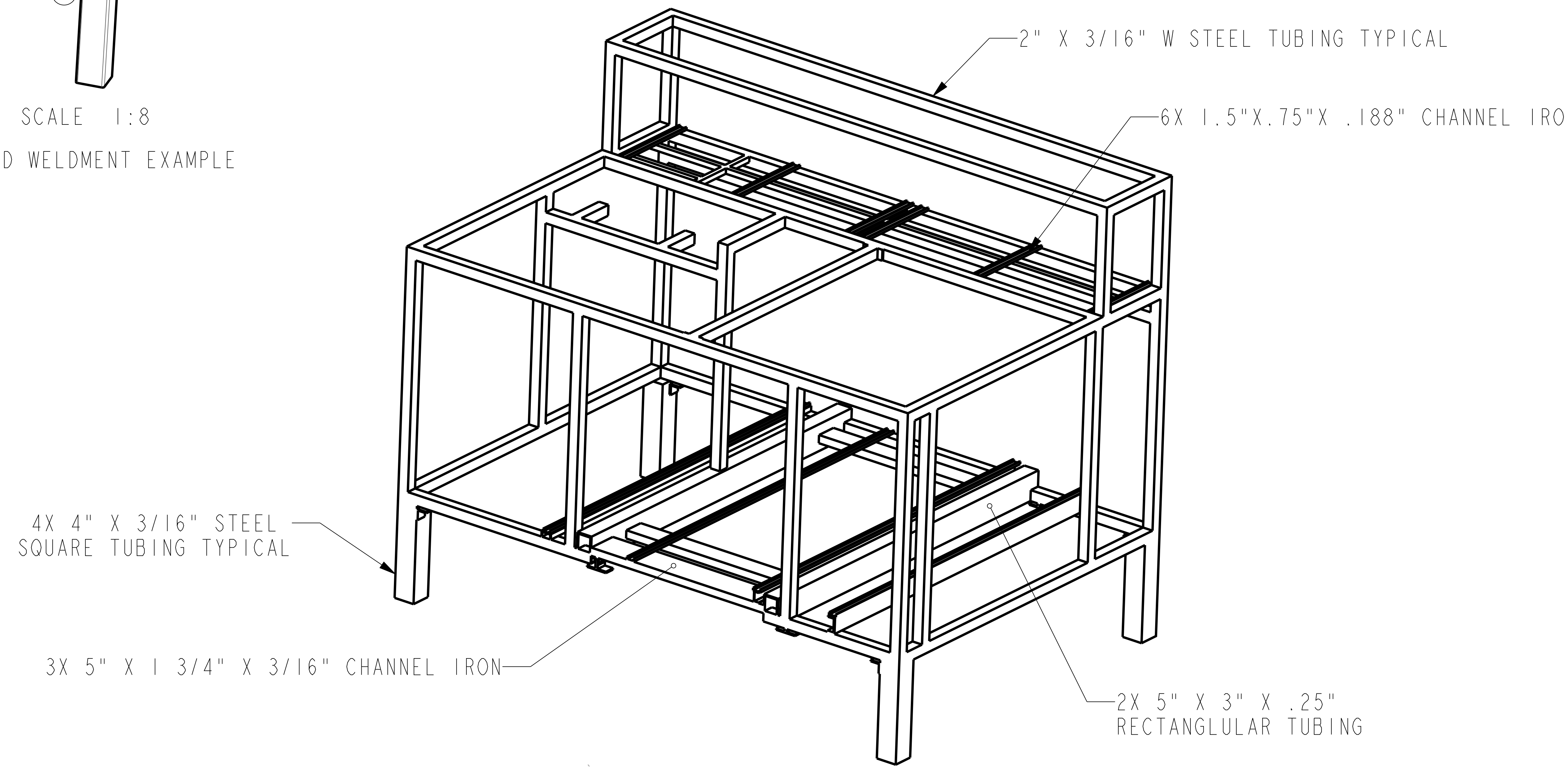

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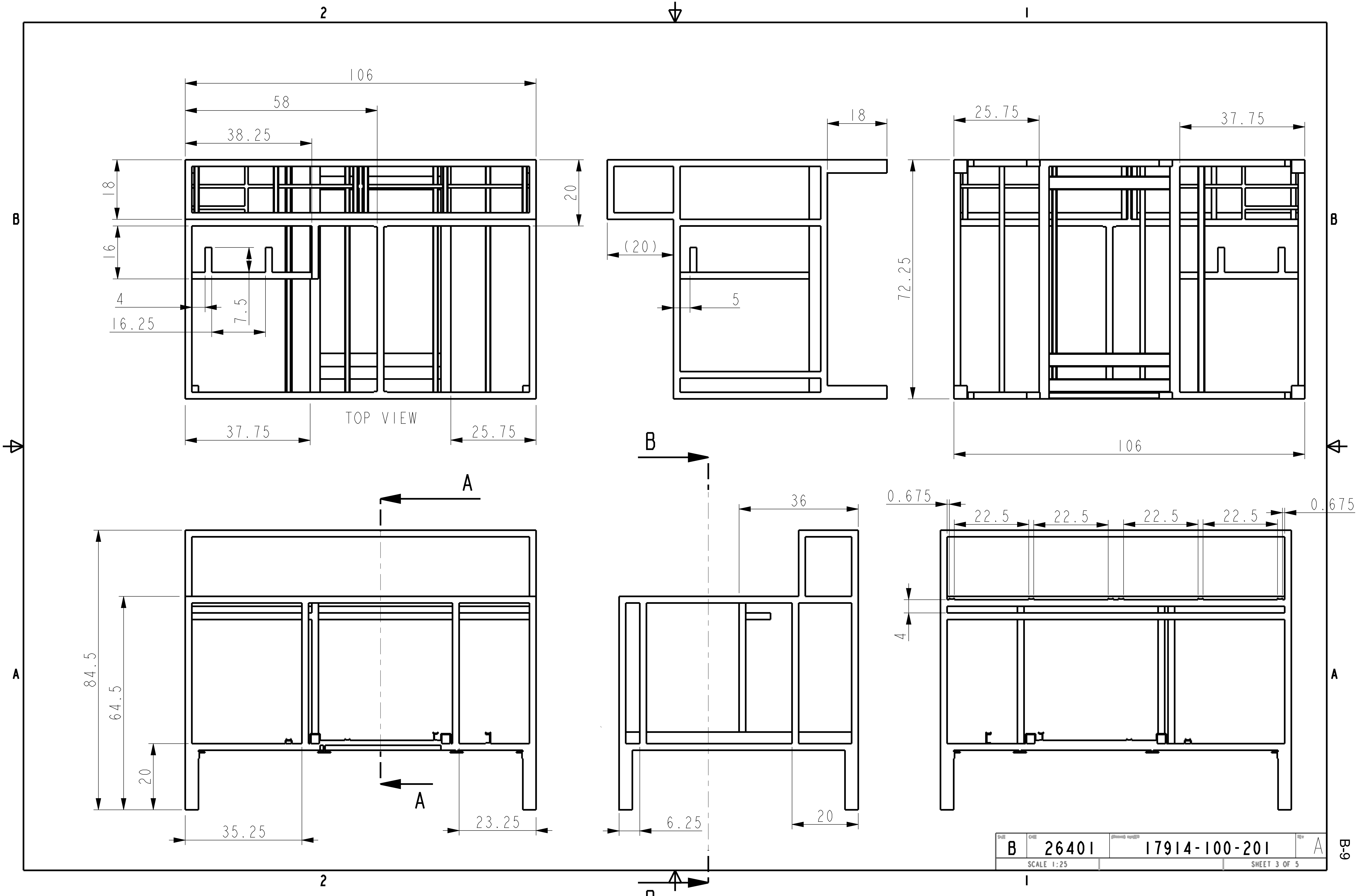

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17914-100-201
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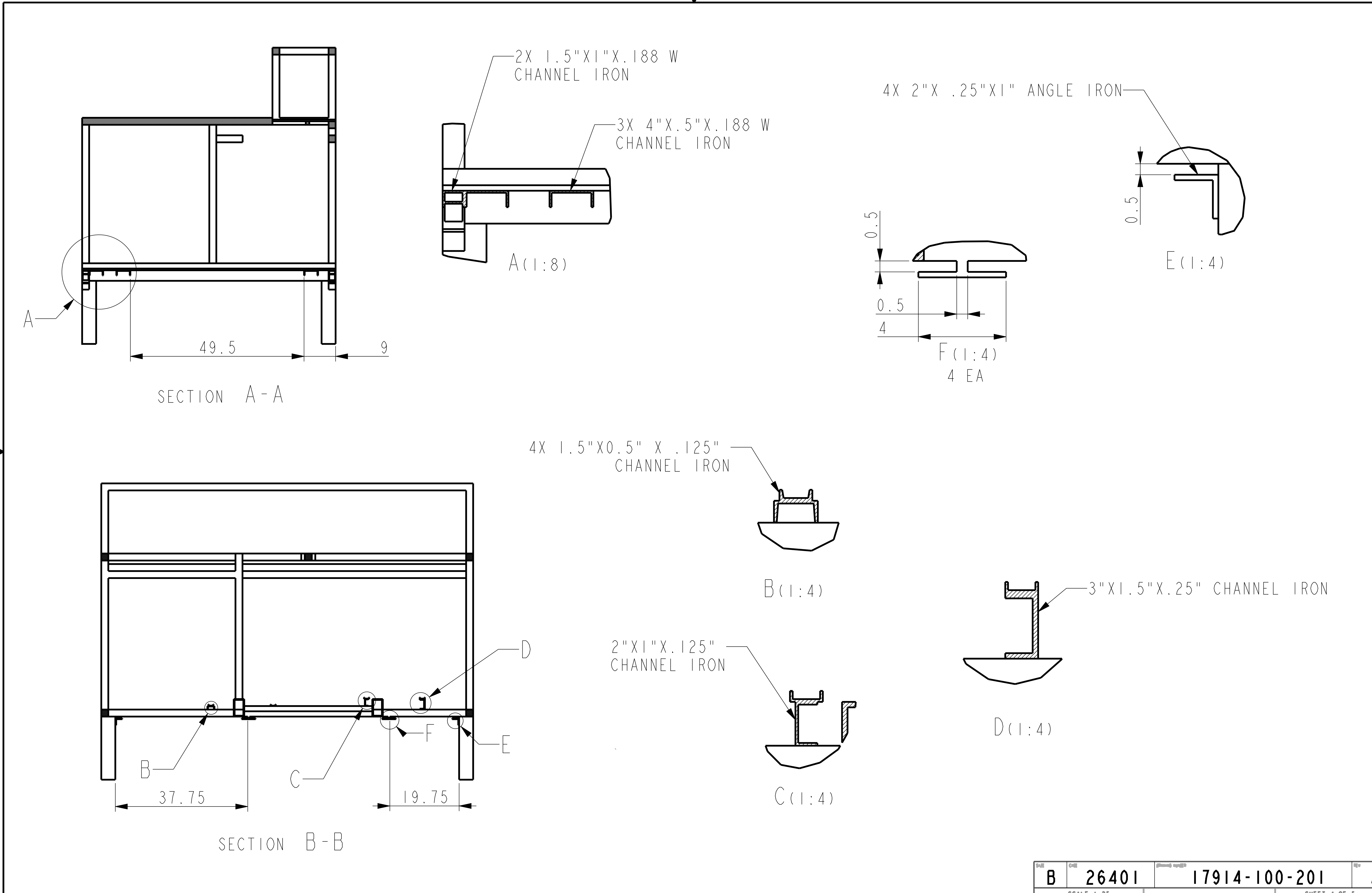
SCALE 1:25
SHEET 3 OF 5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CHANNEL IRON
3X 4"X.5"X.188 W
CHANNEL IRON
A(1:8)
4X 2"X .25"X1" ANGLE IRON
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E(1:4)
0.5
0.5
4
F(1:4)
4 EA
A
49.5
9
SECTION A-A
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B(1:4)
3"X1.5"X.25" CHANNEL IRON
D(1:4)
2"X1"X.125"
CHANNEL IRON
C(1:4)
D
B
C
F
E
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19.75
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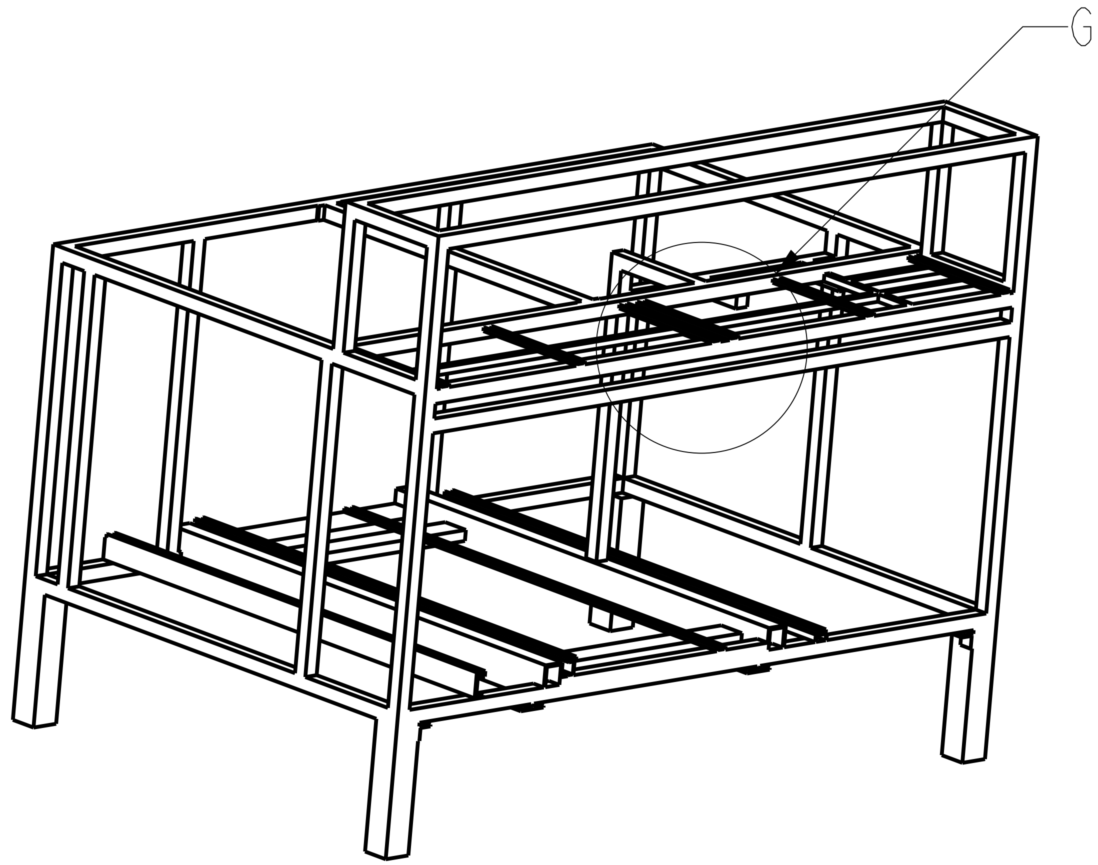
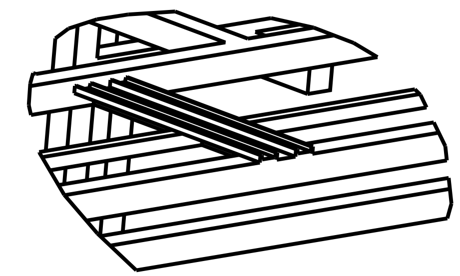
26401
17914-100-201
A
SCALE 1:25
SHEET 4 OF 5





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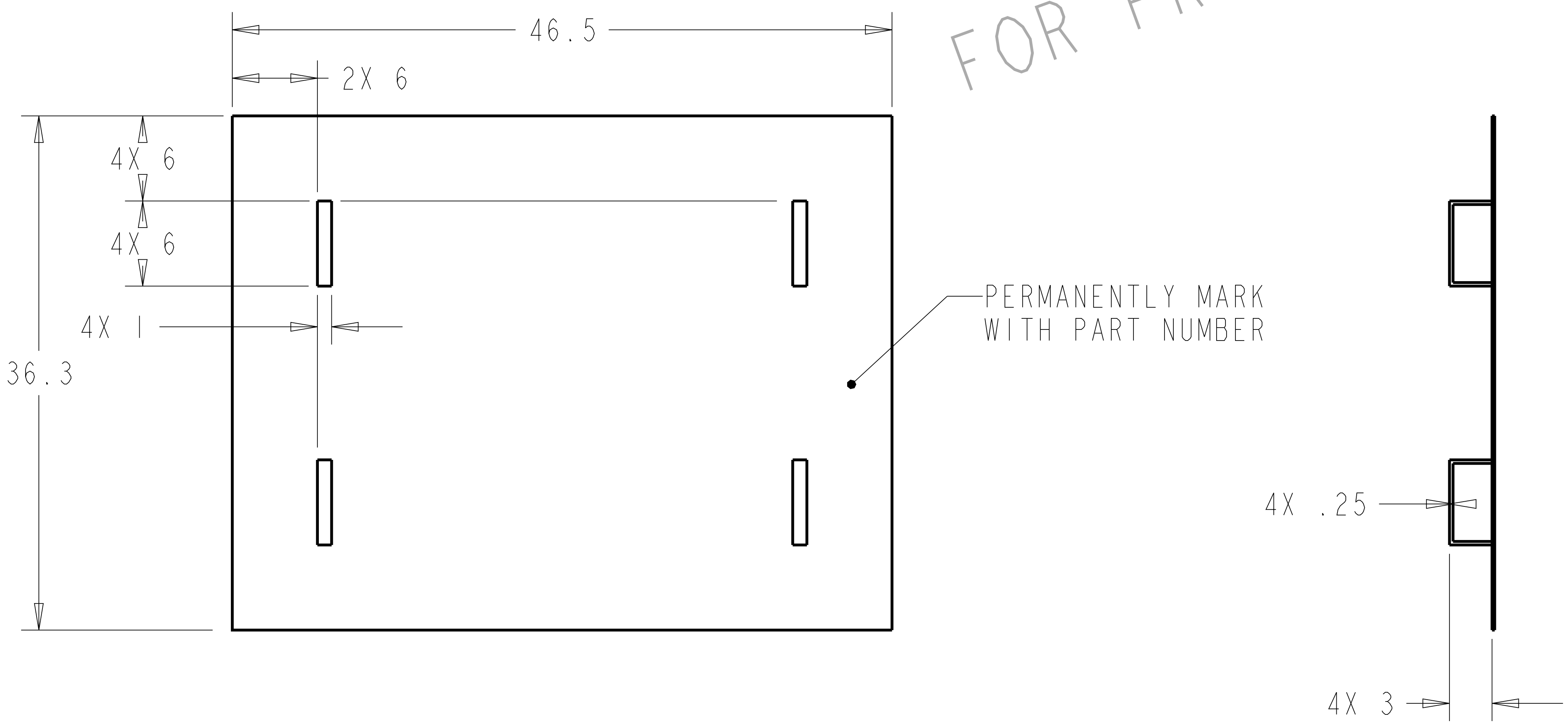
REVISIONS



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 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	FRONT WALL	3/16" STEEL PLATE WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 08-01-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: WALL_FRONT_RIGHT

THIRD ANGLE PROJECTION

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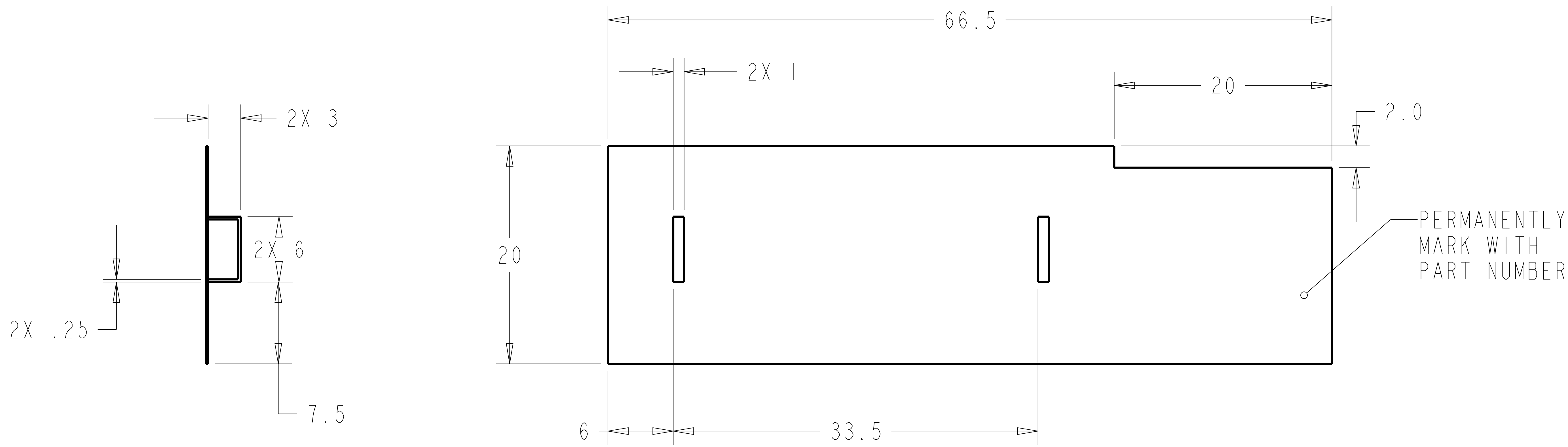
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238

WALL, FRONT RIGHT

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-100-202	A
SCALE 0.100	UNIT WEIGHT = LBS	SHEET 1 OF 1	

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-04-14



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FOR PRODUCTION

GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	RIGHT WALL	3/16 STEEL PLATE WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HURCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 08-01-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: WALL_LEFT_REAR
THIRD ANGLE PROJECTION	EXCEPT AS MAY OTHERWISE BE PROVIDED BY CONTRACT THESE DRAWINGS AND SPECIFICATIONS ARE THE PROPERTY OF SOUTHWEST RESEARCH INSTITUTE, ARE ISSUED IN STRICT CONFIDENCE, AND SHALL NOT BE REPRODUCED, OR COPIED, OR USED AS THE BASIS FOR MANUFACTURE OR SALE OF ANY APPARATUS SHOWN THEREON WITHOUT PERMISSION

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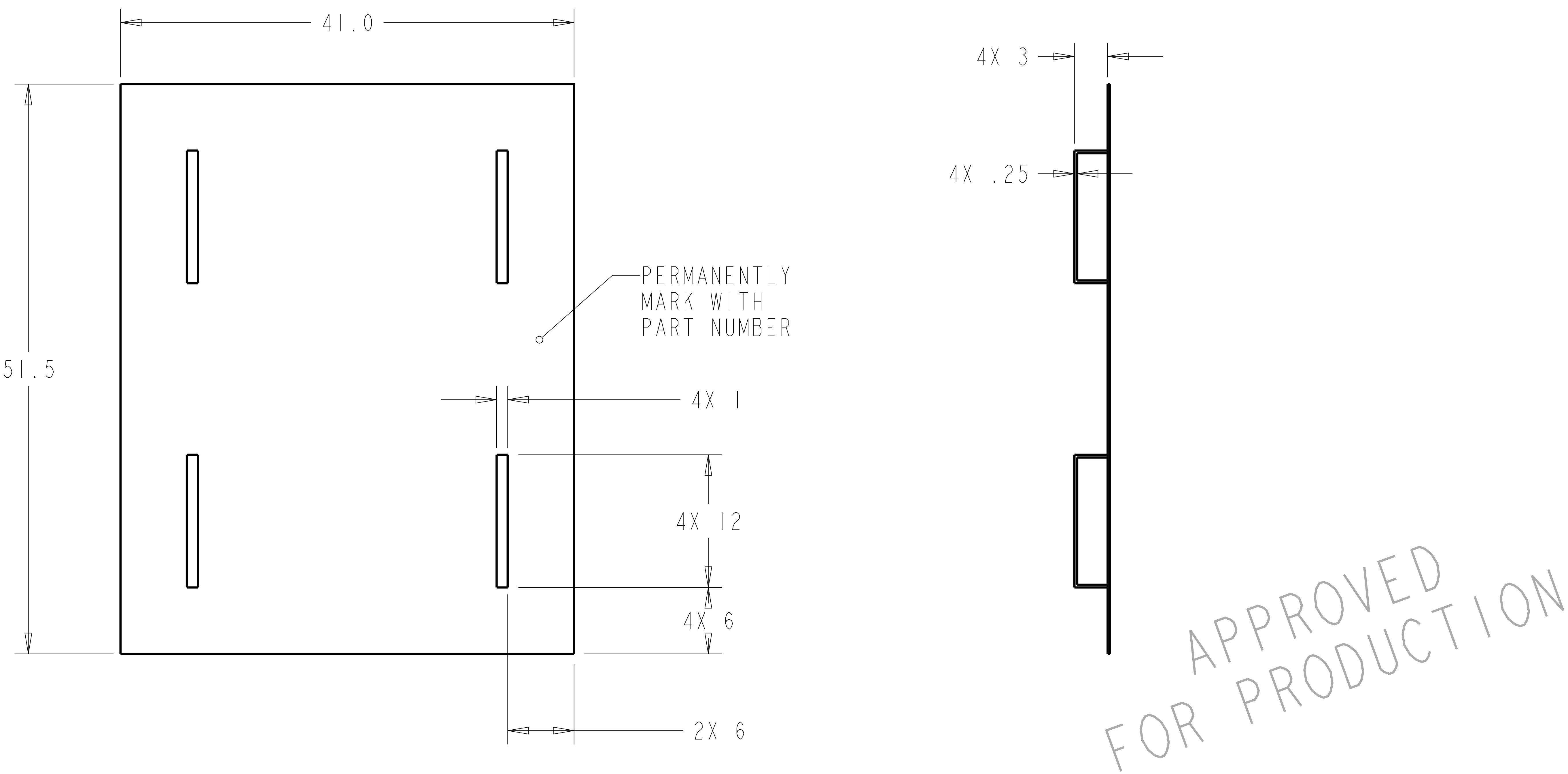
WALL, LEFT REAR

SIZE	CODE	DRAWING NUMBER	REV
B	26401	17914-100-203	A

SCALE 0.100 | UNIT WEIGHT = LBS | SHEET 1 OF 1

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-04-14



GENERAL NOTES

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2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	BACK WALL	3/16" STEEL PLATE WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HURCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 08-02-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: BACK_WALL
THIRD ANGLE PROJECTION	EXCEPT AS MAY OTHERWISE BE PROVIDED BY CONTRACT THESE DRAWINGS AND SPECIFICATIONS ARE THE PROPERTY OF SOUTHWEST RESEARCH INSTITUTE, ARE ISSUED IN STRICT CONFIDENCE, AND SHALL NOT BE REPRODUCED, OR COPIED, OR USED AS THE BASIS FOR MANUFACTURE OR SALE OF ANY APPARATUS SHOWN THEREON WITHOUT PERMISSION

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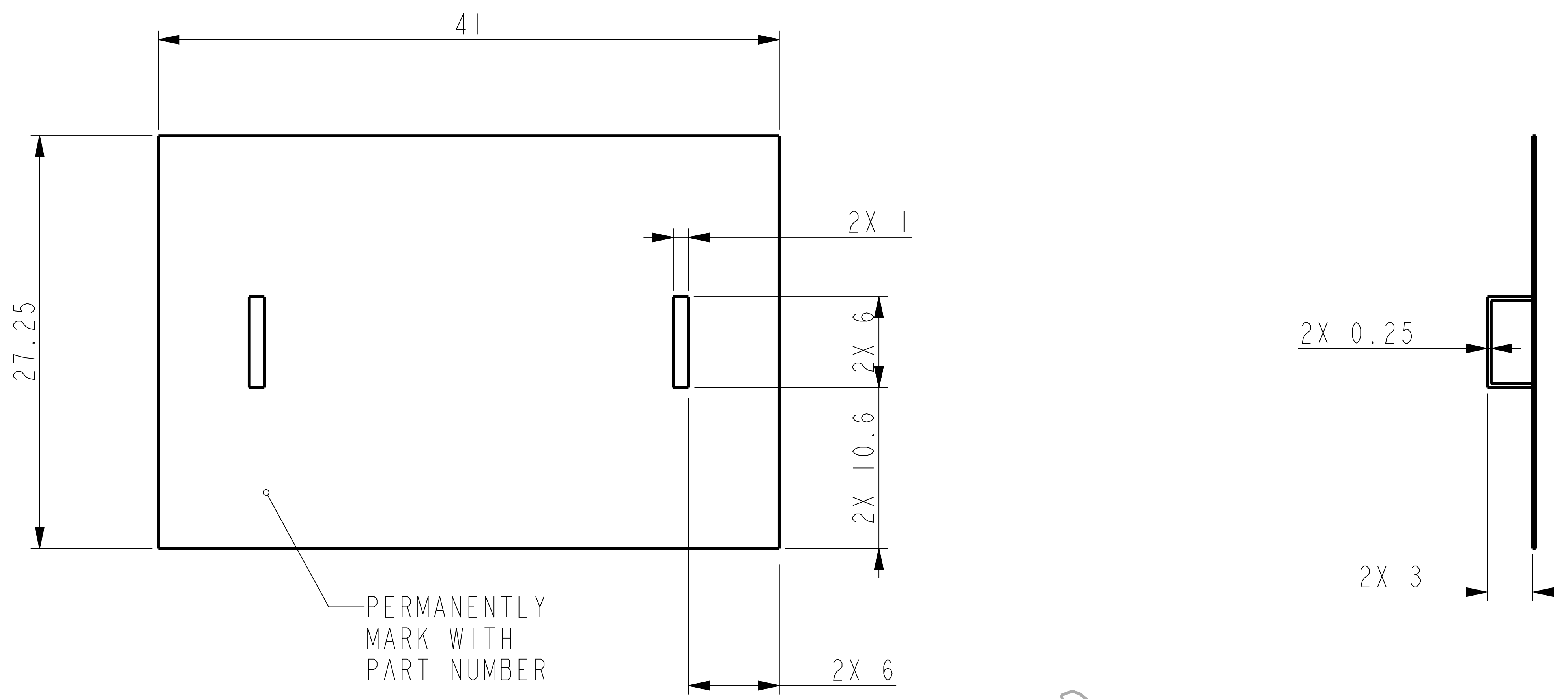
WALL, REAR LOWER MID

SIZE	CAGE	DWG NO	REV
B	26401	17914-100-204	A
SCALE 0.100	UNIT WEIGHT = LBS	SHEET 1 OF 1	

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-04-14



GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	BACK WALL	3/16 STEEL PLATE WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 10-30-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: WALL_BACK_LOWER_SIDE
THIRD ANGLE PROJECTION	

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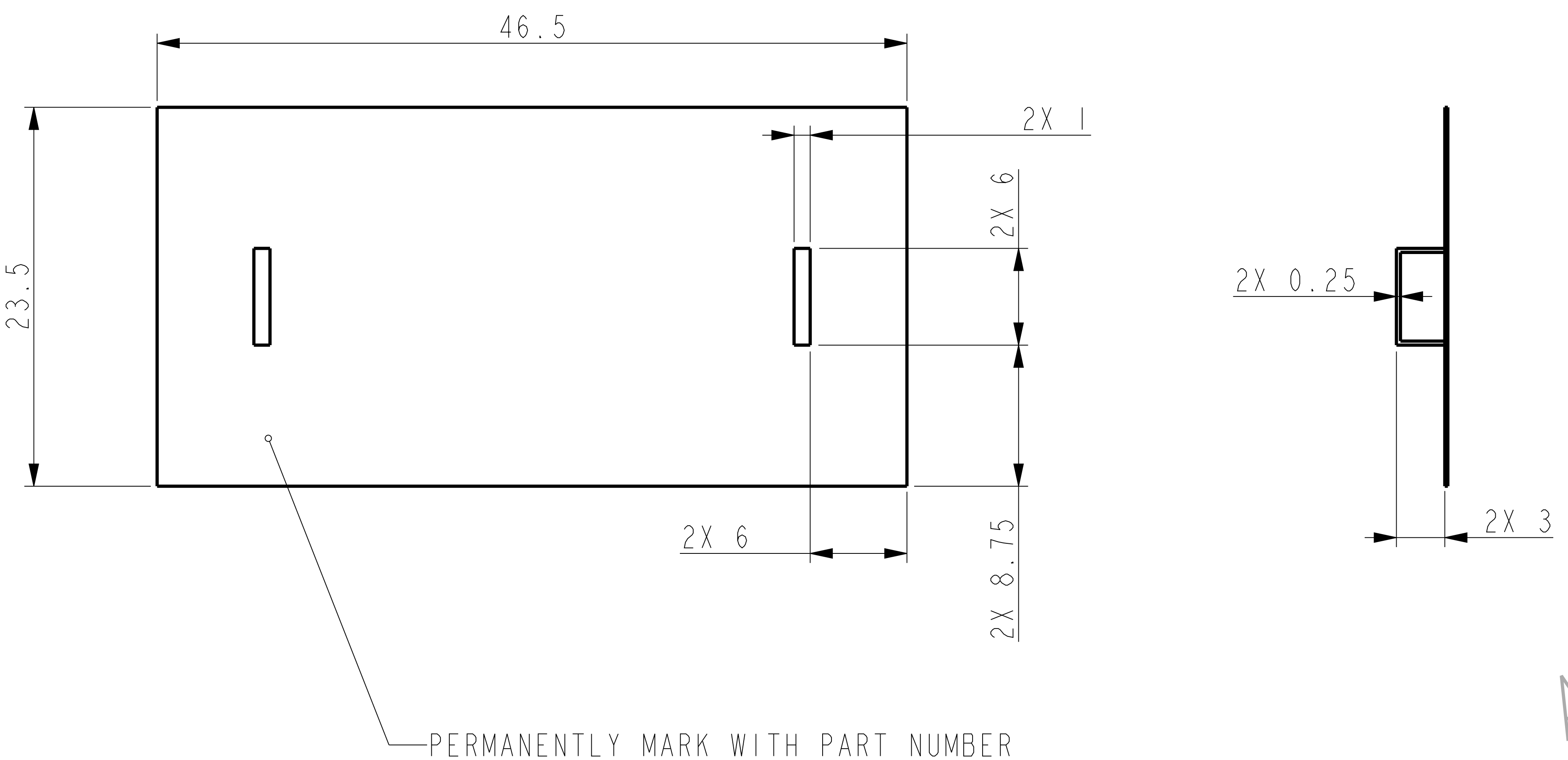
WALL, BACK LOWER SIDE

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-100-205	A
SCALE 1:10	UNIT WEIGHT = LBS	SHEET 1 OF 1	

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-04-14



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GENERAL NOTES

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2) UNLESS OTHERWISE STATED:
a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	BACK WALL	3/16" STEEL PLATE WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 10-30-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: WALL_BACK_TOP_HALF

THIRD ANGLE PROJECTION

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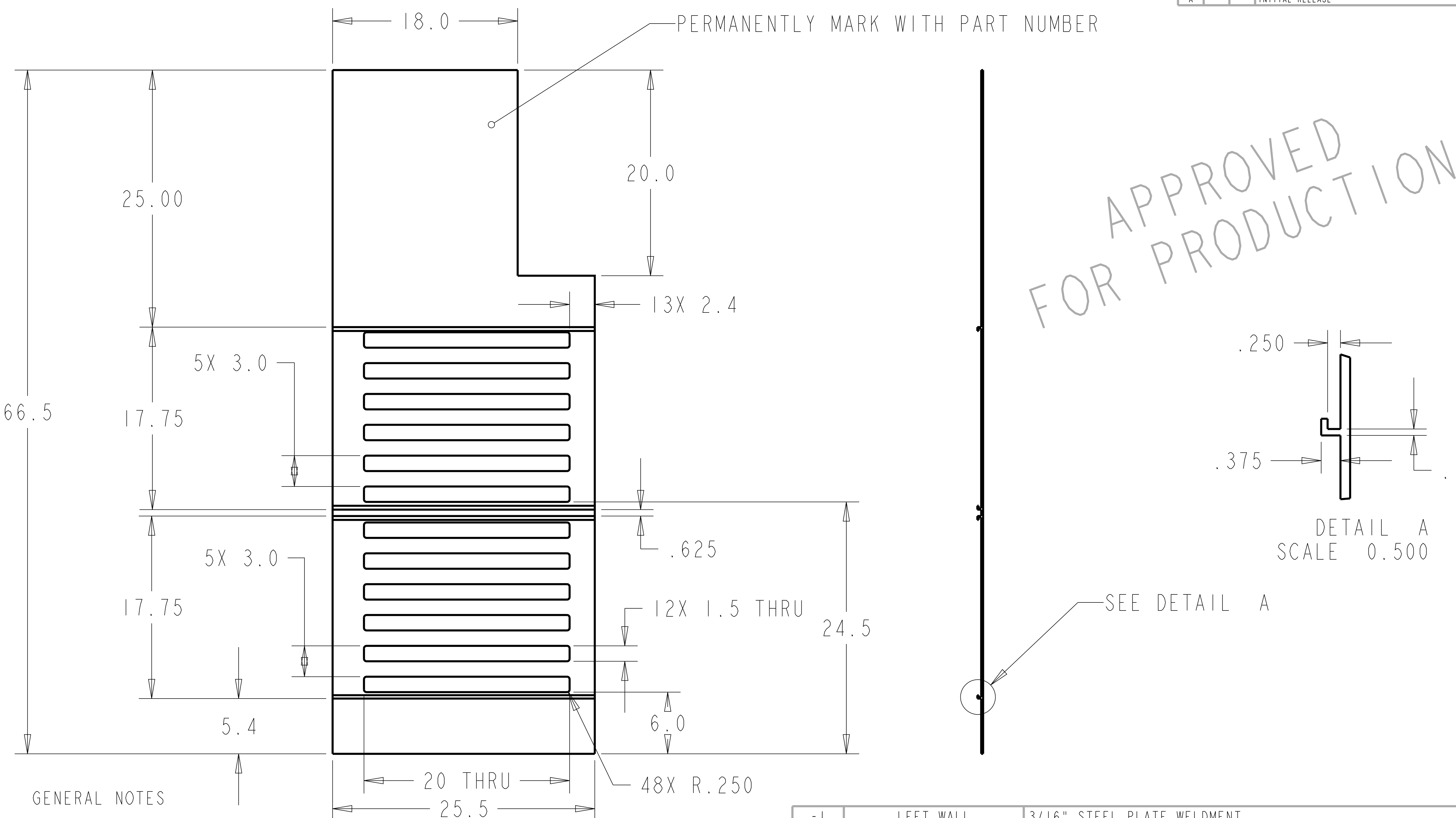
WALL, BACK TOP HALF

SIZE	CODE	DRAWING NUMBER	REV
B	26401	17914-100-206	A

SCALE 1:10 | UNIT WEIGHT = LBS | SHEET 1 OF 1

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-04-14



GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	LEFT WALL	3/16" STEEL PLATE WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HURCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 08-02-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: LEFT_WALL

THIRD ANGLE PROJECTION

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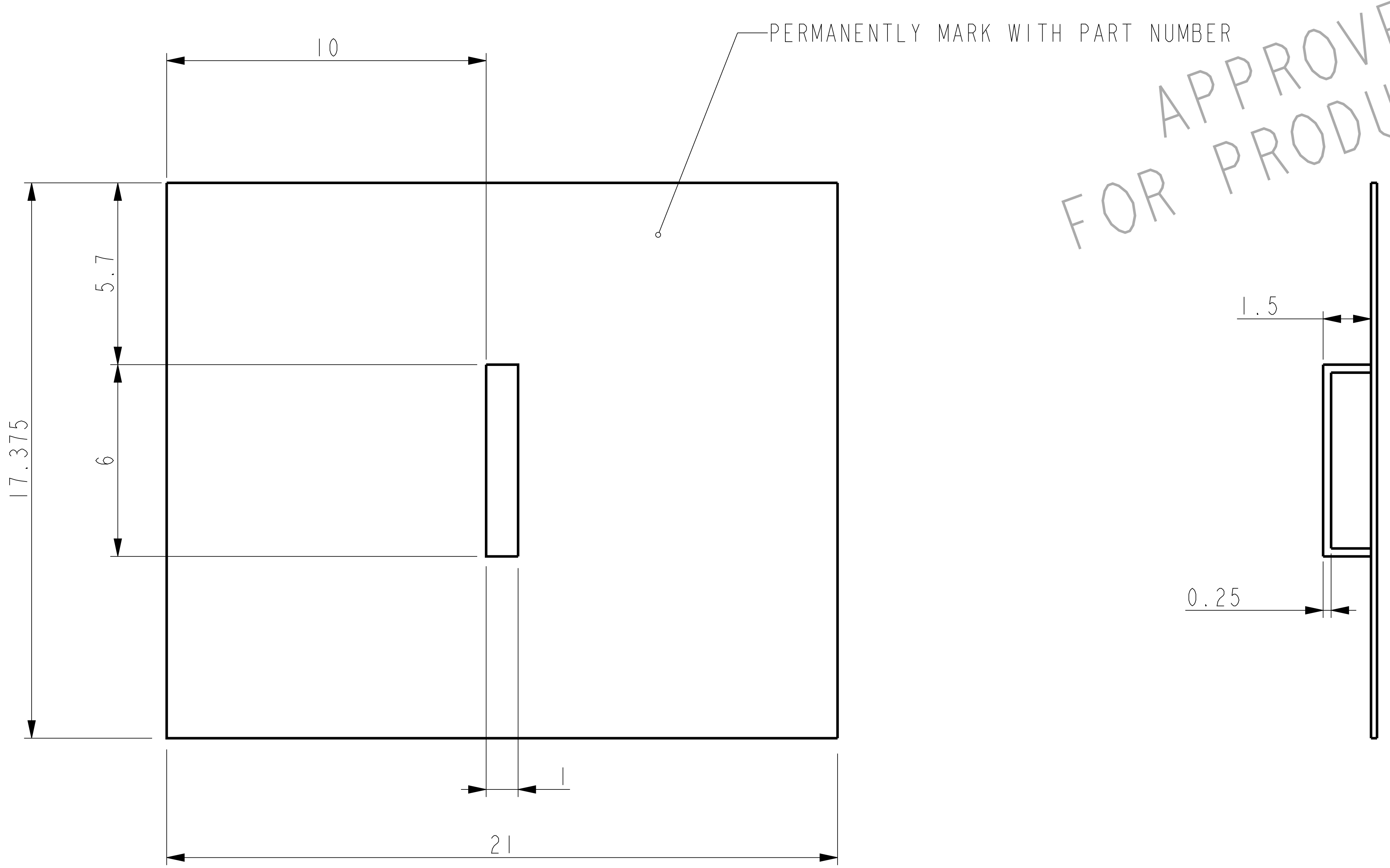
WALL , RIGHT, VENT

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-100-207	A

SCALE 0.100 | UNIT WEIGHT = LBS | SHEET 1 OF 1

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-04-14



APPROVED FOR PRODUCTION

QTY: 2 EACH

-1	DAMPER PLATE	3/16" STEEL PLATE WELDMENT	1
P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM

BILL OF MATERIAL/PARTS LIST

GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 01-30-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: PLATE_VENT_DAMPER
THIRD ANGLE PROJECTION	EXCEPT AS MAY OTHERWISE BE PROVIDED BY CONTRACT THESE DRAWINGS AND SPECIFICATIONS ARE THE PROPERTY OF SOUTHWEST RESEARCH INSTITUTE, ARE ISSUED IN STRICT CONFIDENCE, AND SHALL NOT BE REPRODUCED, OR COPIED, OR USED AS THE BASIS FOR MANUFACTURE OR SALE OF ANY APPARATUS SHOWN THEREON WITHOUT PERMISSION

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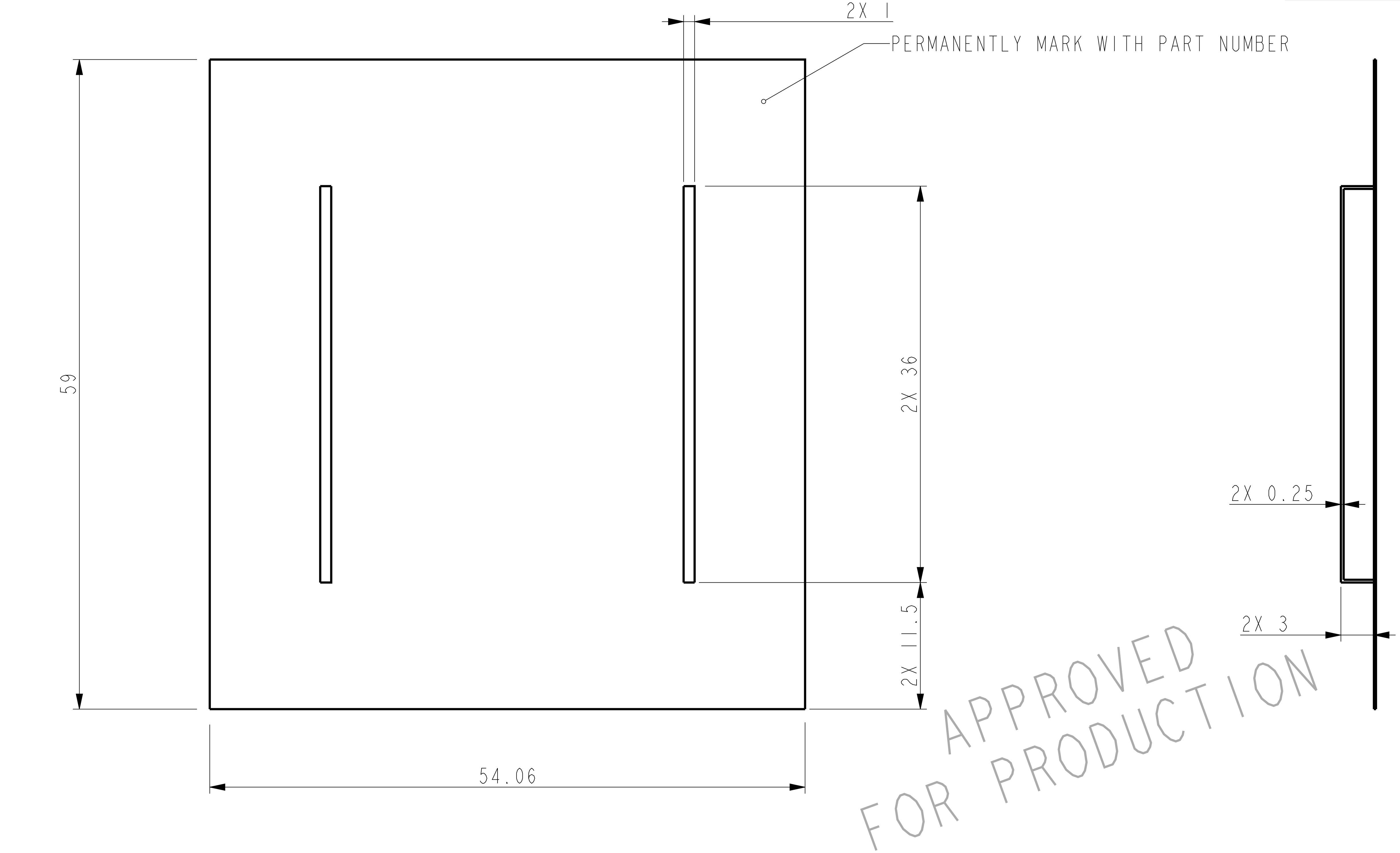
PLATE, VENT DAMPER

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-100-208	A
SCALE 1:4	UNIT WEIGHT = LBS	SHEET 1 OF 1	

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-04-14



GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	WALL	3/16" STEEL PLATE WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 01-07-14
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: WALL_MAIN_TOP_RIGHT

THIRD ANGLE PROJECTION

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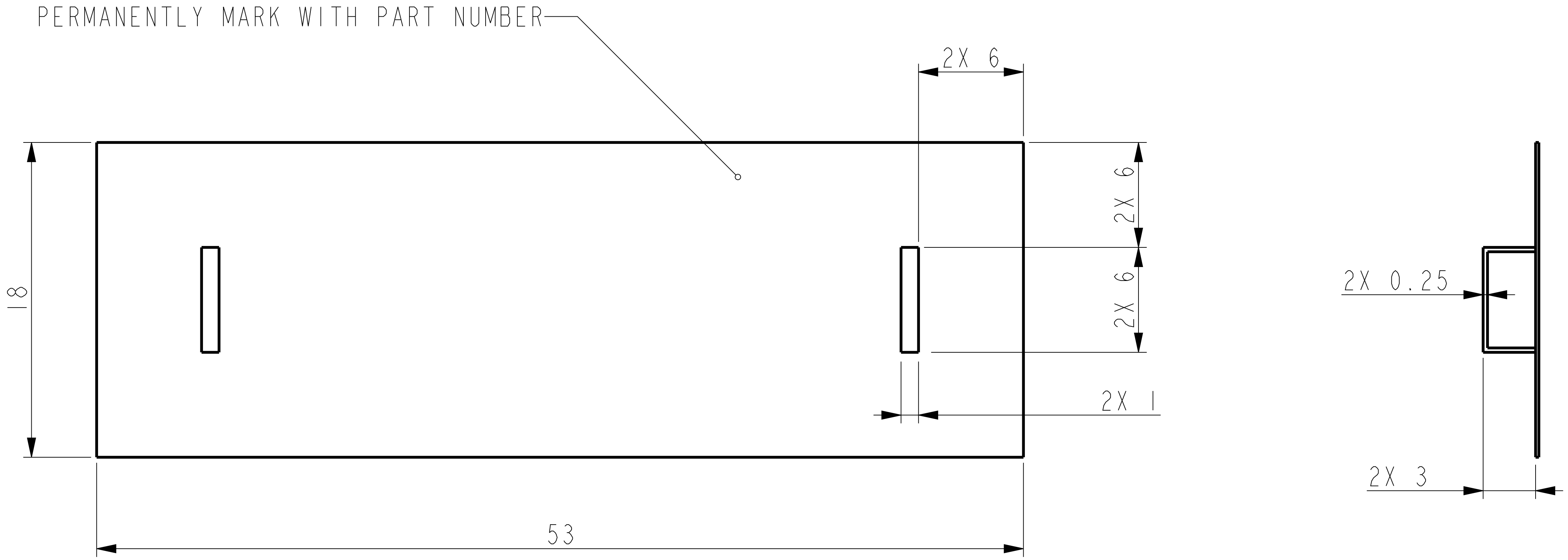
WALL, MAIN TOP RIGHT

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-100-209	A
SCALE 1:10	UNIT WEIGHT = LBS	SHEET 1 OF 1	

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-04-14



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-1	WALL	3/16" STEEL PLATE WELDMENT	1
P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM

BILL OF MATERIAL/PARTS LIST

GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 10-30-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: WALL_UPPER_TOPHAT
THIRD ANGLE PROJECTION	

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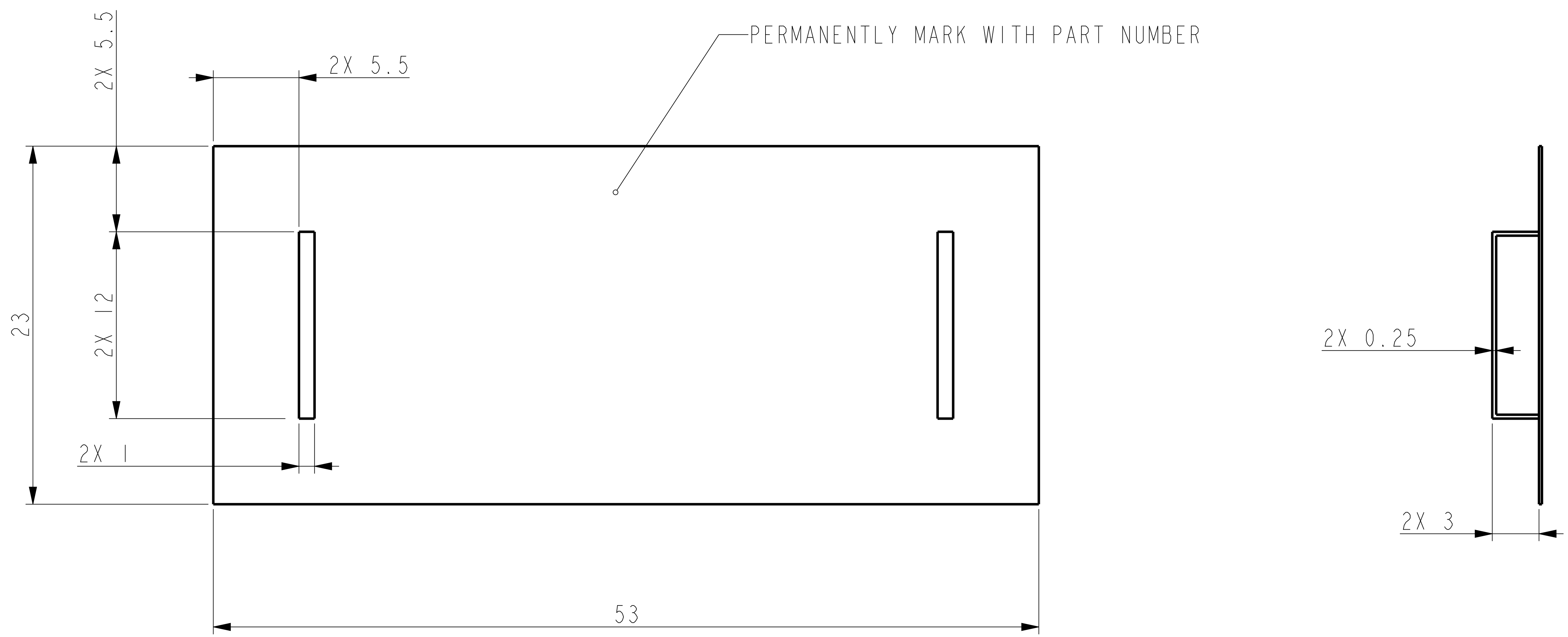
WALL, UPPER TOP HAT

B	26401	17914-100-210	A
SCALE 1:8	UNIT WEIGHT = LBS	SHEET 1 OF 1	

B-20

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RLEASE	08-05-14



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GENERAL NOTES

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 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	WALL	3/16" STEEL PLATE WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 10-30-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: WALL_REAR_TOPHAT
THIRD ANGLE PROJECTION	EXCEPT AS MAY OTHERWISE BE PROVIDED BY CONTRACT THESE DRAWINGS AND SPECIFICATIONS ARE THE PROPERTY OF SOUTHWEST RESEARCH INSTITUTE, ARE ISSUED IN STRICT CONFIDENCE, AND SHALL NOT BE REPRODUCED, OR COPIED, OR USED AS THE BASIS FOR MANUFACTURE OR SALE OF ANY APPARATUS SHOWN THEREON WITHOUT PERMISSION

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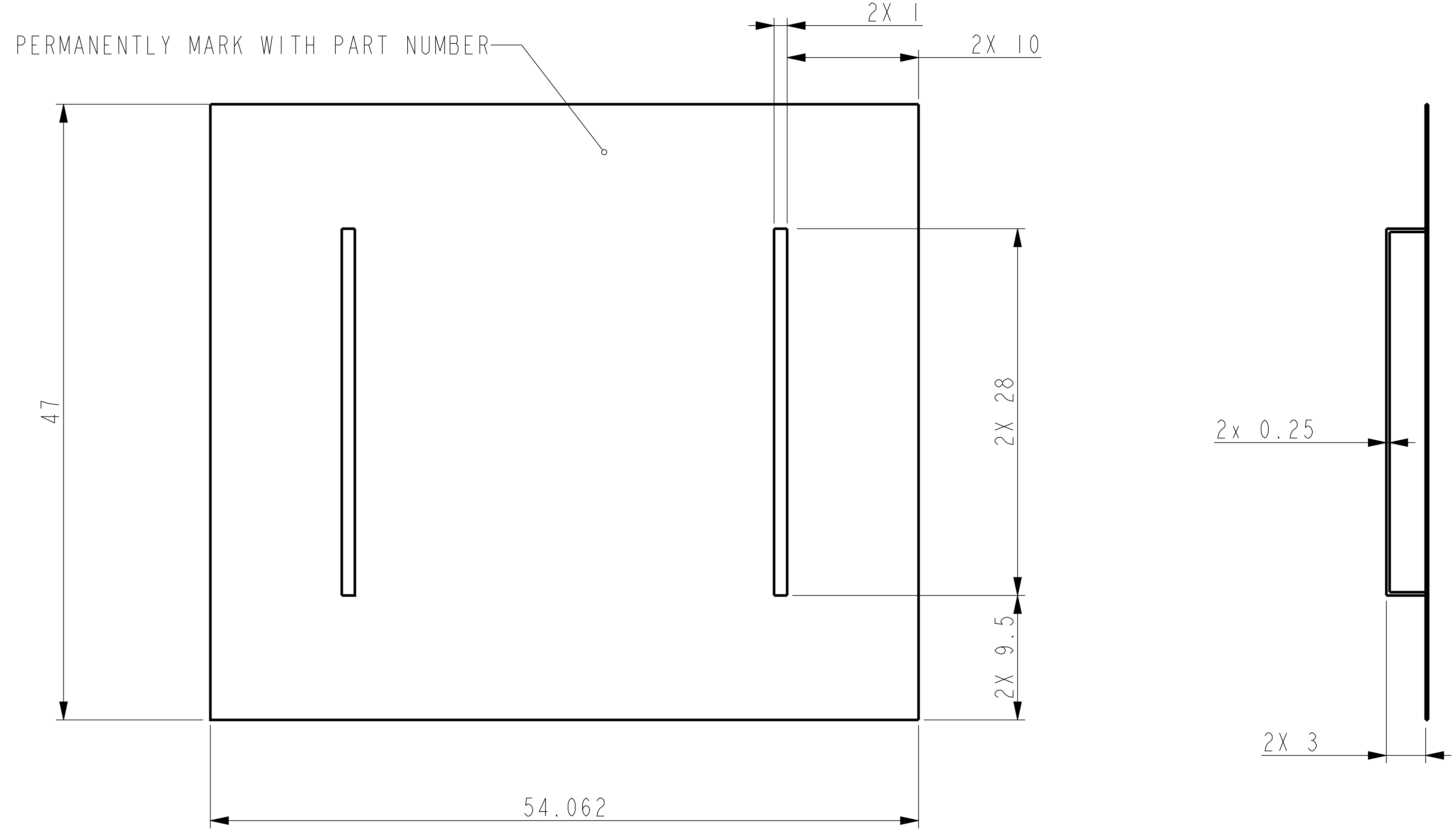
WALL, REAR TOP HAT

SIZE	CAGE	DWG NO	REV
B	26401	17914-100-211	A

SCALE 1:8 | UNIT WEIGHT = LBS | SHEET 1 OF 1

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RLEASE	08-05-14



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GENERAL NOTES

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 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	WALL	3/16" STEEL PLATE WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C RAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 10-30-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: WALL_MAIN_TOP_LEFT
THIRD ANGLE PROJECTION	

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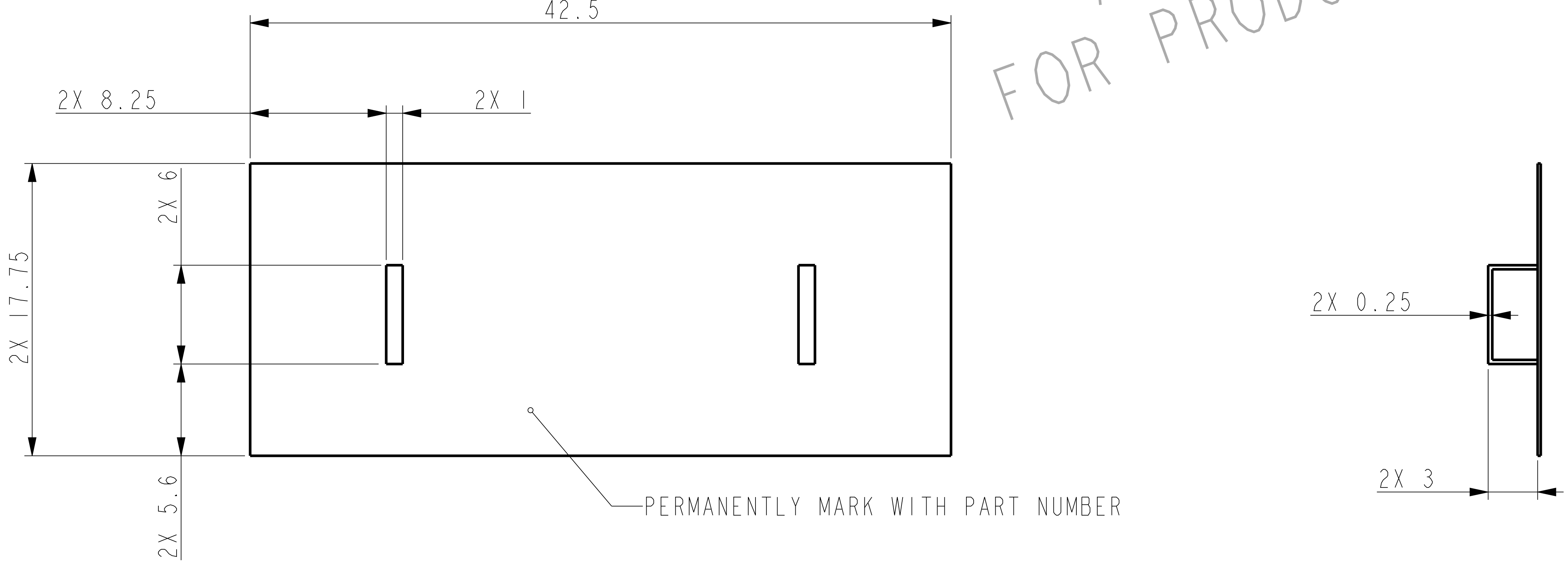
WALL, MAIN TOP LEFT

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-100-212	A
SCALE 1:10	UNIT WEIGHT = LBS	SHEET 1 OF 1	

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RLEASE	08-05-14



GENERAL NOTES

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2) UNLESS OTHERWISE STATED:
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 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	WALL	3/16" STEEL PLATE WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) : ± 0.1	B SCHULTZ
TWO PLACES (X.XX) : ± 0.01	C WRAY
THREE PLACES (X.XXX) : ± 0.005	C WRAY
FOUR PLACES (X.XXXX) : ± 0.0005	J HUCZEK
ANGLES : ± 0.5 DEGREE	COMPLETION DATE: 10-30-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: WALL_TOP_CENTER

THIRD ANGLE PROJECTION

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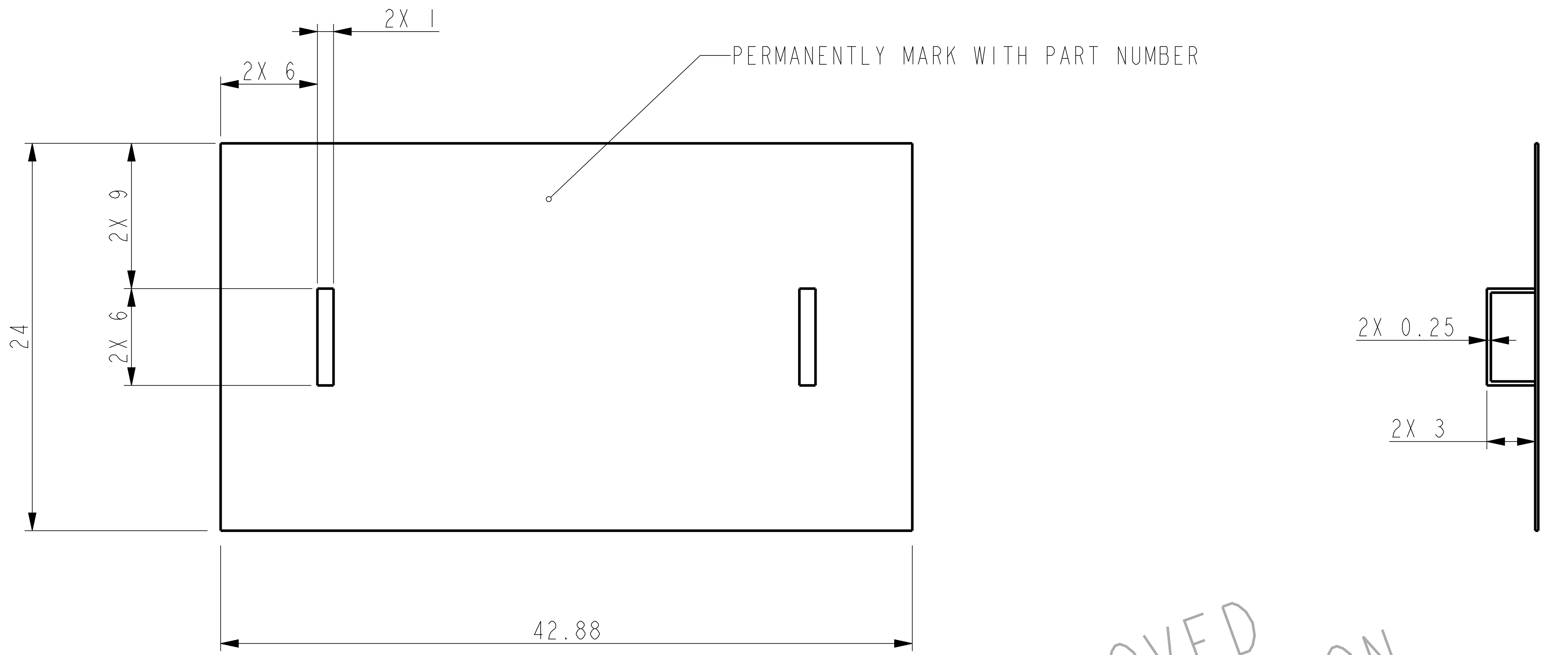
WALL, TOP CENTER

B	26401	17914-100-213	A
SCALE 1:8	UNIT WEIGHT : LBS	SHEET 1 OF 1	

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RLEASE	08-05-14



APPROVED FOR PRODUCTION

GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	WALL	3/16" STEEL PLATE WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	JC WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 01-30-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: WALL_FRONT_LOWER

THIRD ANGLE PROJECTION

EXCEPT AS MAY OTHERWISE BE PROVIDED BY CONTRACT THESE DRAWINGS AND SPECIFICATIONS ARE THE PROPERTY OF SOUTHWEST RESEARCH INSTITUTE, ARE ISSUED IN STRICT CONFIDENCE, AND SHALL NOT BE REPRODUCED, OR COPIED, OR USED AS THE BASIS FOR MANUFACTURE OR SALE OF ANY APPARATUS SHOWN THEREON WITHOUT PERMISSION

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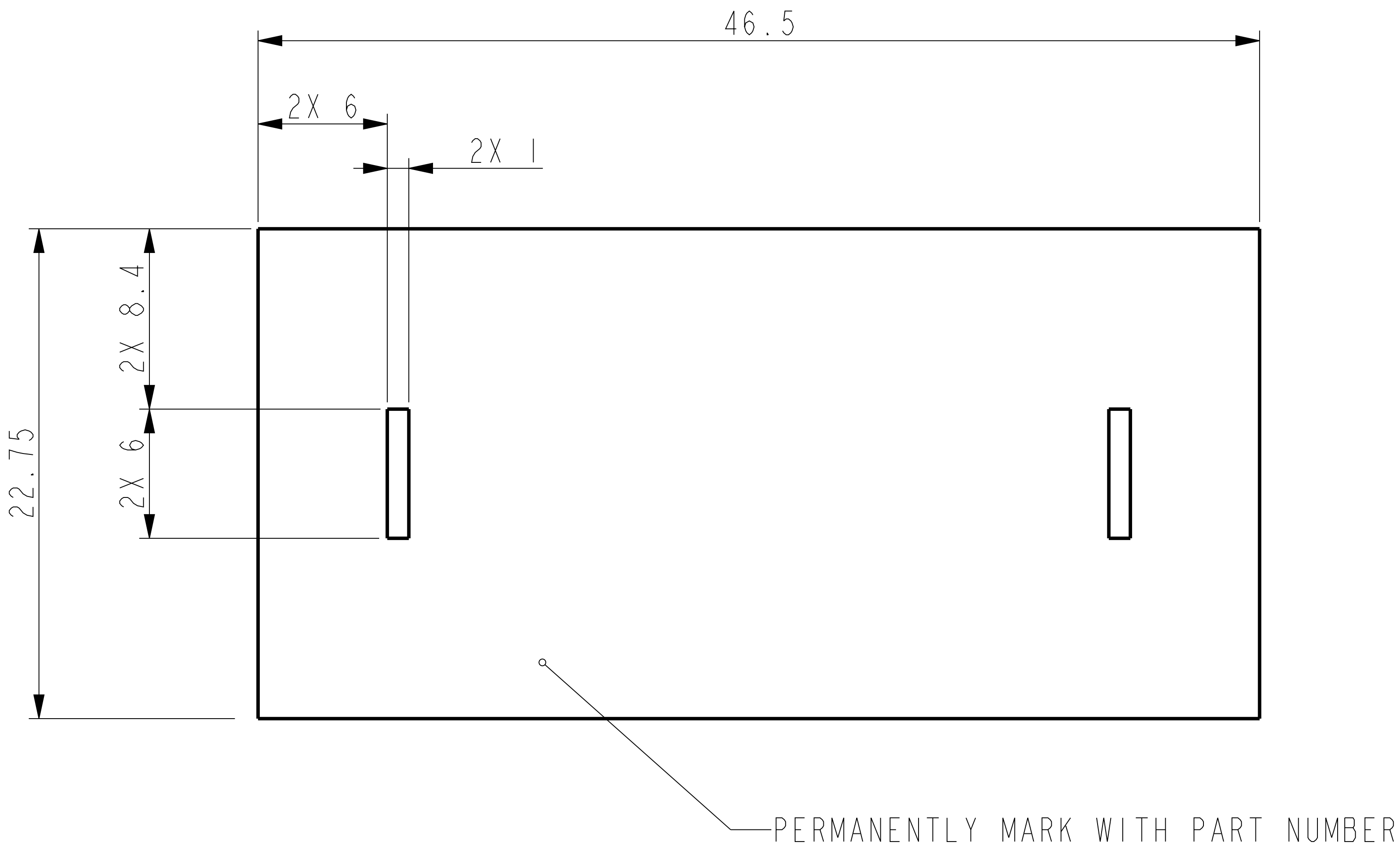
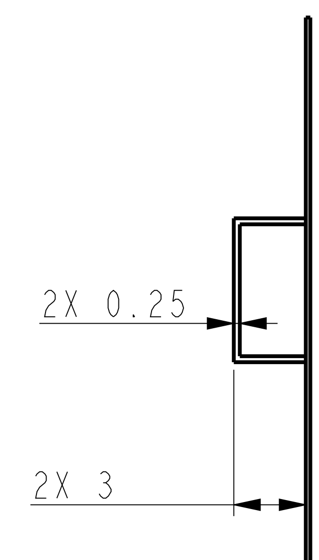
WALL, FRONT LOWER

SIZE	CODE	DRAWING NUMBER	REV
B	26401	17914-100-214	A

SCALE 1:8 | UNIT WEIGHT = LBS | SHEET 1 OF 1

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RLEASE	08-05-14





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QTY: 2 EACH

GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	WALL	3/16" STEEL PLATE WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	CWRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 10-30-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: WALL_FRONT_CENTER

THIRD ANGLE PROJECTION

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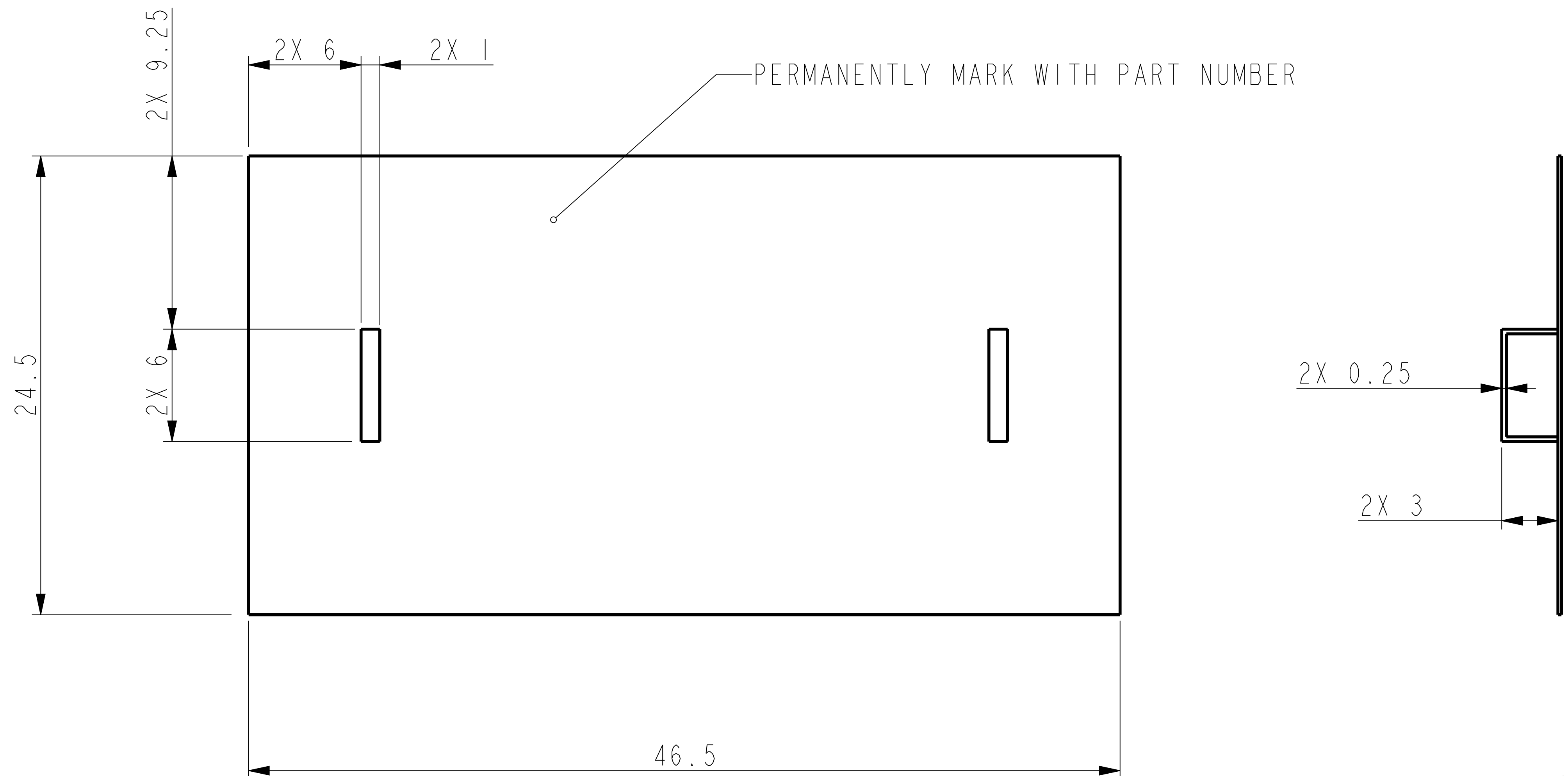
WALL, FRONT CENTER

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-100-215	A
SCALE 1:8	UNIT WEIGHT = LBS	SHEET 1 OF 1	

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RLEASE	08-05-14



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GENERAL NOTES

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 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	WALL	3/16" STEEL PLATE WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 10-30-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: WALL_FRONT_LEFT

THIRD ANGLE PROJECTION

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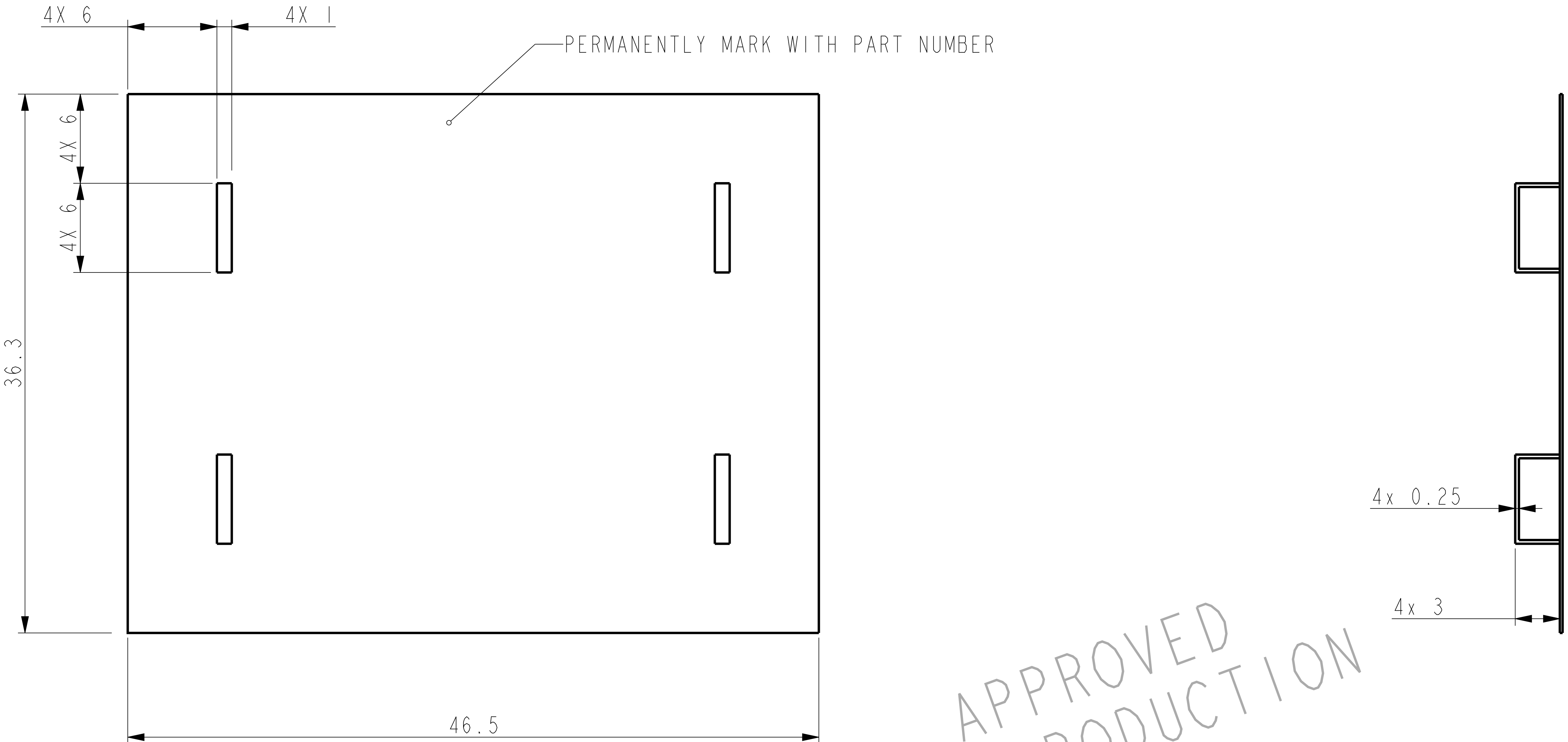
WALL, FRONT LEFT

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-100-216	A

SCALE 1:8 | UNIT WEIGHT = LBS | SHEET 1 OF 1

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RLEASE	08-05-14



GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	WALL	3/16" STEEL PLATE WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 10-30-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: WALL_FRONT_INNER_RIGHT

THIRD ANGLE PROJECTION

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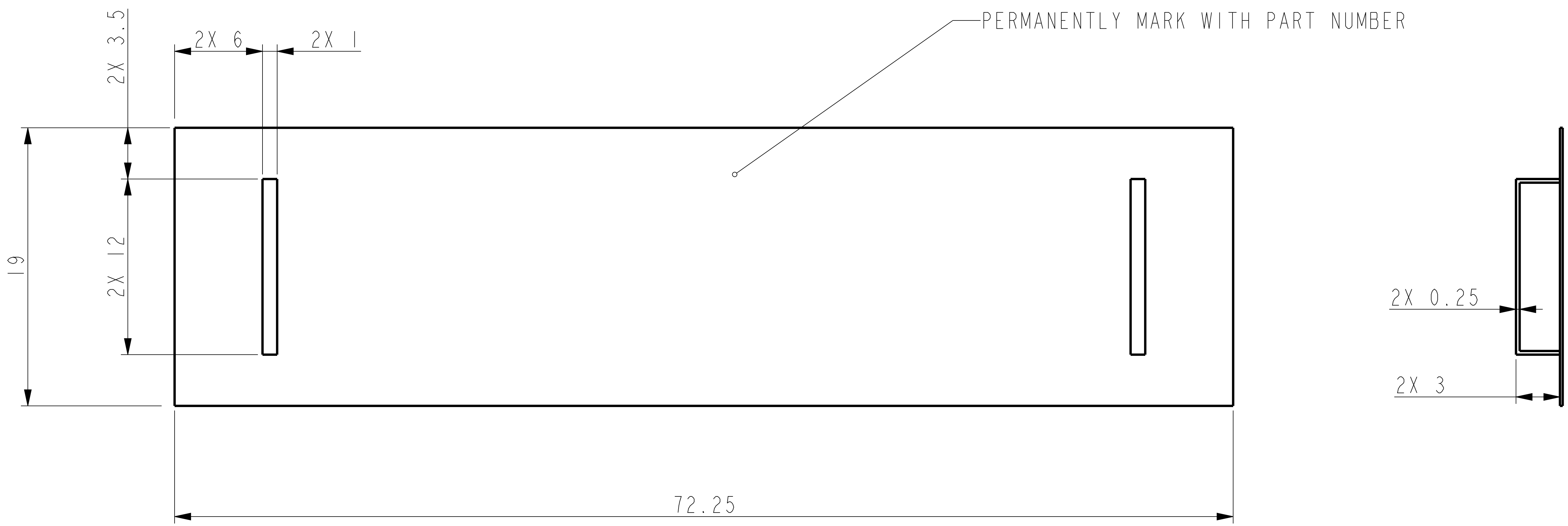
WALL, FRONT RIGHT

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-100-217	A
SCALE 1:8	UNIT WEIGHT = LBS	SHEET 1 OF 1	

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RLEASE	08-05-14



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GENERAL NOTES

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 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	WALL	3/16" STEEL PLATE WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 10-30-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: WALL_BOTTOM_SIDE_LEFT

THIRD ANGLE PROJECTION

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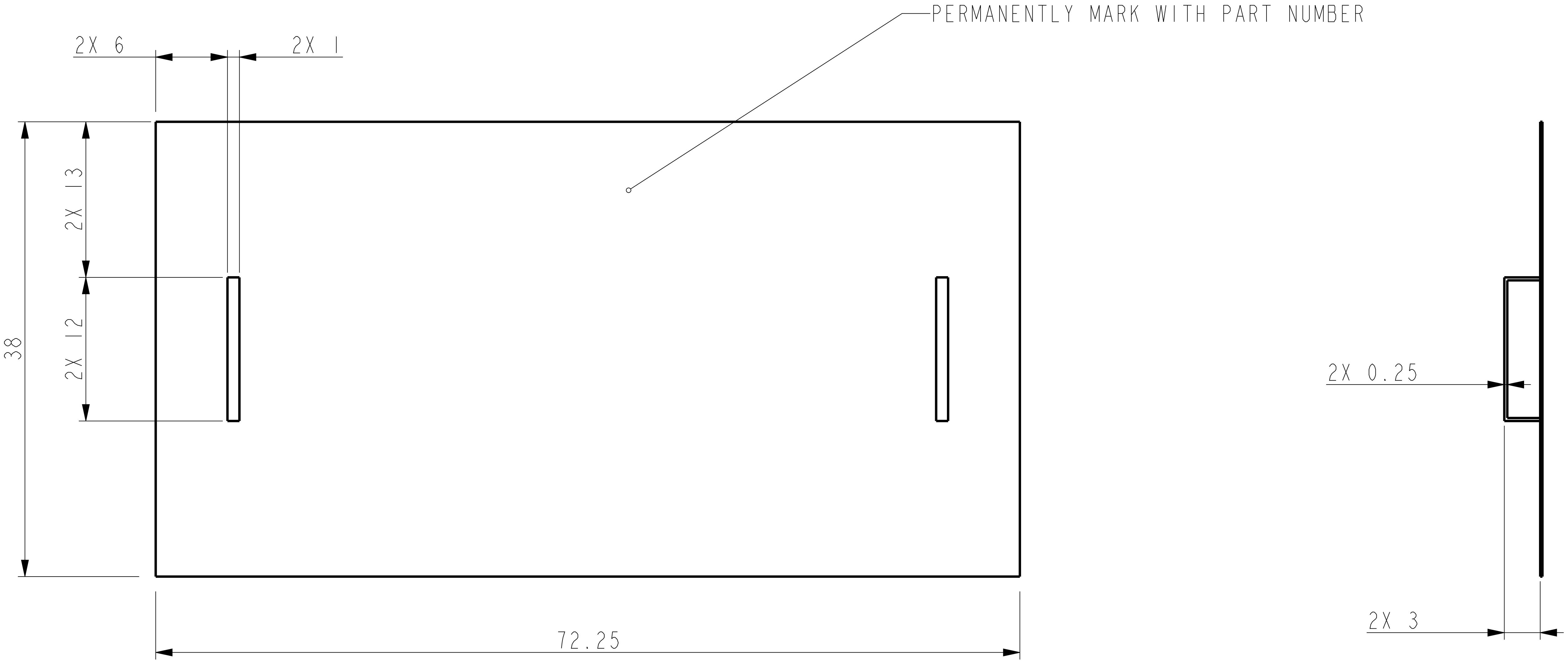
WALL, BOTTOM SIDE, LEFT

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-100-218	A

SCALE 1:8 | UNIT WEIGHT = LBS | SHEET 1 OF 1

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELASE	08-05-14



GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	WALL	3/16" STEEL PLATE WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 10-30-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: WALL_BOTTOM_CENTER
THIRD ANGLE PROJECTION	EXCEPT AS MAY OTHERWISE BE PROVIDED BY CONTRACT THESE DRAWINGS AND SPECIFICATIONS ARE THE PROPERTY OF SOUTHWEST RESEARCH INSTITUTE, ARE ISSUED IN STRICT CONFIDENCE, AND SHALL NOT BE REPRODUCED, OR COPIED, OR USED AS THE BASIS FOR MANUFACTURE OR SALE OF ANY APPARATUS SHOWN THEREON WITHOUT PERMISSION

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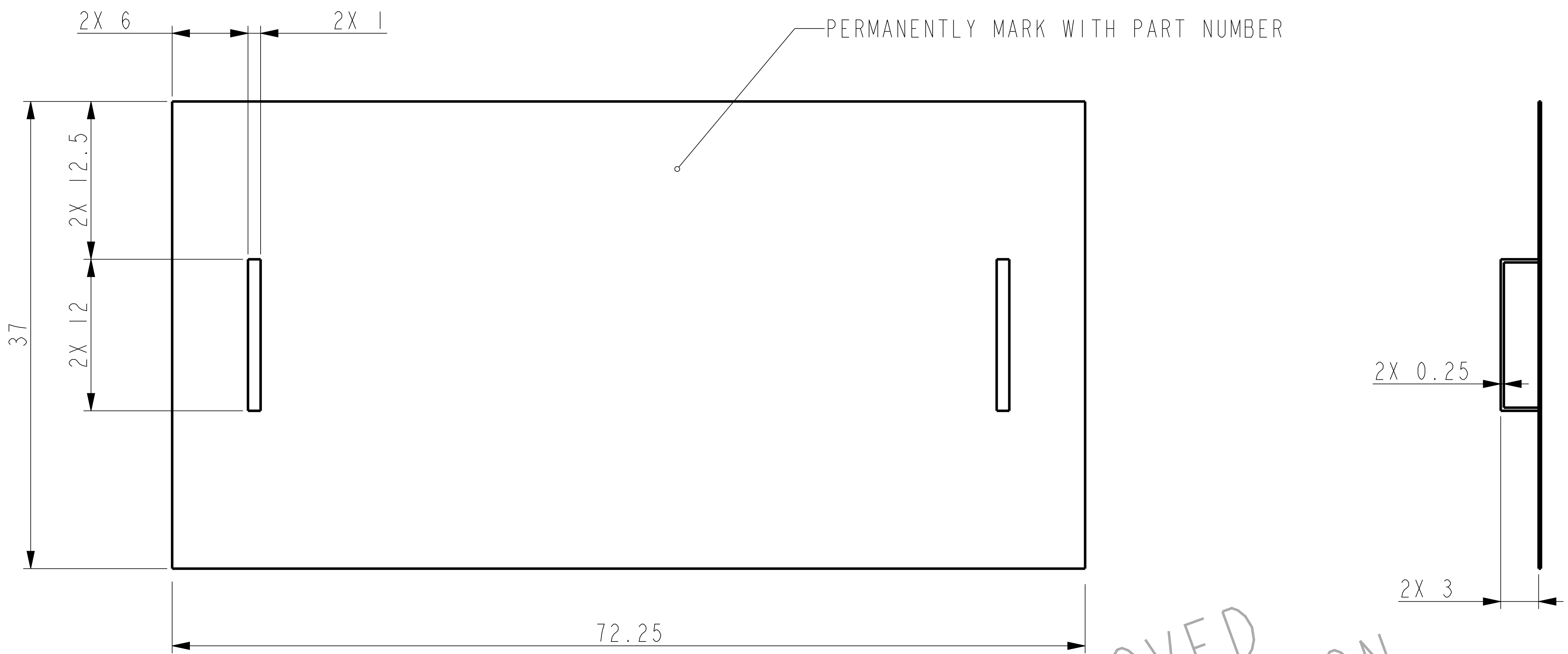
WALL, BOTTOM CENTER

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-100-219	A
SCALE 1:10	UNIT WEIGHT = LBS	SHEET 1 OF 1	

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RLEASE	08-05-14



GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	WALL	3/16" STEEL PLATE WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 12-16-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: WALL_BOTTOM_SIDE_RIGHT

THIRD ANGLE PROJECTION

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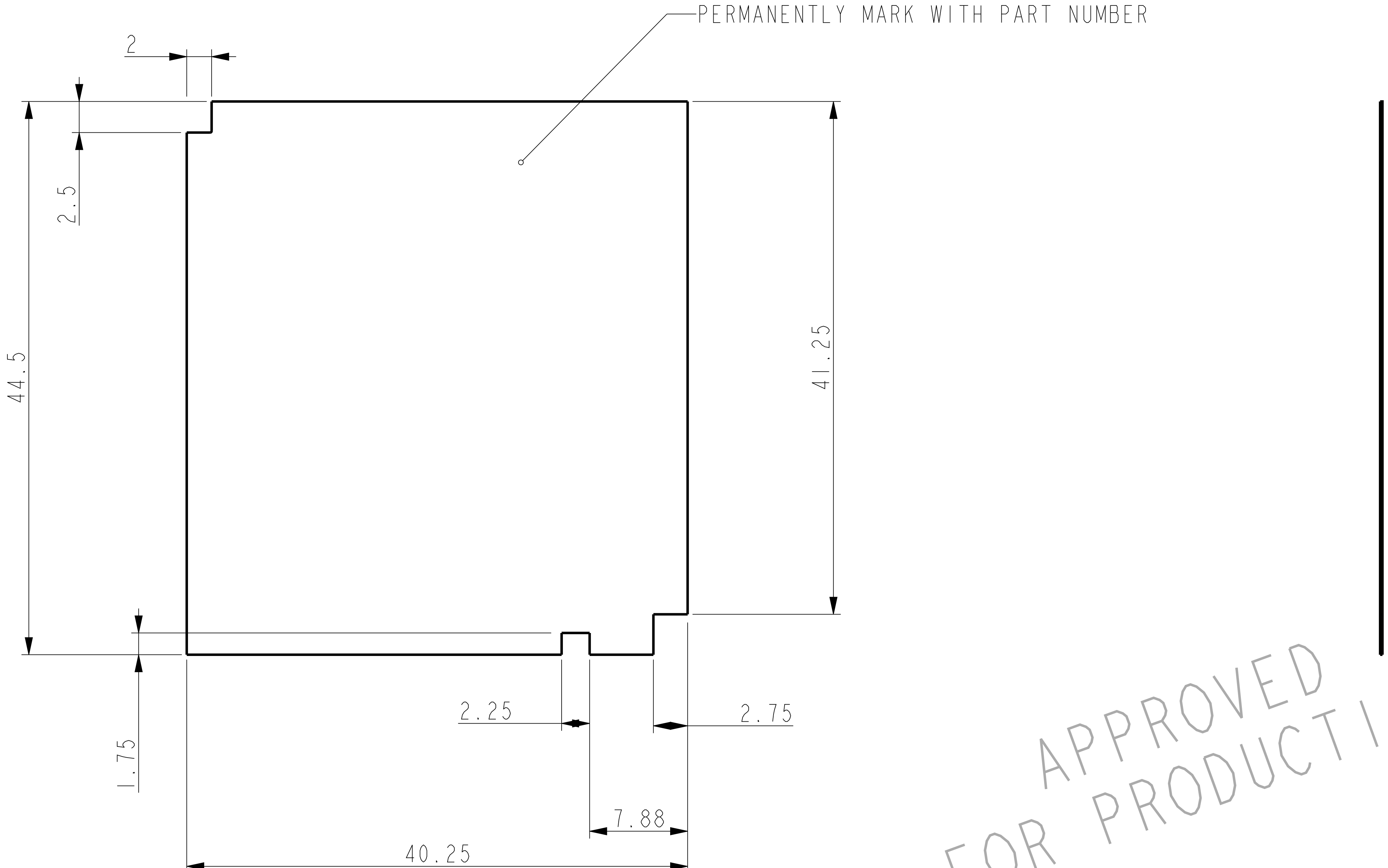
WALL, BOTTOM SIDE RIGHT

SIZE	CODE	DRAWING NUMBER	REV
B	26401	17914-100-220	A
SCALE 1:10	UNIT WEIGHT = LBS	SHEET 1 OF 1	

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RLEASE	08-05-14

REVISIONS



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GENERAL NOTES

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2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	WALL	3/16" STEEL PLATE	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 10-30-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: WALL_DIVIDER

THIRD ANGLE PROJECTION

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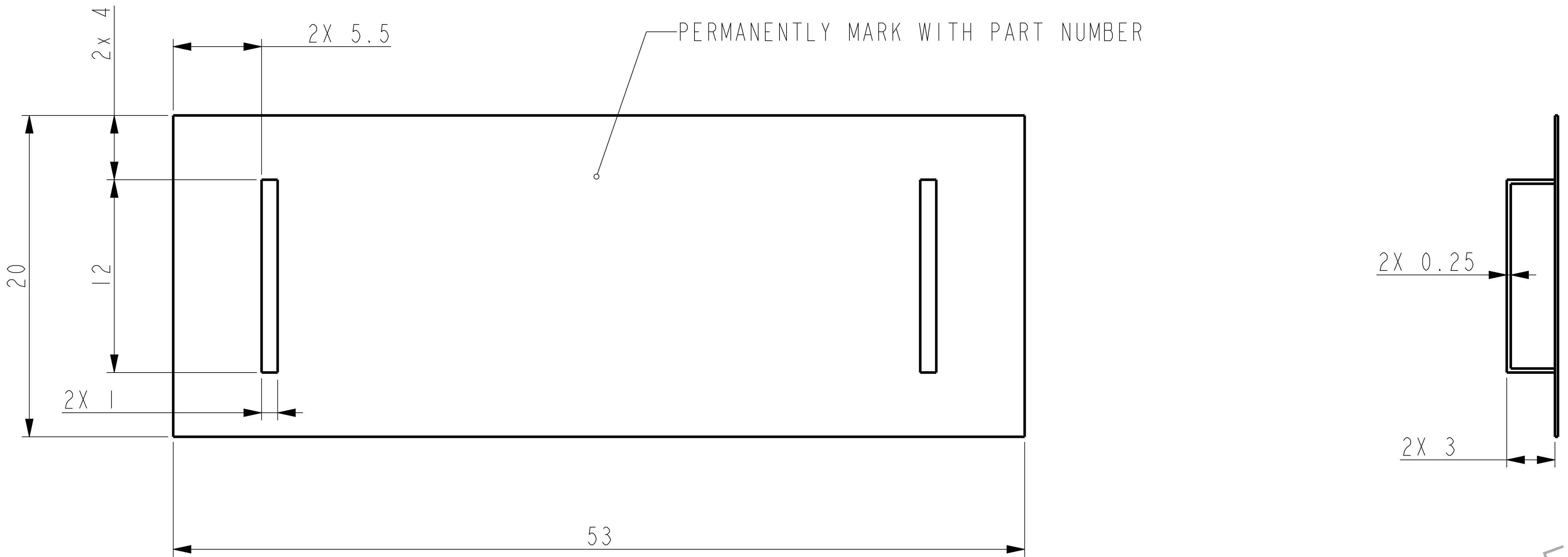
WALL, DIVIDER

SIZE	CAGE	DWG NO.	REV
B	26401	17914-100-221	A

SCALE 1:10 UNIT WEIGHT = LBS SHEET 1 OF 1

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RLEASE	08-05-14



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GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	WALL	3/16" STEEL PLATE	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) : ± 0.1	B SCHULTZ
TWO PLACES (X.XX) : ± 0.01	C WRAY
THREE PLACES (X.XXX) : ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) : ± 0.0005	J HUCZEK
ANGLES : ± 0.5 DEGREE	COMPLETION DATE: 01-17-14
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: WALL_FRONT_TOPHAT

THIRD ANGLE PROJECTION

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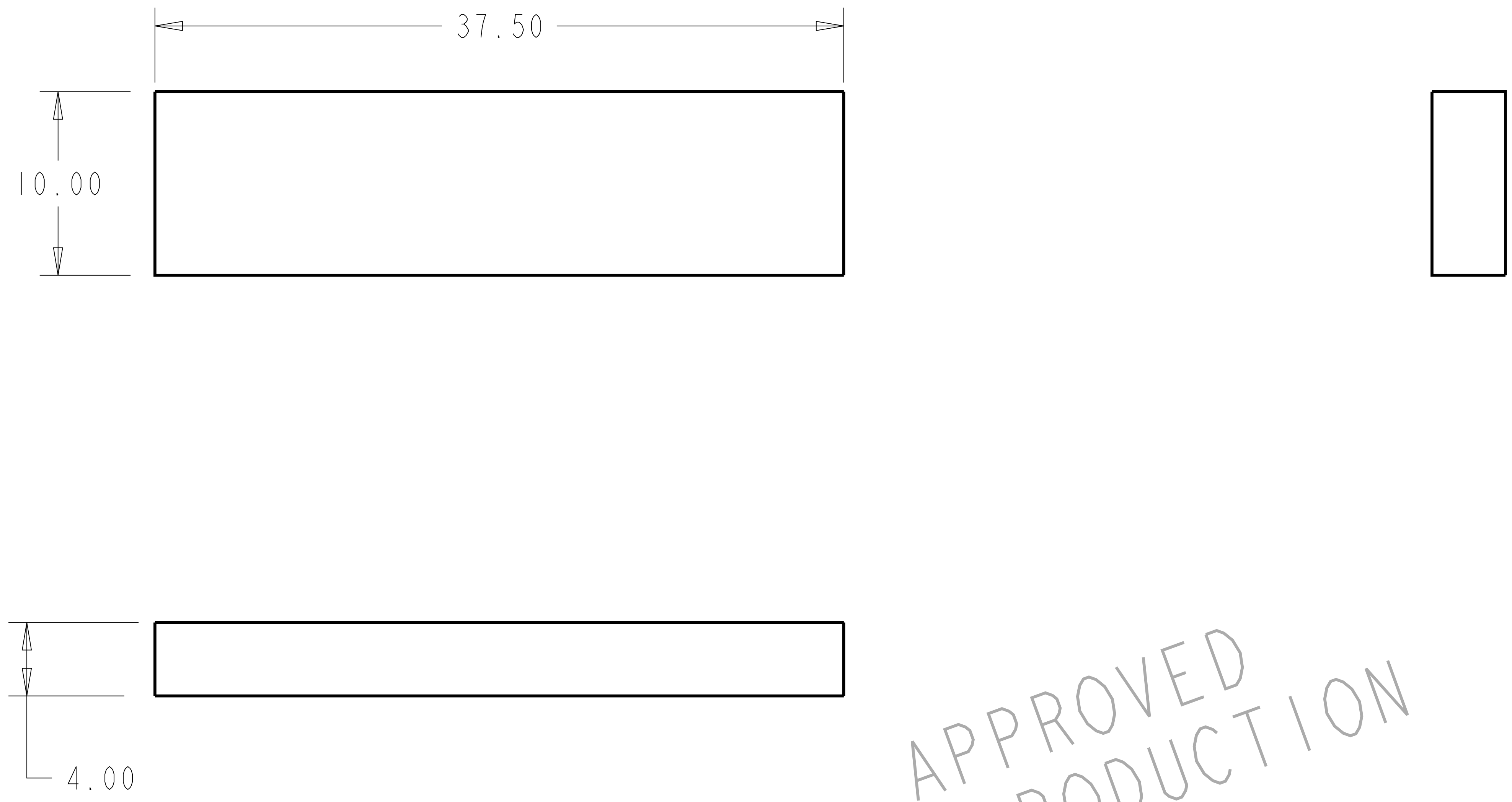
WALL, FRONT TOP HAT

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-100-222	A
SCALE 1:8		UNIT WEIGHT : LBS	SHEET 1 OF 1

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RLEASE	08-05-14



GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	HEATER	3/16" STEEL PLATE BOX WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 08-06-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: SCR-DPF_HEATER

THIRD ANGLE PROJECTION

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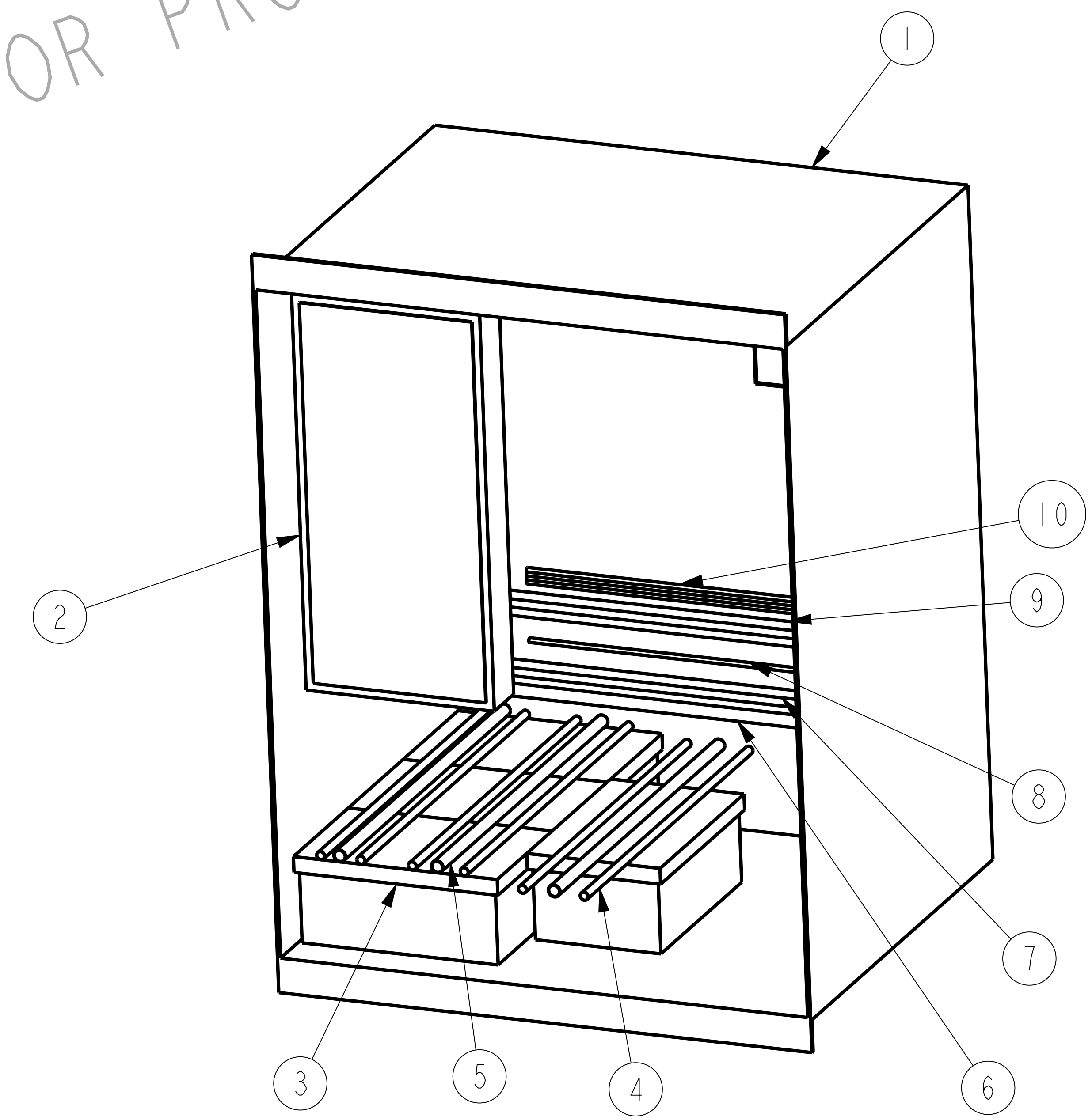
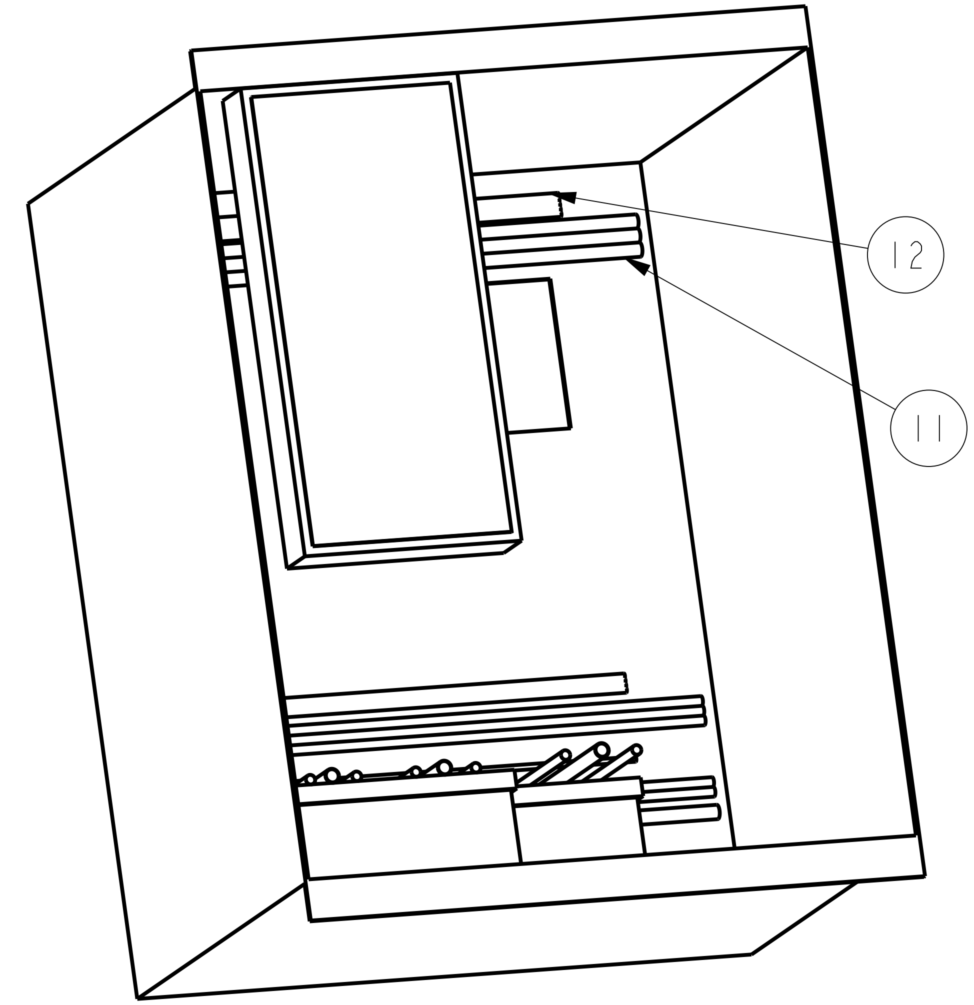
DPF HEATER

B	26401	17914-100-502	A
SCALE 0.125	UNIT WEIGHT : LBS	SHEET 1 OF 1	

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RLEASE	08-05-14

APPROVED
FOR PRODUCTION





QTY	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
5	MULTI CONDUCTOR WIRE	JAMECO #644463	12
3	LARGE CONDUIT	3/4 DIAMETER PVC CONDUIT, McMASTER CARR #8067K122	11
4	MULTI CONDUCTOR WIRE	JAMECO #644463	10
6	BATTERY CABLE	PURCHASED, MCMASTER CARR 6948K941	9
1	MULTI CONDUCTOR WIRE	JAMECO #644463	8
6	BATTERY CABLE	PURCHASED, MCMASTER CARR 6948K941	7
1	LARGE CONDUIT	3/4 DIAMETER PVC CONDUIT, McMASTER CARR #8067K122	6
3	LARGE CONDUIT	3/4 DIAMETER PVC CONDUIT, McMASTER CARR #8067K122	5
4	BATTERY CABLE	PURCHASED, MCMASTER CARR 6948K941	4
4	CONSUMABLE MODULE 1	PLASTIC TOOLBOX,PURCHASED, GRAINGER #1RC60	3
1	FUSE BOX ASSEMBLY	SEE DRAWING 17914-200-200	2
1	ENCLOSURE	SEE DRAWING 17914-200-101	1

BILL OF MATERIAL/PARTS LIST

GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
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 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 10-31-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: STORAGE_SPACE

THIRD ANGLE PROJECTION

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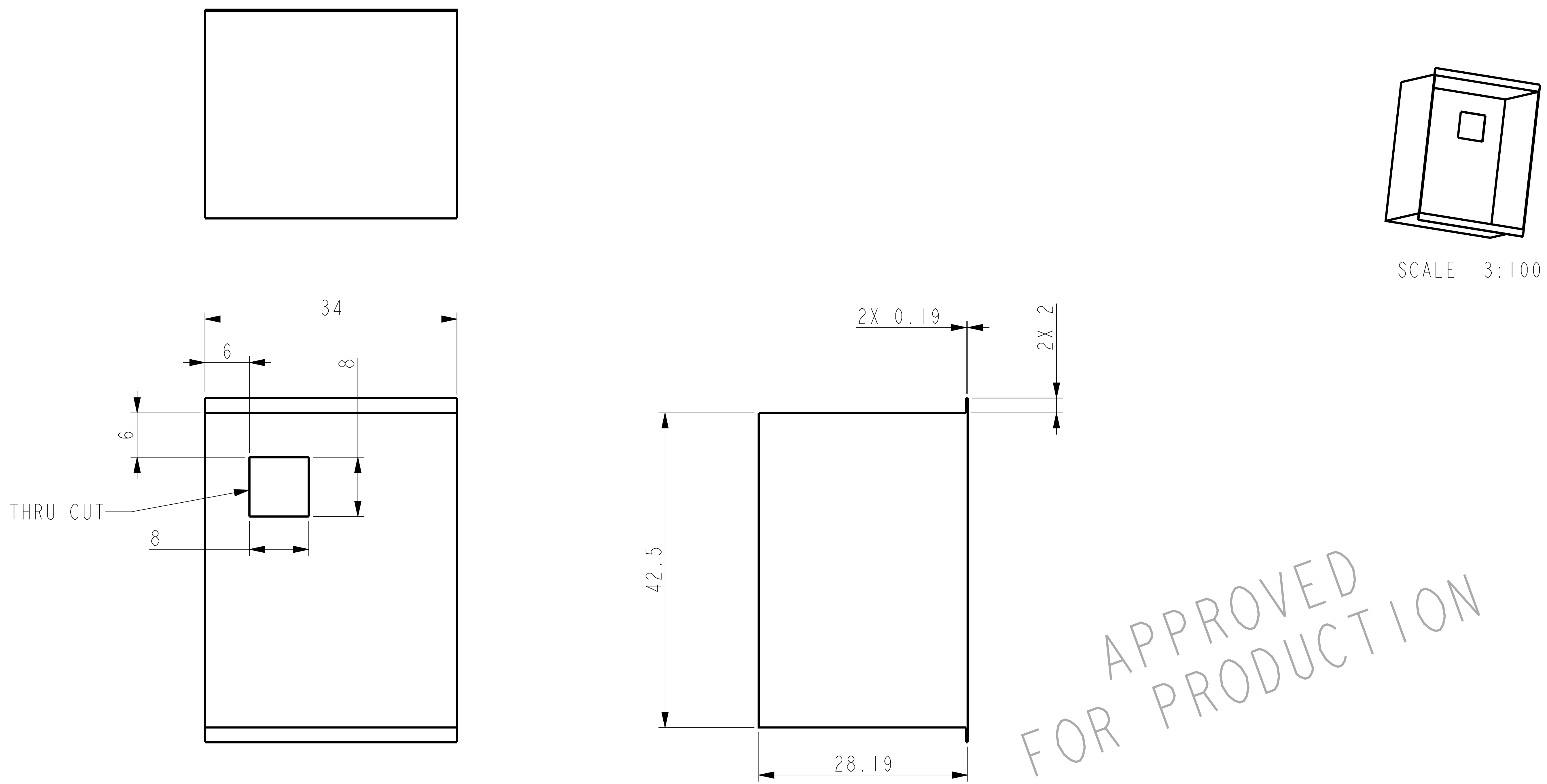
STORAGE SPACE ASSEMBLY

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-200-000	A

SCALE 1:10 UNIT WEIGHT = LBS SHEET 1 OF 1

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RLEASE	08-05-14



-1	BOX	3/16" STEEL PLATE BOX WELDMENT	1
P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM

BILL OF MATERIAL/PARTS LIST

GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 10-31-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: STORAGE_SPACE
THIRD ANGLE PROJECTION	

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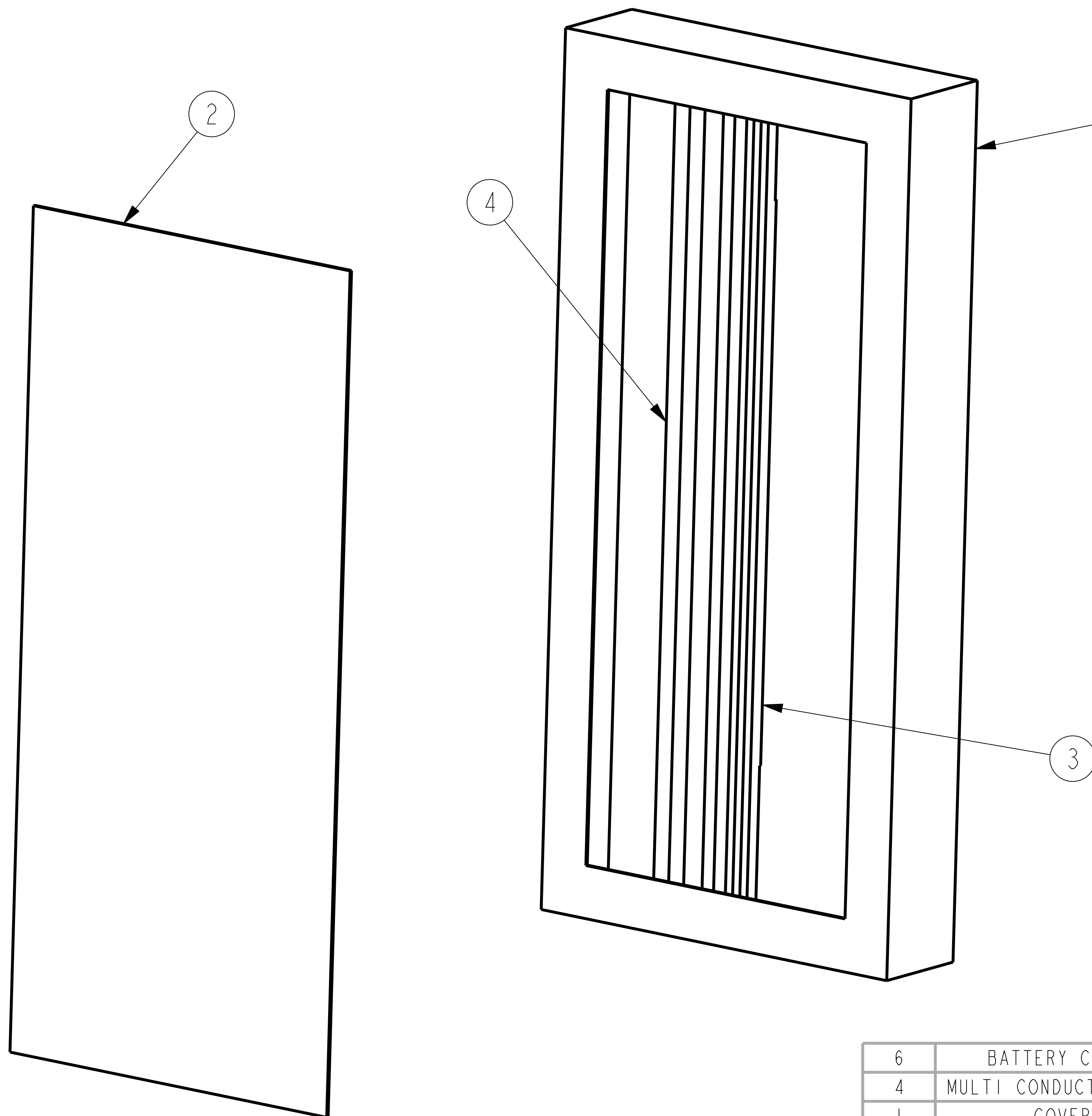
STORAGE SPACE

B	26401	17914-200-101	A
SCALE 67:1000	UNIT WEIGHT = LBS	SHEET 1 OF 1	

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RLEASE	08-05-14



APPROVED FOR PRODUCTION

6	BATTERY CABLE	PURCHASED, MCMASTER CARR 6948K941	4
4	MULTI CONDUCTOR WIRE	PURCHASED JAMECO #644463	3
1	COVER	SEE DRAWING: 17914-200-202	2
1	ENCLOSURE	SEE DRAWING: 17014-200-201	1
QTY	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM

BILL OF MATERIAL/PARTS LIST

GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 01-03-14
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: FUSE_BOX_MODULE

THIRD ANGLE PROJECTION

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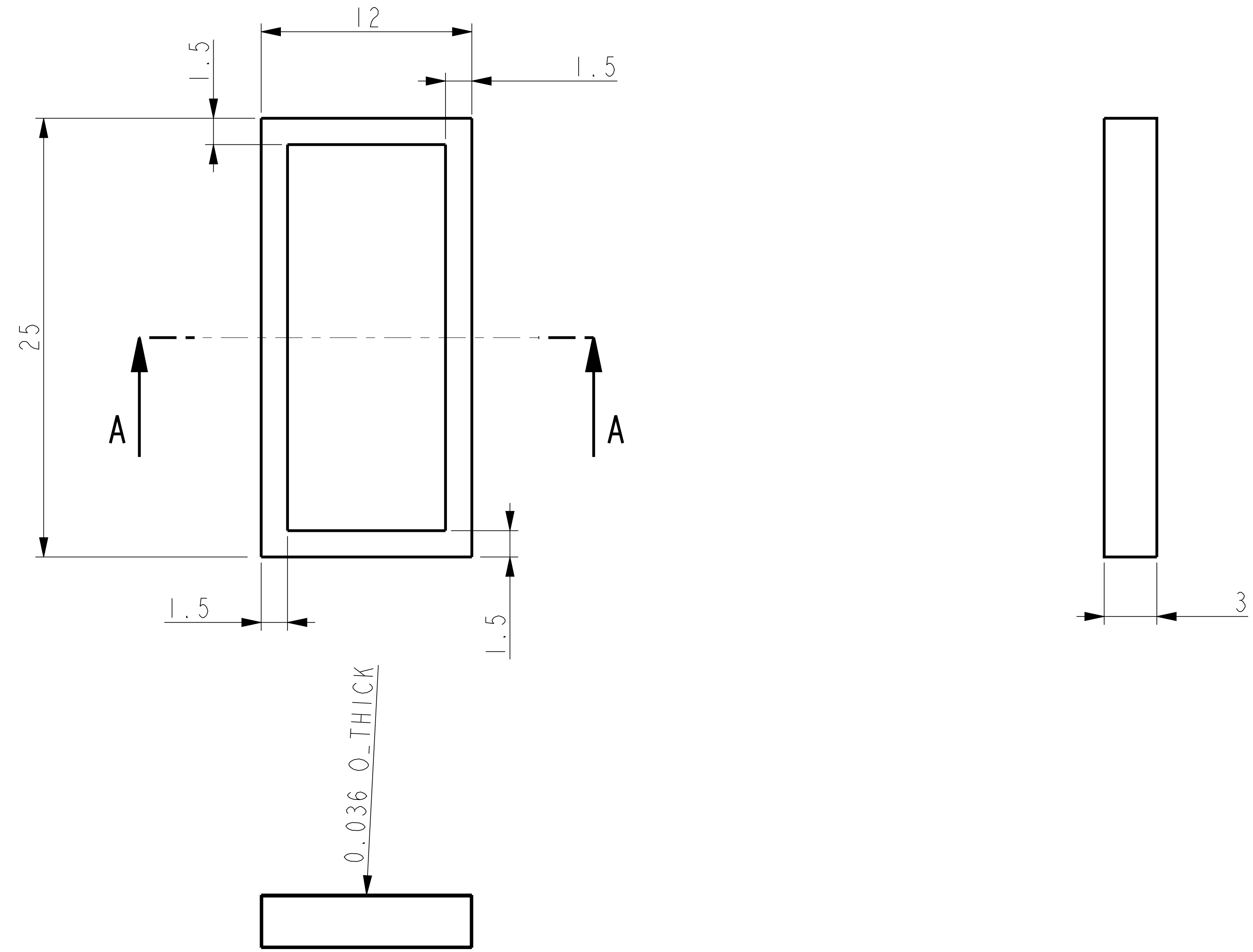
FUSE BOX ASSEMBLY

SIZE	CAGE	DRAWING NO.	REV
B	26401	17914-200-200	A

SCALE 1:4 UNIT WEIGHT = LBS SHEET 1 OF 1

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14



SECTION A-A

GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	ENCLOSURE	20 GA SHEET METAL	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 01-03-14
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: FUSE_BOX_MODULE

THIRD ANGLE PROJECTION

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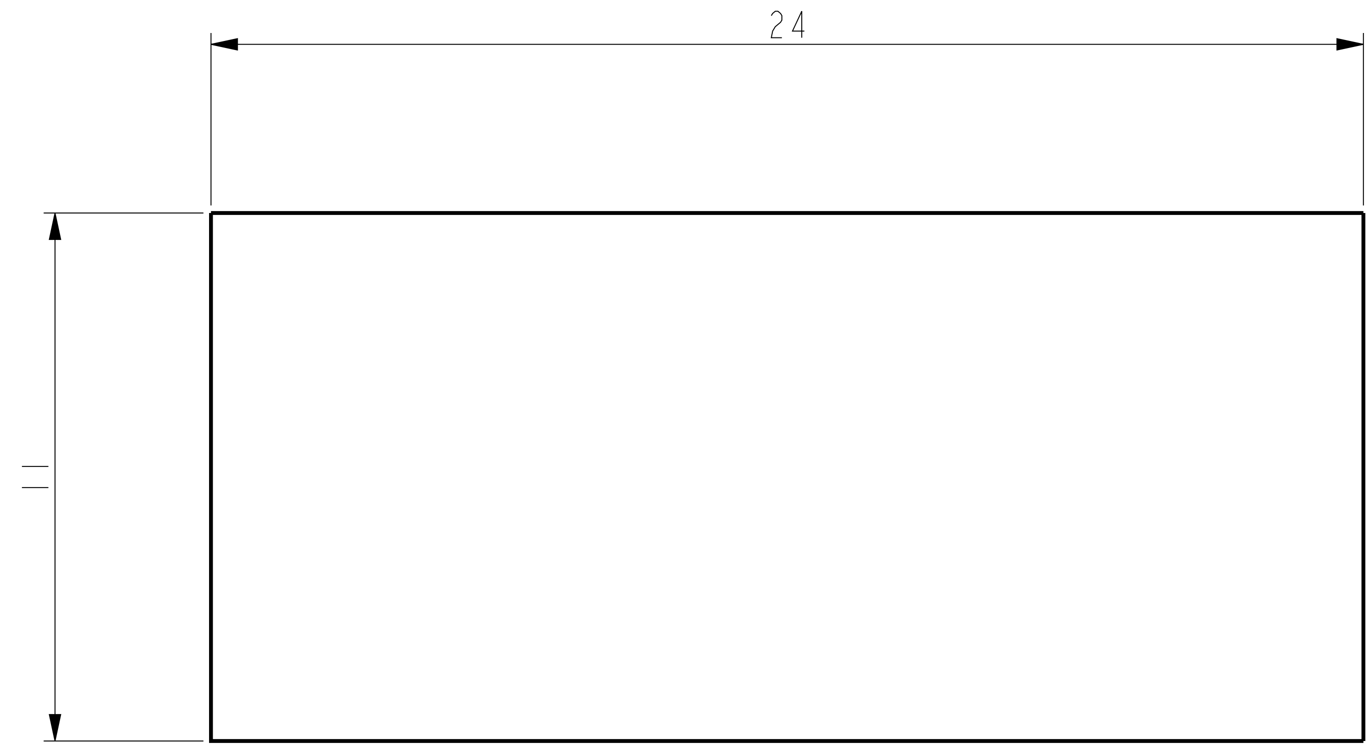
FUSE BOX ENCLOSURE

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-200-201	A

SCALE 1:8 | UNIT WEIGHT = LBS | SHEET 1 OF 1

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14



APPROVED
FOR PRODUCTION

GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

-1	COVER	20 GA SHEET METAL	1
P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 01-03-14
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: FUSE_BOX_DOOR
THIRD ANGLE PROJECTION	

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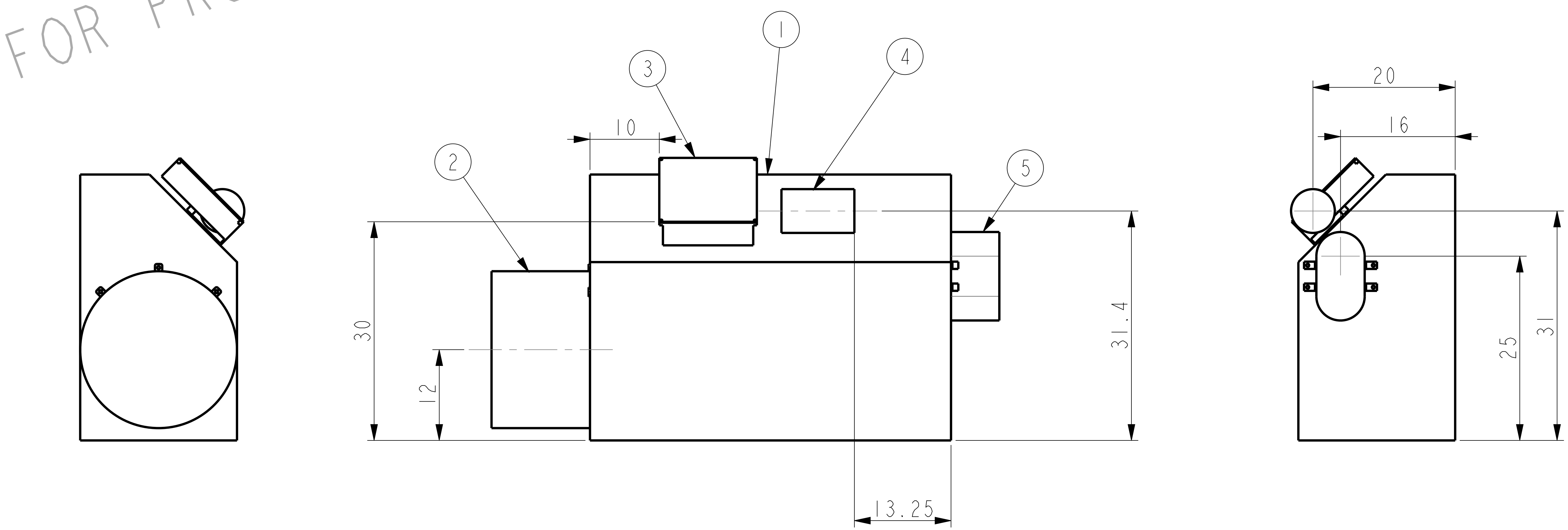
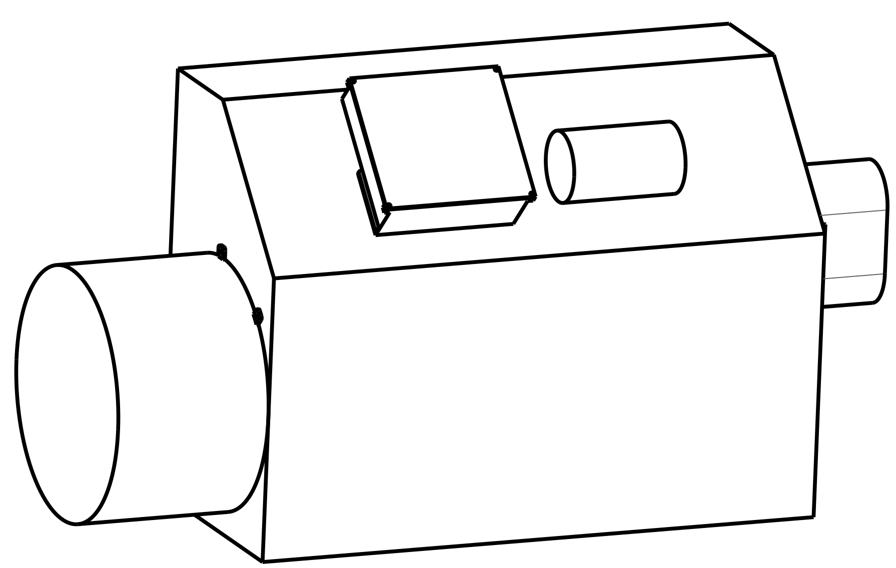
FUSE BOX COVER

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-200-202	A

SCALE 1:4 | UNIT WEIGHT = LBS | SHEET 1 OF 1

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14





1	ALTERNATOR		5
1	TURBO HEATER		4
1	MAINFOLD HEATER ASSY		3
1	TRANSMISSION		2
1	ENGINE BLOCK		1
QTY	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 09-12-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: ENGINE

THIRD ANGLE PROJECTION

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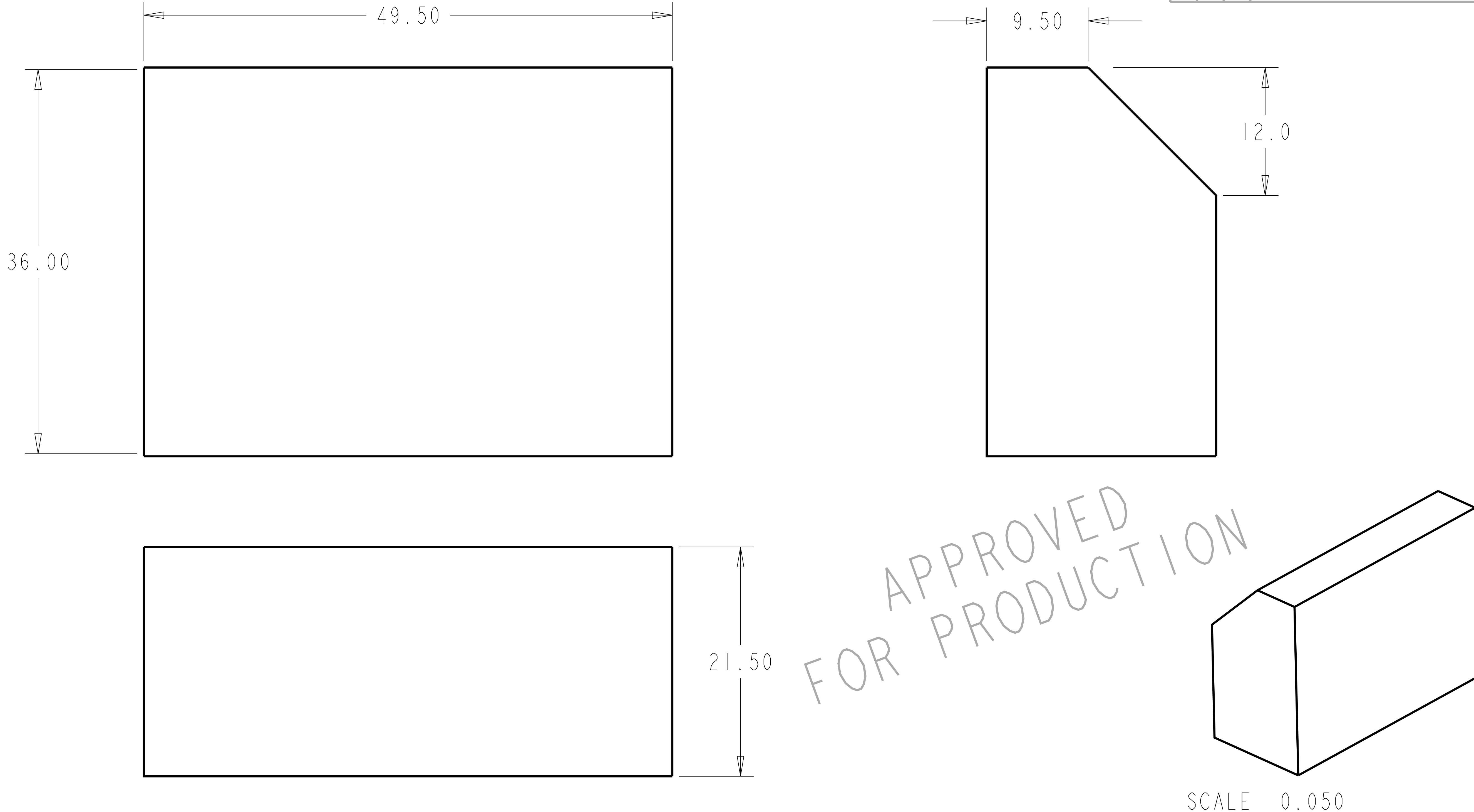
ENGINE ASSEMBLY

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-300-000	A
SCALE 1:8	UNIT WEIGHT = LBS	SHEET 1 OF 1	

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14



GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	METAL BOX	3/16" STEEL BOX WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HURCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 08-02-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: ENGINE_BLOCK

THIRD ANGLE PROJECTION

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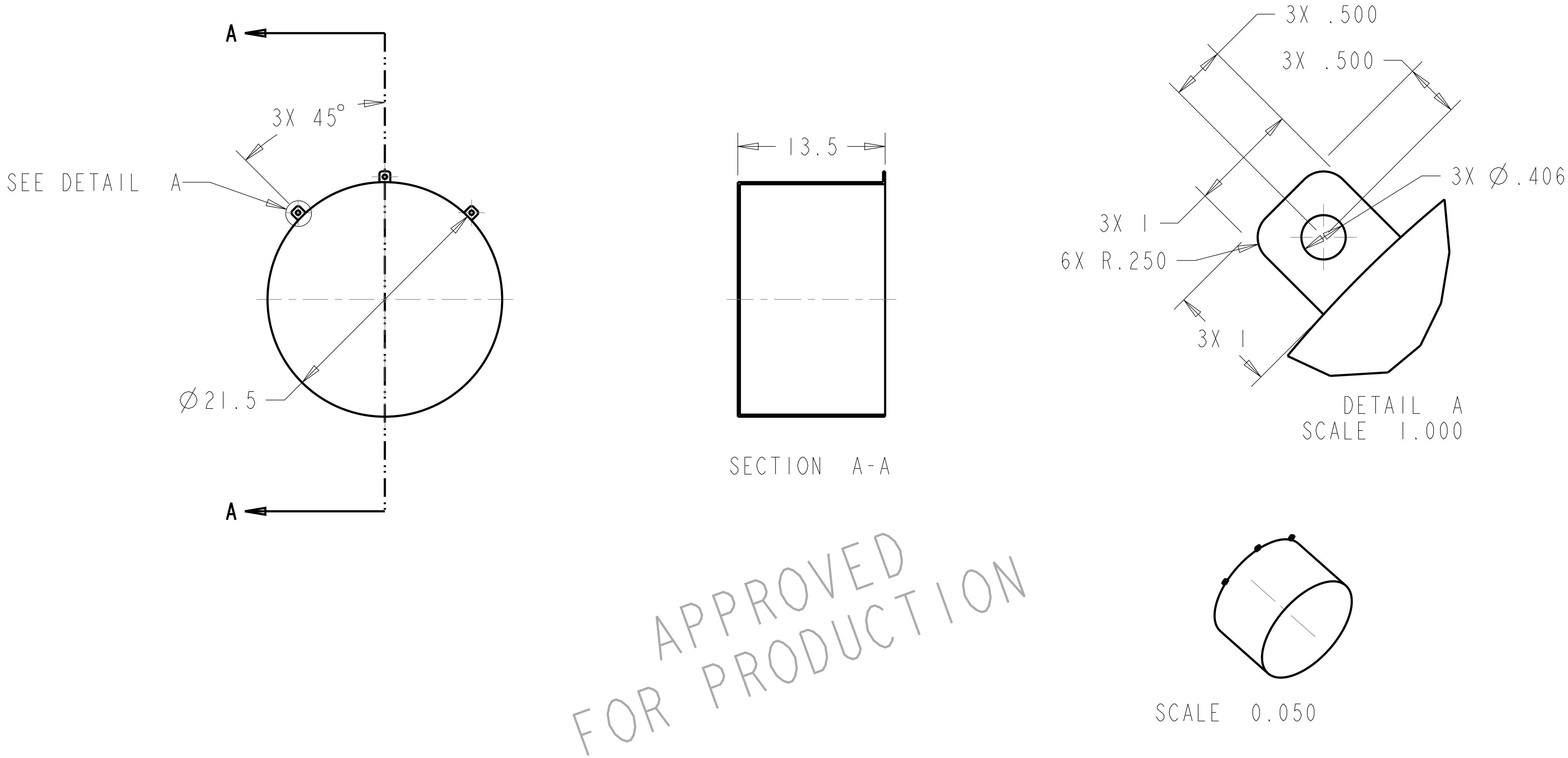
ENGINE BLOCK SIMULATOR

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-300-301	A

SCALE 0.100 UNIT WEIGHT = LBS SHEET 1 OF 1

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14



GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	STEEL WELDMENT	3/16" STEEL WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 08-02-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: TRANSMISSION

THIRD ANGLE PROJECTION

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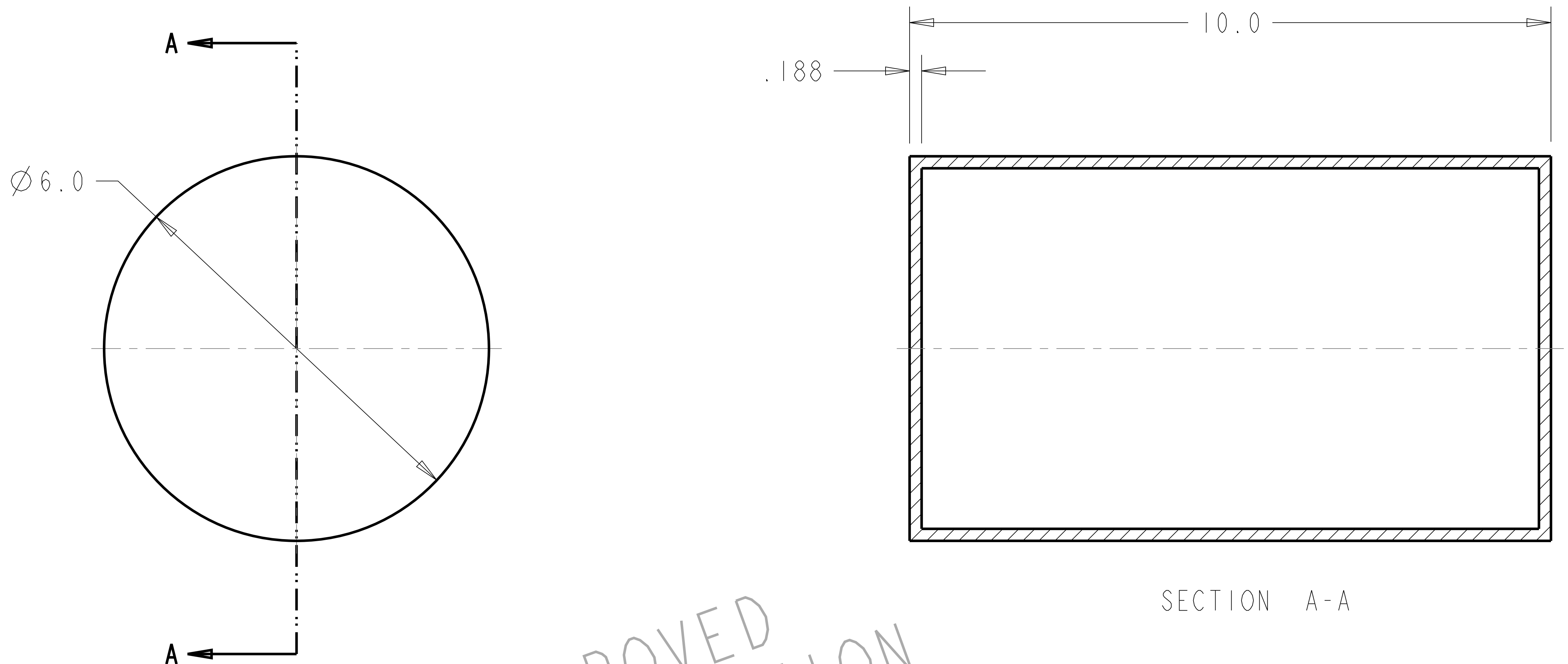
TRANSMISSION SIMULATION

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-300-302	A

SCALE 0.100 UNIT WEIGHT : LBS SHEET 1 OF 1

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14



APPROVED FOR PRODUCTION

GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	CYLINDER	3/16" STEEL PIPE W/ CAPPED ENDS	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 08-05-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: TURBO_HEATER
THIRD ANGLE PROJECTION	EXCEPT AS MAY OTHERWISE BE PROVIDED BY CONTRACT THESE DRAWINGS AND SPECIFICATIONS ARE THE PROPERTY OF SOUTHWEST RESEARCH INSTITUTE, ARE ISSUED IN STRICT CONFIDENCE, AND SHALL NOT BE REPRODUCED, OR COPIED, OR USED AS THE BASIS FOR MANUFACTURE OR SALE OF ANY APPARATUS SHOWN THEREON WITHOUT PERMISSION

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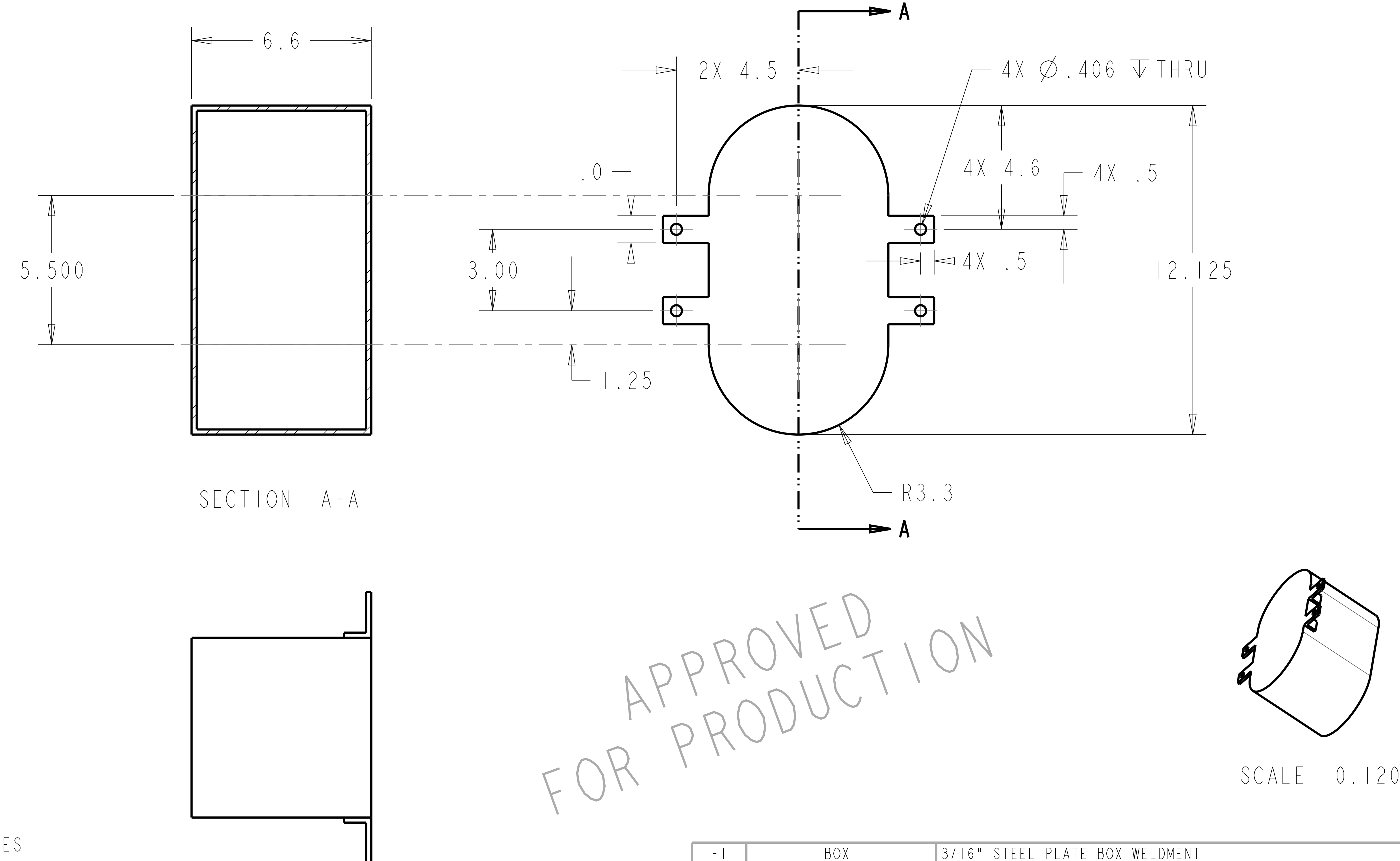
TURBO HEATER

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-300-303	A

SCALE 0.500 UNIT WEIGHT = LBS SHEET 1 OF 1

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14



GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

-1	BOX	3/16" STEEL PLATE BOX WELDMENT	1
P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 08-06-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: ALTERNATOR_HEATER

THIRD ANGLE PROJECTION

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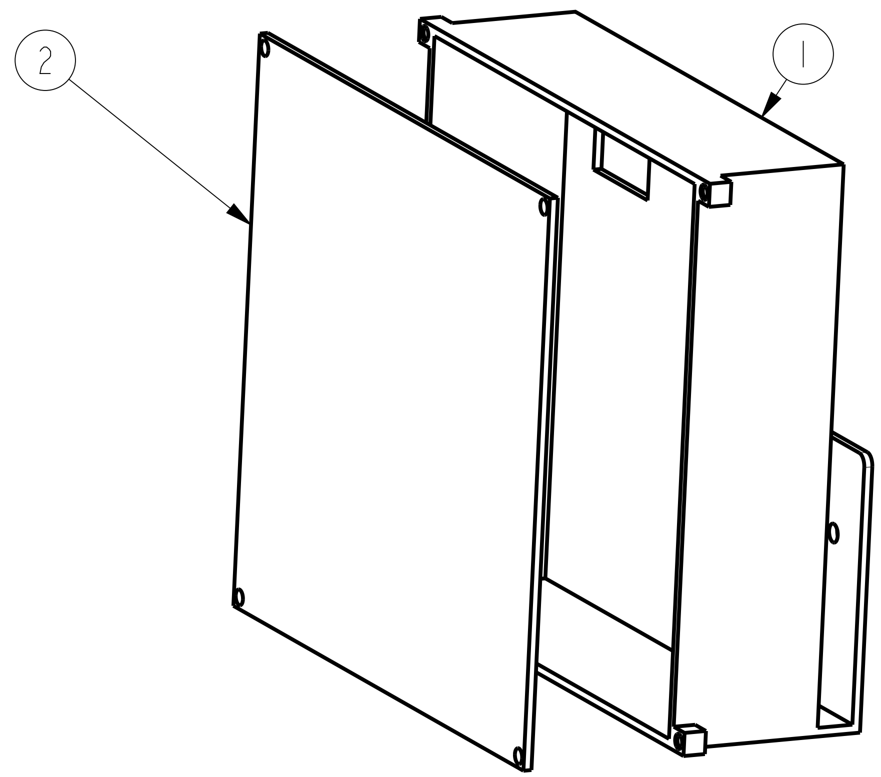
ALTERNATOR SIMULATOR

B	26401	17914-300-304	A

SCALE 0.250 | UNIT WEIGHT = LBS | SHEET 1 OF 1

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14



APPROVED FOR PRODUCTION

GENERAL NOTES

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2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

QTY	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
1	HEATER BOX COVER	SEE DRAWING 17914-310-002	2
1	MANIFOLD HEATER BOX	SEE DRAWING 17914-310-001	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 10-30-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: MANIFOLD_HEATER

THIRD ANGLE PROJECTION

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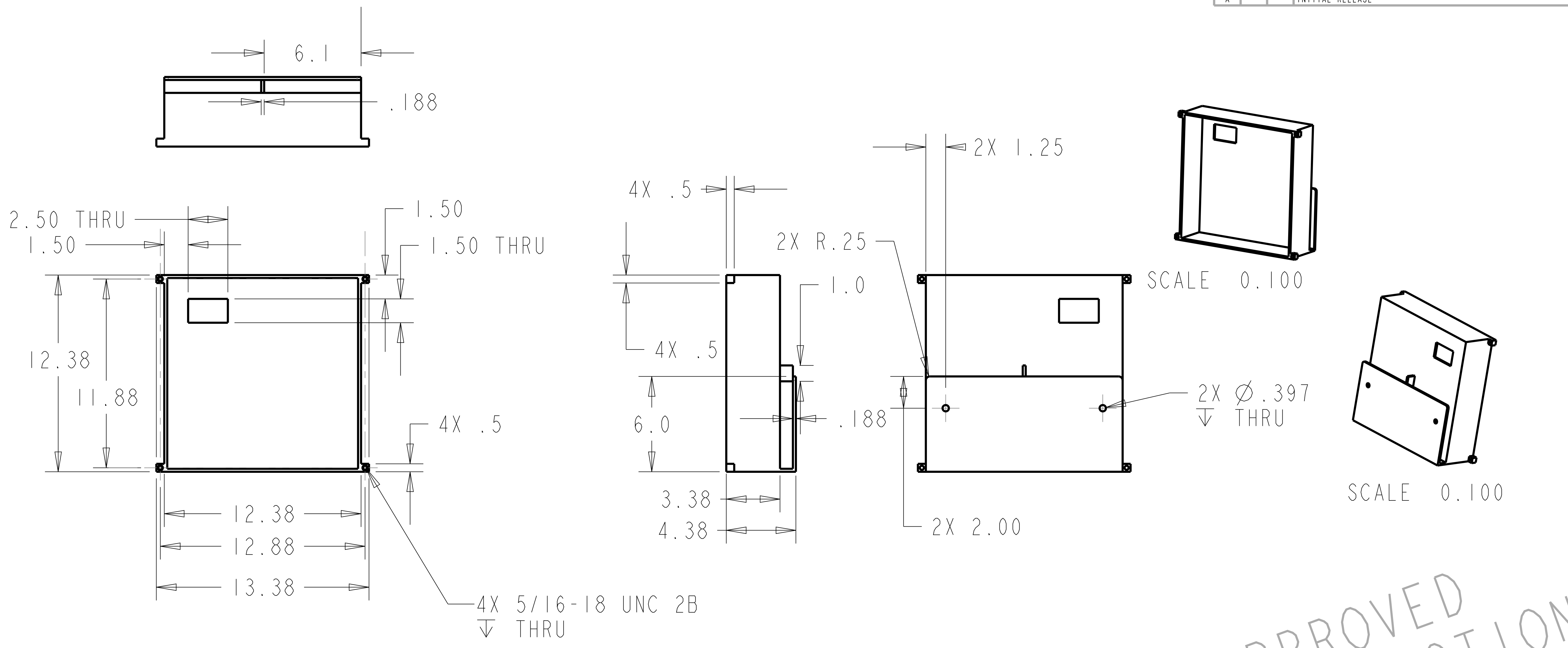
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238

MANIFOLD HEATER ASSEMBLY

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-310-000	A
SCALE 1:4	UNIT WEIGHT = LBS	SHEET 1 OF 1	

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14



GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

-1	STEEL BOX	3/16" STEEL PLATE WELDMENT	1
P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 08-05-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: MANIFOLD_HEATER_BOX
THIRD ANGLE PROJECTION	

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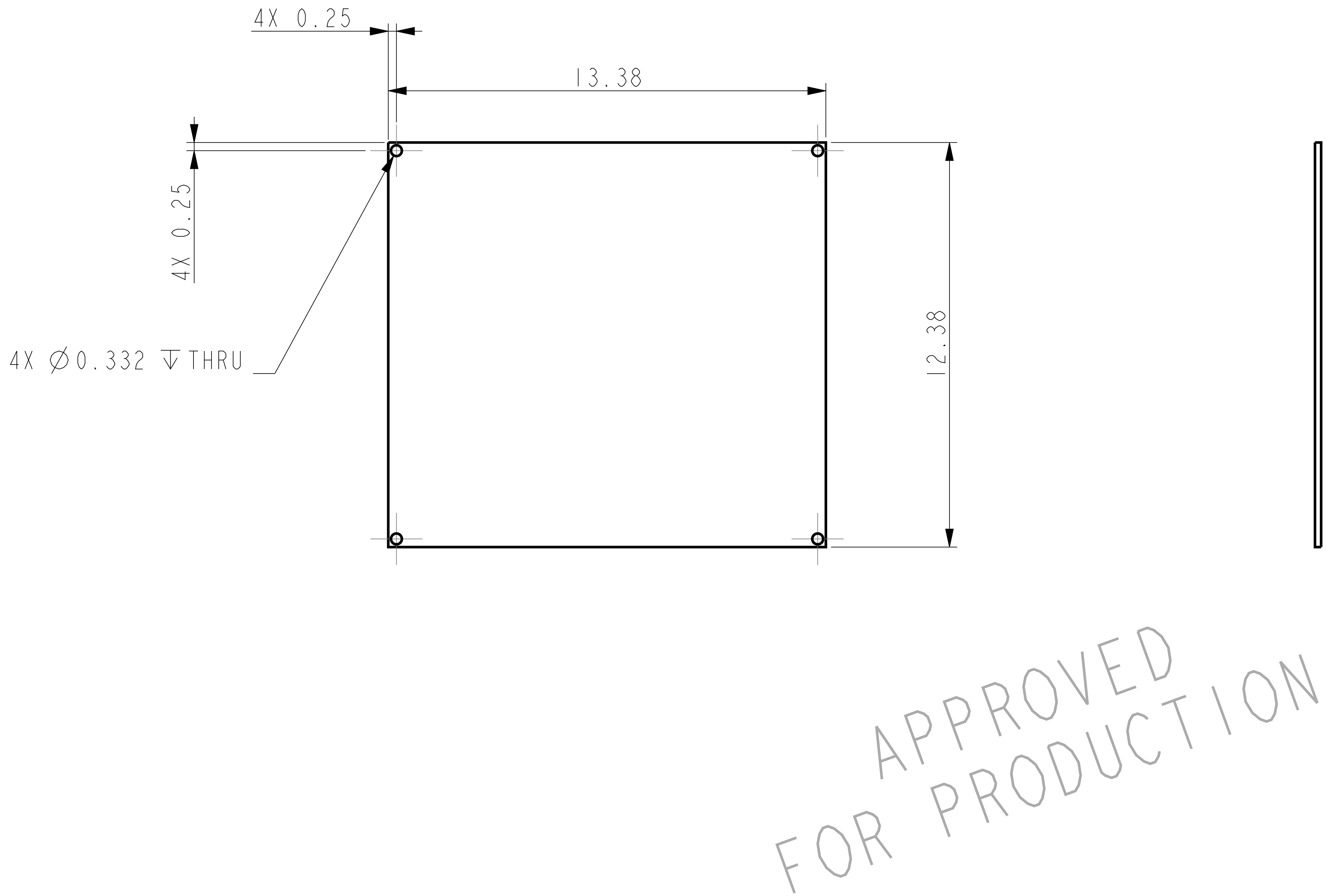
MANIFOLD HEATER BOX

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-310-001	A
SCALE 0.150	UNIT WEIGHT = LBS	SHEET 1 OF 1	



REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14

GENERAL NOTES

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2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	COVER	3/16" STEEL PLATE	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 12-18-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: MANIFOLD_BOX_COVER

THIRD ANGLE PROJECTION

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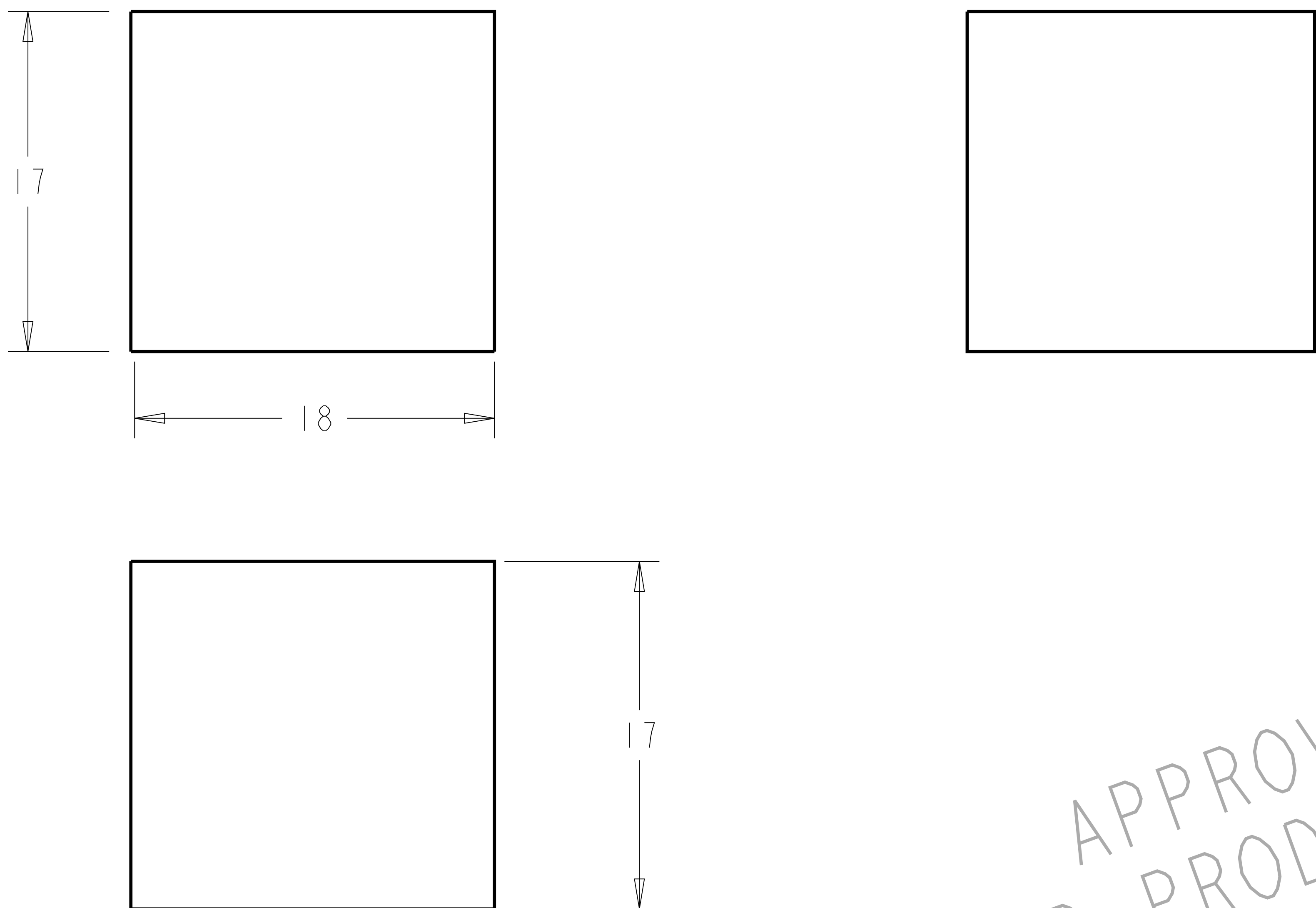
MANIFOLD HEATER BOX COVER

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-310-002	A

SCALE 1:4 | UNIT WEIGHT = LBS | SHEET 1 OF 1

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14



GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	BOX	3/16" WALL STEEL BOX	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 08-02-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: CYLINDER_1

THIRD ANGLE PROJECTION

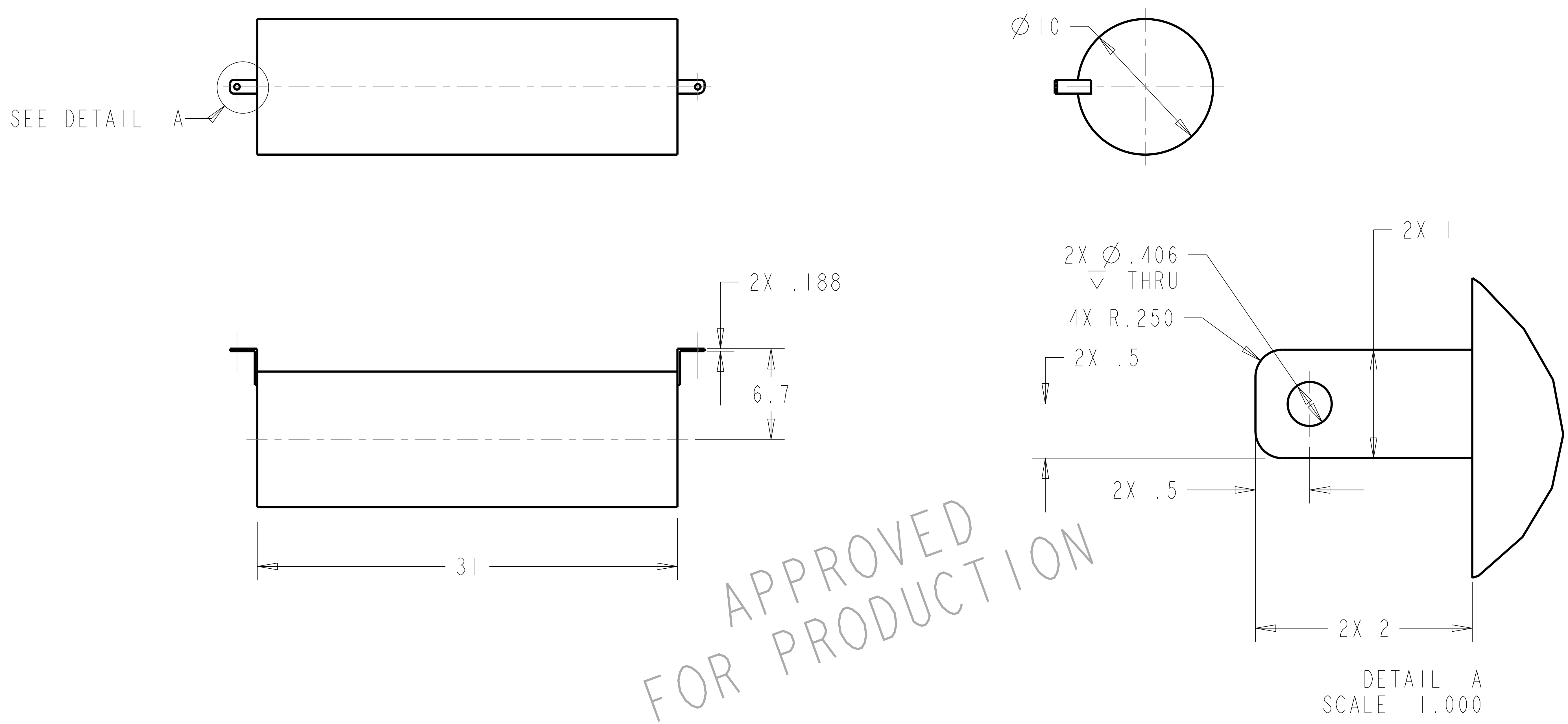
SOUTHWEST RESEARCH INSTITUTE
OFFICE of AUTOMOTIVE ENGINEERING
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238

AC COMPRESSOR

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-400-100	A

SCALE 0.500 | UNIT WEIGHT = LBS | SHEET 1 OF 1

REV	SHT	ZONE	DESCRIPTION	DATE
			REVISIONS	
A			INITIAL RELEASE	08-05-14



GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	CYLINDER	3/16" WALL PIPE W/ CAPPED ENDS WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 08-05-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: RADIATOR_SURGE_TANK
THIRD ANGLE PROJECTION	

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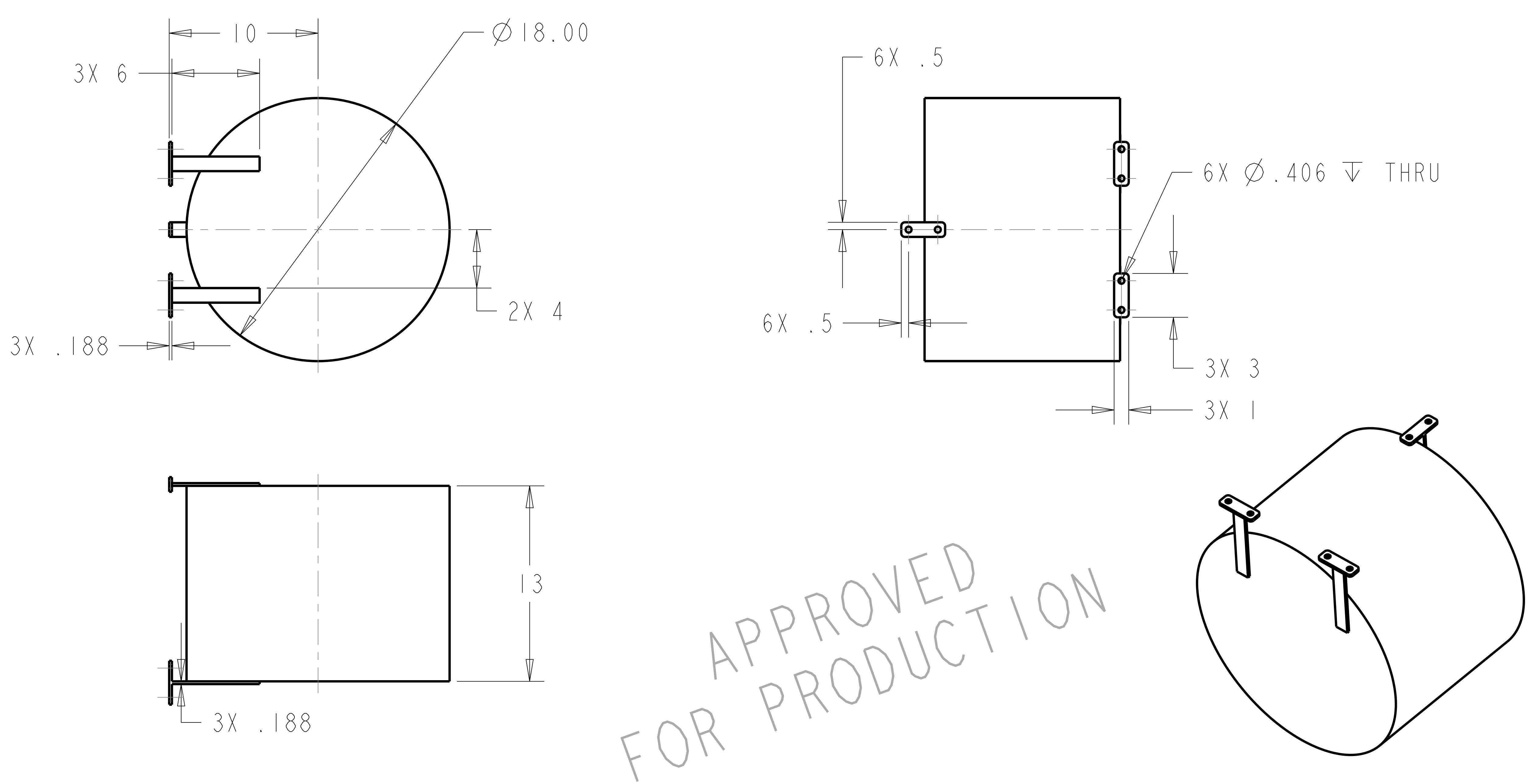
RADIATOR SURGE TANK

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-500-100	A
SCALE 0.125		UNIT WEIGHT = LBS	SHEET 1 OF 1

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14



GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	CYLINDER	3/16" CYLINDER W/ CAPPED ENDS WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 08-05-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: AIR_FILTER_HOUSING

THIRD ANGLE PROJECTION

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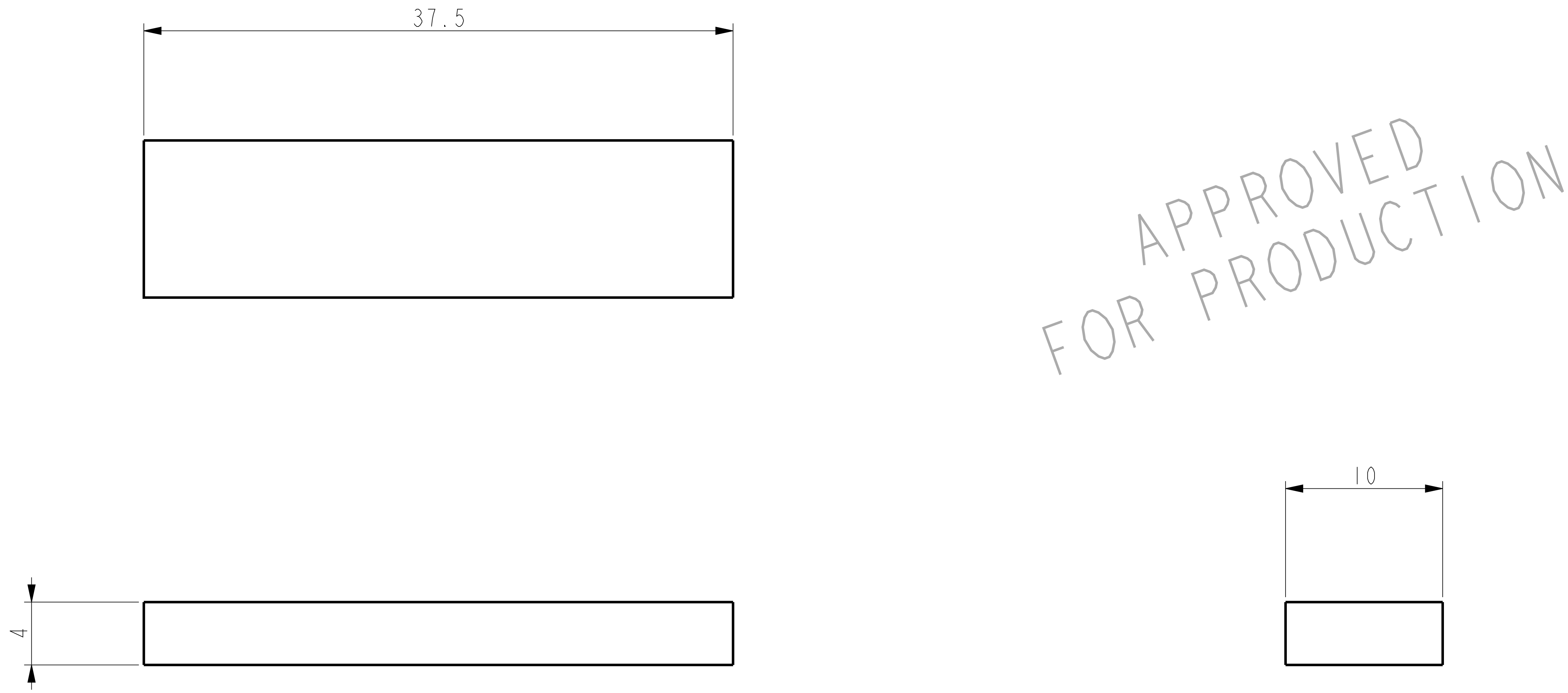
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238

AIR FILTER HOUSING

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-600-100	A
SCALE 0.125	UNIT WEIGHT = LBS	SHEET 1 OF 1	

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14



GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	BOX	3/16" STEEL PLATE BOX WELMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 10-31-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: SCR-DPF_HEATER

THIRD ANGLE PROJECTION

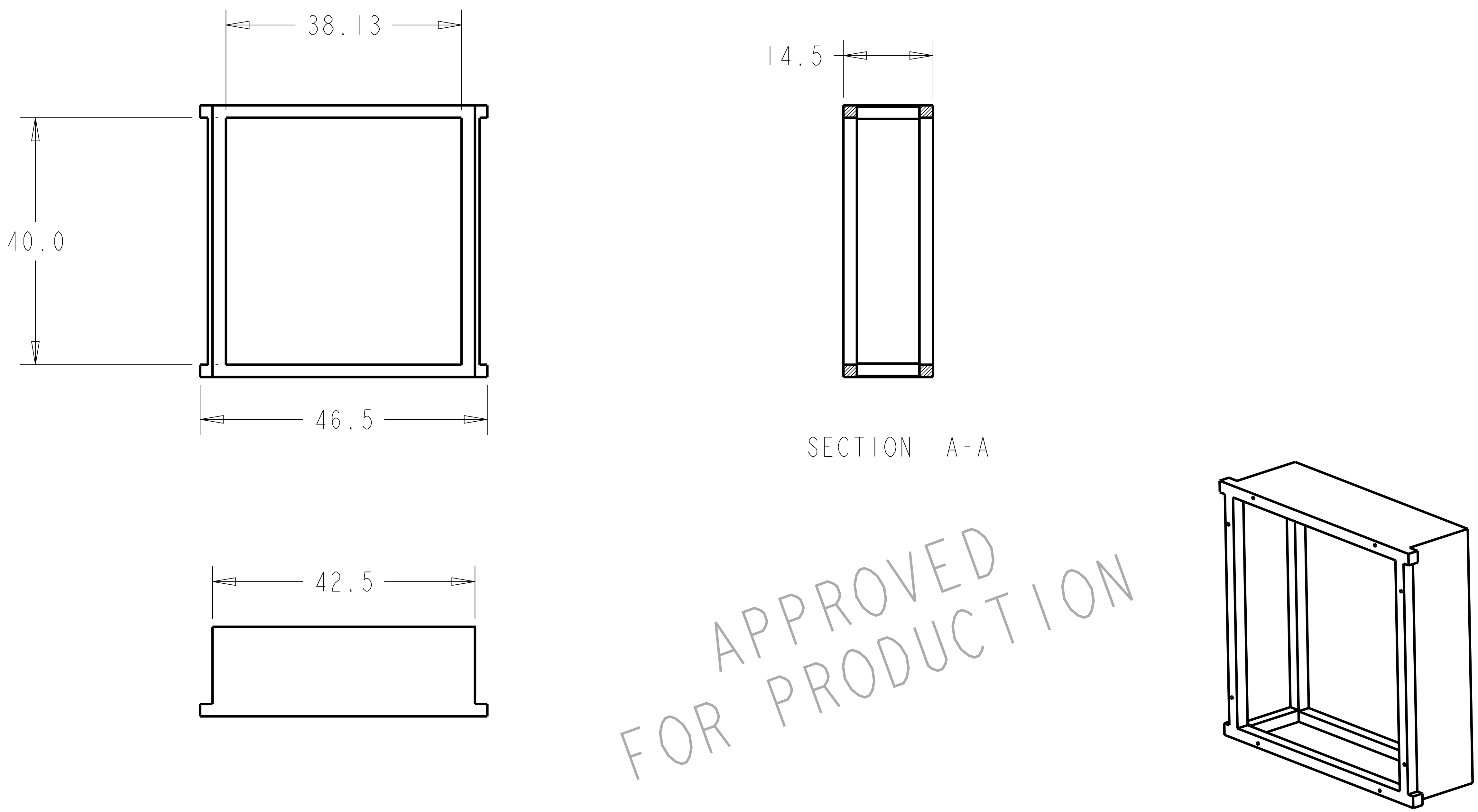
SOUTHWEST RESEARCH INSTITUTE
OFFICE of AUTOMOTIVE ENGINEERING
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238

SCR- DPF SIMULATOR

SIZE	CAGE	DWG NO	REV
B	26401	17914-700-100	A

SCALE 1:8 | UNIT WEIGHT : LBS | SHEET 1 OF 1

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14



GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	BOX WELDMENT	2" X 3/16" WALL SQ TUBING FRAME WITH 3/16" STEEL PLATE	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 08-06-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: radiator

THIRD ANGLE PROJECTION

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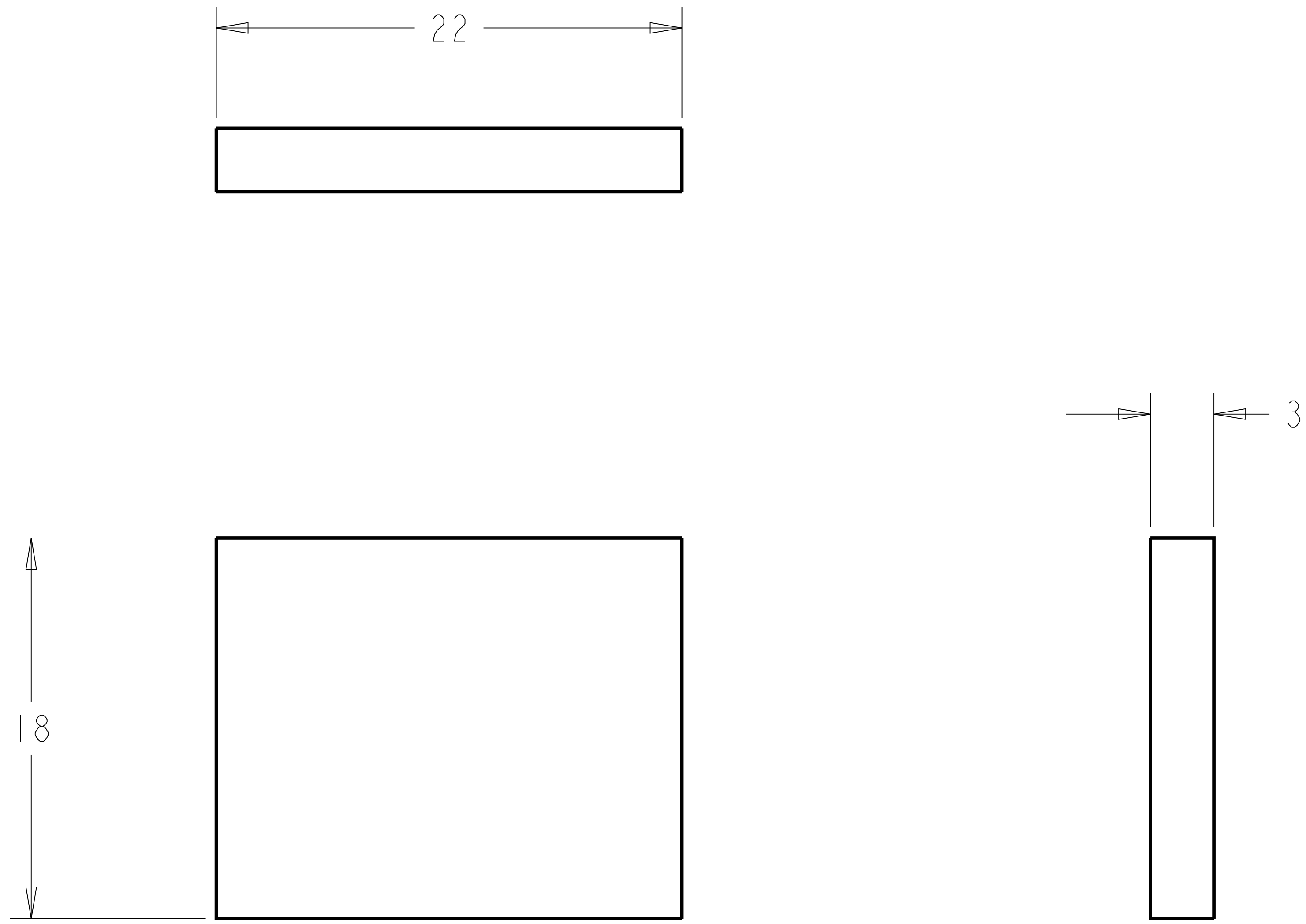
RADIATOR

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-800-100	A

SCALE 0.125 | UNIT WEIGHT : LBS | SHEET 1 OF 1

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14



GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	BOX	3/16" STEEL PLATE BOX WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	C WRAY
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 08-06-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: SEWAGE_TANK

THIRD ANGLE PROJECTION

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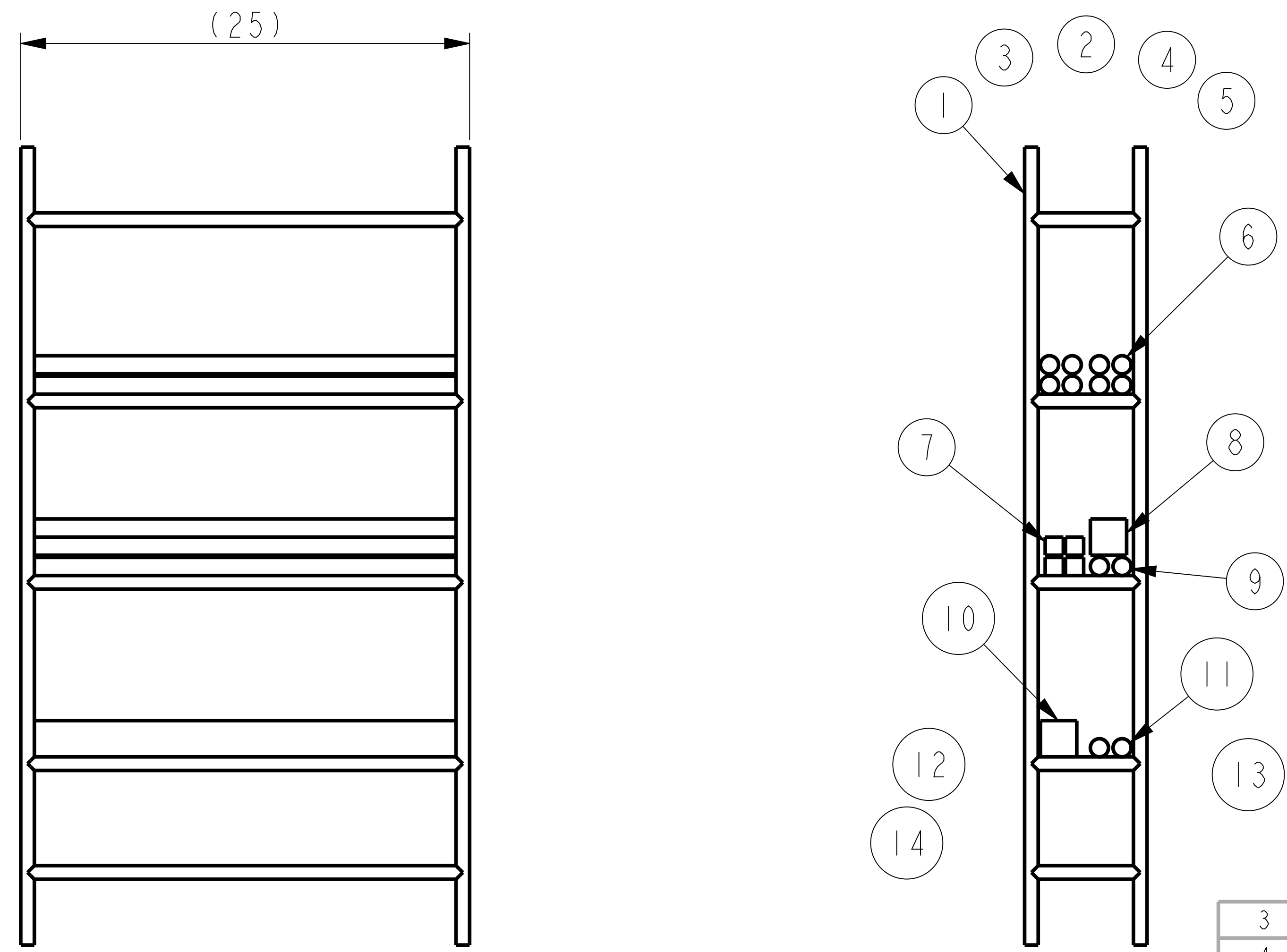
OFFICE of AUTOMOTIVE ENGINEERING
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238

SEWAGE TANK

B	26401	17914-900-100	A
SCALE 0.125	UNIT WEIGHT = LBS	SHEET 1 OF 1	

REV	SHT	ZONE	DESCRIPTION	DATE
			REVISIONS	
A			INITIAL RELEASE	08-05-14



QTY	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
3	HOSE	3/4" EPDM HOSE, (OMITTED FROM TEST)	14
4	CONDUIT	1/2" DIAMETER PVC CONDUIT, (OMITTED FROM TEST)	13
2	HOSE	1" EPDM HOSE, McMASTER CARR #5282K65 (OMITTED FROM TEST)	12
2	ROUND TUBING	1" THIN WALL STEEL TUBING, CAPPED	11
1	SQUARE TUBING	2" THIN WALL STEEL TUBING, CAPPED	10
2	ROUND TUBING	1" THIN WALL STEEL TUBING, CAPPED	9
1	SQUARE TUBING	2" THIN WALL STEEL TUBING, CAPPED	8
4	SQUARE TUBING	1" THIN WALL STEEL TUBING, CAPPED	7
8	ROUND TUBING	1" THIN WALL STEEL TUBING, CAPPED	6
4	CONDUIT	1/2" DIAMETER PVC CONDUIT, (OMITTED FROM TEST)	5
2	MULTI CONDUCTOR WIRE	JAMECO #644463 (OMITTED FROM TEST)	4
2	CONDUIT	3/4" DIAMETER PVC CONDUIT, (OMITTED FROM TEST)	3
1	INSULATION	1-3/4" OD X 1" ID FOAM PIPE INSULATION (OMITTED FROM TEST)	2
1	FRAME	SEE DRAWING 17914-1000-201	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 01-13-14
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: CM_2

THIRD ANGLE PROJECTION

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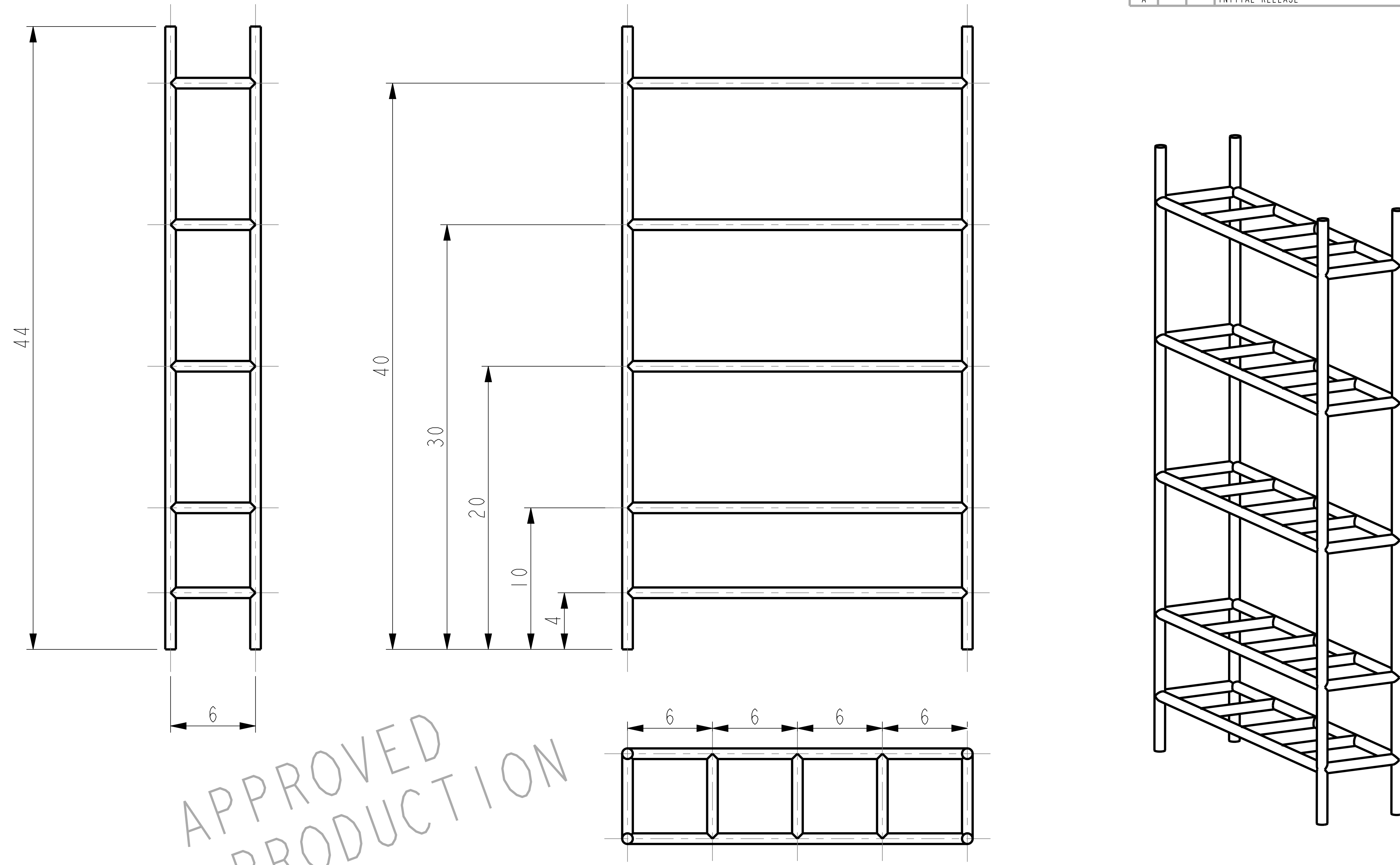
OFFICE of AUTOMOTIVE ENGINEERING
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238

CONSUMABLE MODULE 2

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-1000-200	A

SCALE 1:10 | UNIT WEIGHT = LBS | SHEET 1 OF 1

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14



GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	RACK / FRAME	3/4 X .120 W STEEL ROUND TUBING WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 12-23-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: CM_2_FRAME

THIRD ANGLE PROJECTION

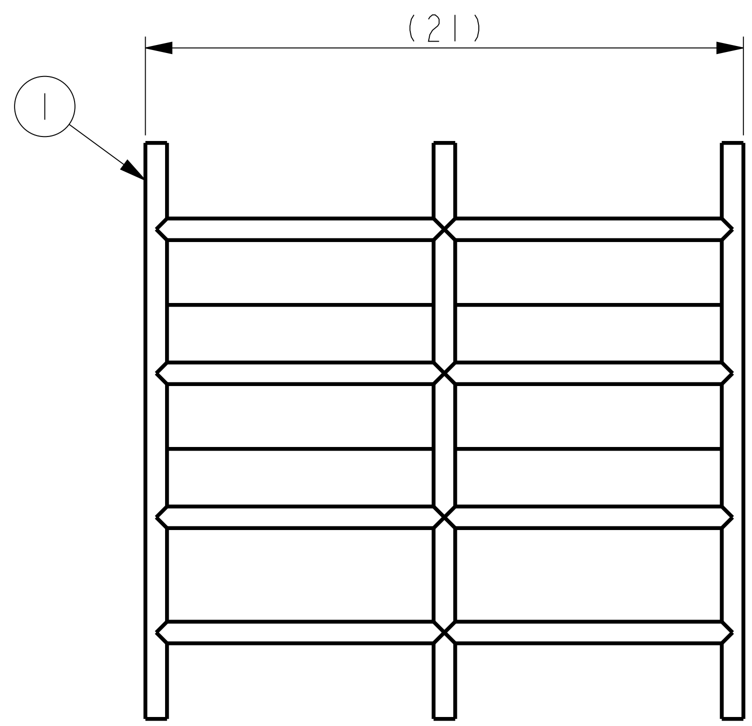
SOUTHWEST RESEARCH INSTITUTE
OFFICE of AUTOMOTIVE ENGINEERING
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238

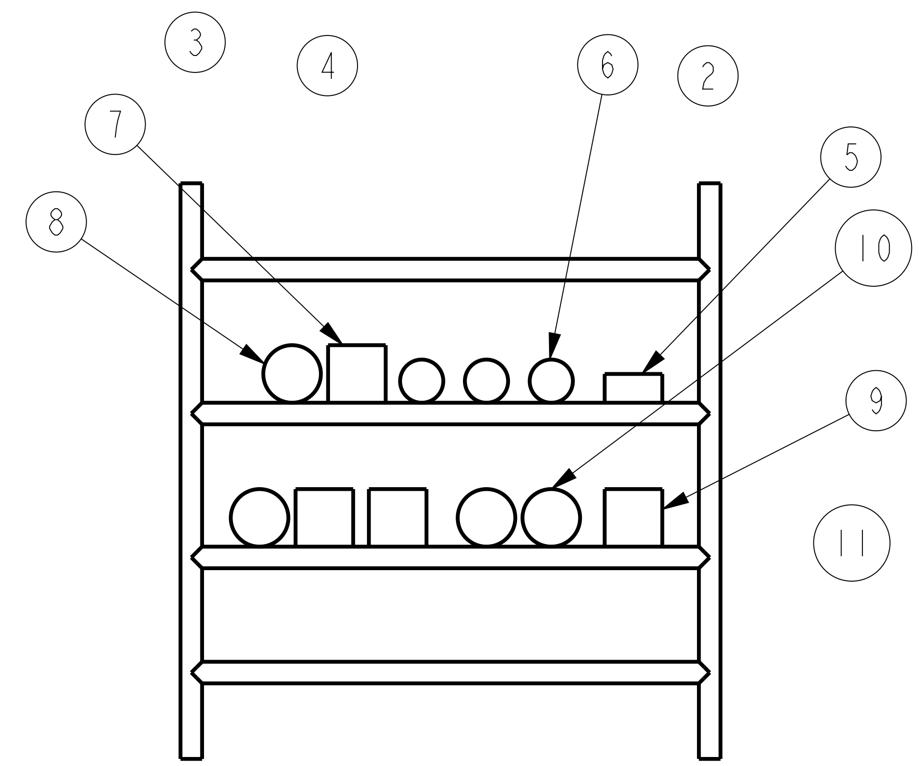
CONSUMABLE MODULE FRAME 2

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-1000-201	A

SCALE 1:8 | UNIT WEIGHT : LBS | SHEET 1 OF 1

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14





QTY	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
3	CONDUIT W/ BATTERY CABLE	3/4" DIAMETER PVC CONDUIT, McMASTER CARR #8067K122 W/ BATTERY CABLE McMASTER #6948K941 (OMITTED FROM TEST)	11
3	ROUND TUBING	2" THIN WALL TUBING, CAPPED	10
3	SQUARE TUBING	2" THIN WALL TUBING, CAPPED	9
1	ROUND TUBING	2" THIN WALL TUBING, CAPPED	8
1	SQUARE TUBING	2" THIN WALL TUBING, CAPPED	7
3	ROUND TUBING	1-1/2" THIN WALL TUBING, CAPPED	6
1	RECTANGULAR TUBING	2" X 1" THIN WALL TUBING, CAPPED	5
2	HOSE	EPDM HOSE, 3/4" DIAMETER (OMITTED FROM TEST)	4
3	CONDUIT	1/2" DIAMETER PVC CONDUIT, (OMITTED FROM TEST)	3
3	CONDUIT W/ WIRE	3/4"OD CONDUIT MCMASTER CARR #8067K122 W/ MULTI CONDUCTOR WIRE JAMECO #644463 (OMITTED FROM TEST)	2
1	FRAME	SEE DRAWING 17914-1000-301	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 01-10-14
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: CM_3

THIRD ANGLE PROJECTION

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OFFICE of AUTOMOTIVE ENGINEERING
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238

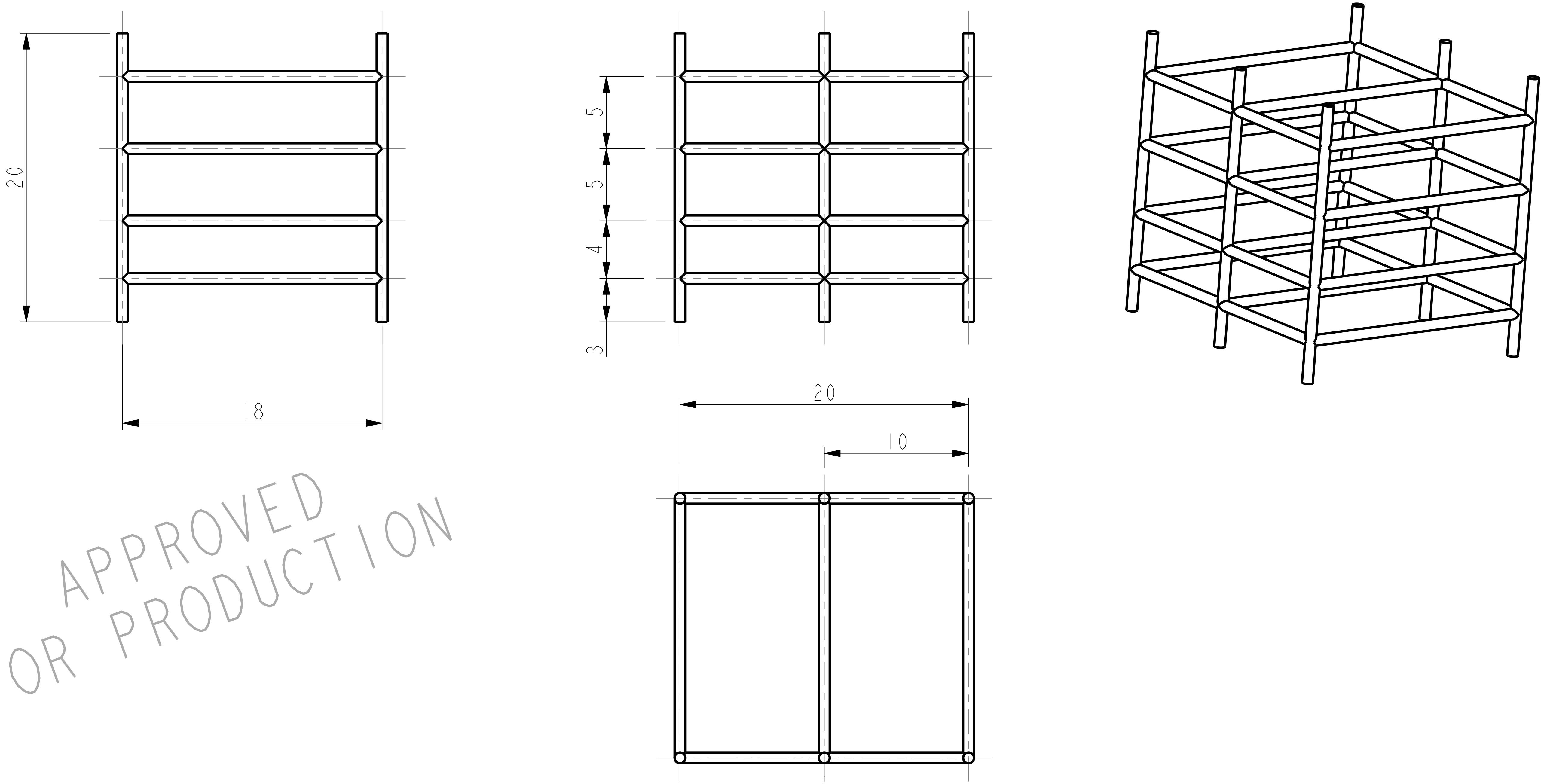
CONSUMABLE MODULE 3

B | 26401 | 17914-1000-300 | A

SCALE 3:20 | UNIT WEIGHT = LBS | SHEET 1 OF 1

APPROVED FOR PRODUCTION

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14



APPROVED
FOR PRODUCTION

GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	RACK / FRAME	3/4" X .120 W STEEL ROUND TUBING WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 12-23-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: CM_3_FRAME

THIRD ANGLE PROJECTION

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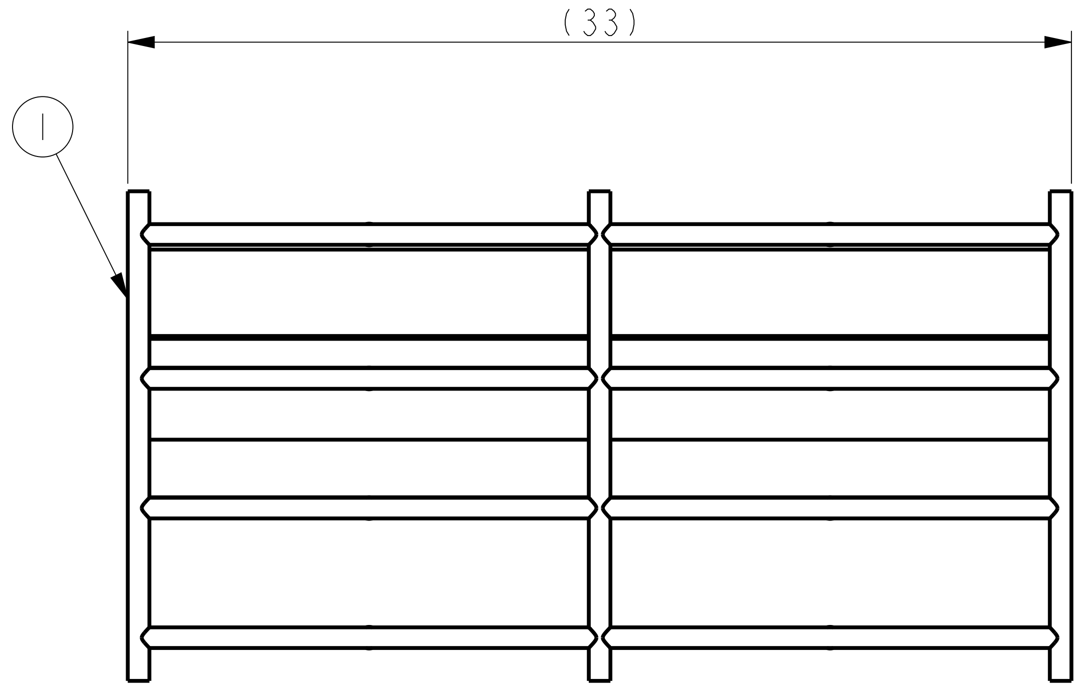
OFFICE of AUTOMOTIVE ENGINEERING
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238

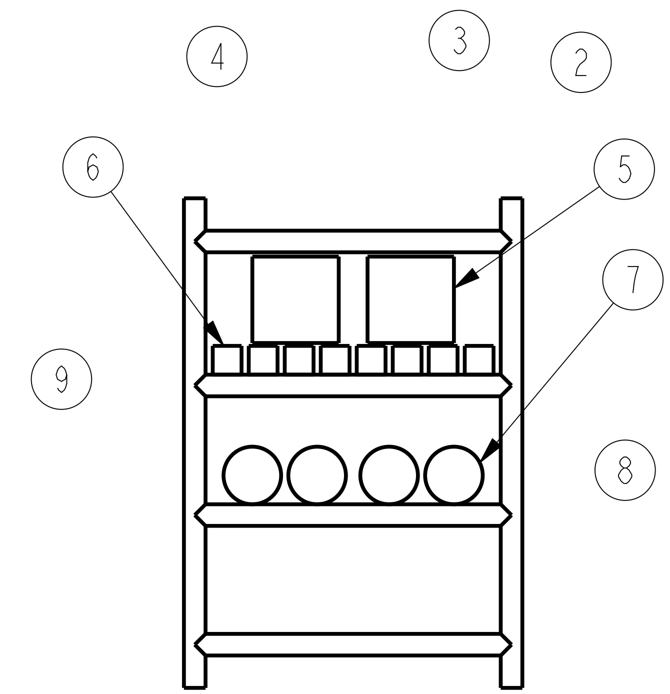
CONSUMABLE MODULE FRAME 3

SIZE	CODE	DRAWING NUMBER	REV
B	26401	17914-1000-301	A

SCALE 1:8 | UNIT WEIGHT = LBS | SHEET 1 OF 1

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14





APPROVED FOR PRODUCTION

QTY	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
3	CONDUIT	3/4" DIAMETER PVC CONDUIT,(OMITTED FROM TEST)	9
2	HOSE	EPDM HOSE, 1" DIAMETER, (OMITTED FROM TEST)	8
4	ROUND TUBING	2" THIN WALL STEEL TUBING, CAPPED	7
8	SQUARE TUBING	1" THIN WALL STEEL TUBING, CAPPED	6
2	SQUARE TUBING	3" THIN WALL STEEL TUBING, CAPPED	5
2	HOSE	EPDM HOSE, 1" DIAMETER, (OMITTED FROM TEST)	4
5	CONDUIT W/ WIRE	3/4" PVC CONDUIT, McMASTER CARR #8067K122 W/ BATTERY CABLE, McMASTER #6948K941 (OMITTED FROM TEST)	3
3	CONDUIT	1/2" DIAMETER PVC CONDUIT, (OMITTED FROM TEST)	2
1	FRAME	SEE DRAWING 17914-1000-401	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 01-10-14
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: CM_4

THIRD ANGLE PROJECTION

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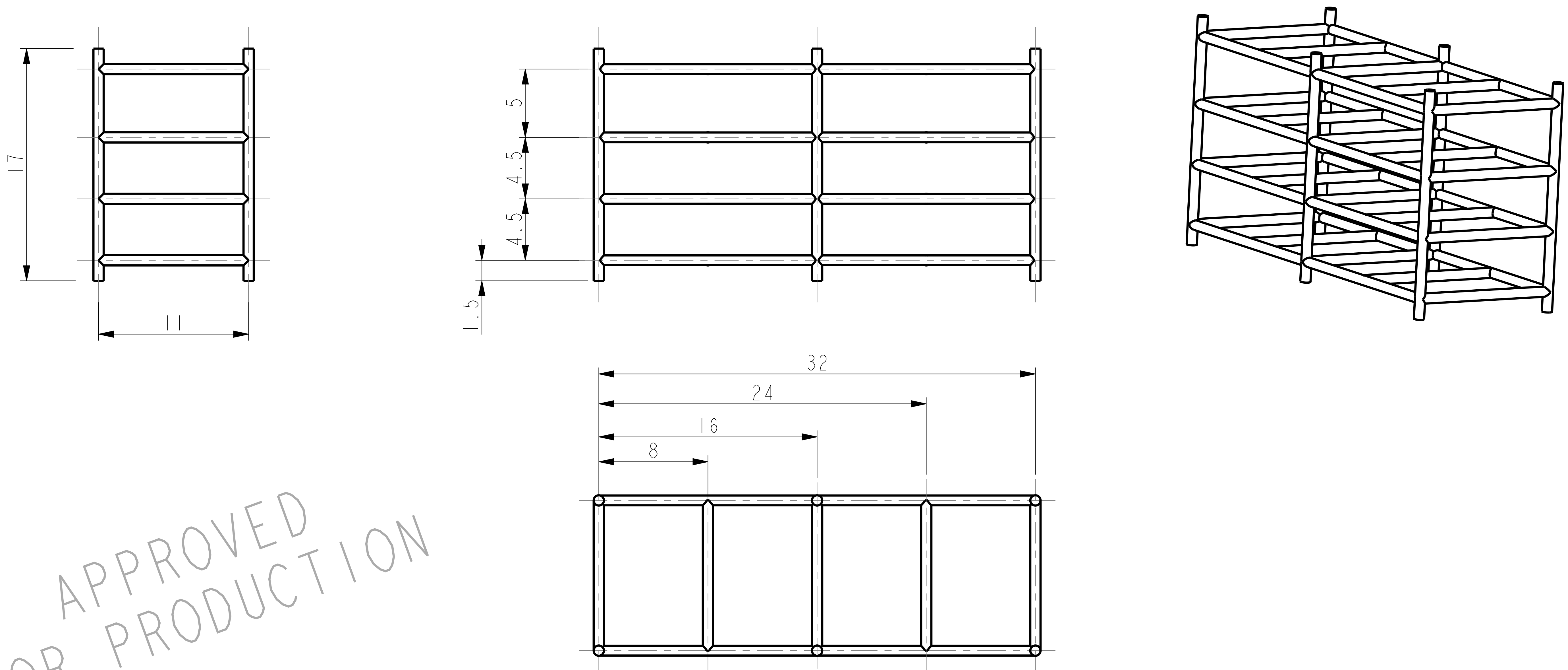
OFFICE of AUTOMOTIVE ENGINEERING
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238

CONSUMABLE MODULE 4

SIZE	CAGE	DRAWING NO.	REV
B	26401	17914-1000-400	A

SCALE 3:20 | UNIT WEIGHT : LBS | SHEET 1 OF 1

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14



GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	RACK / FRAME	3/4" x .120 W STEEL ROUND TUBING WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 12-23-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: CM_4_FRAME

THIRD ANGLE PROJECTION

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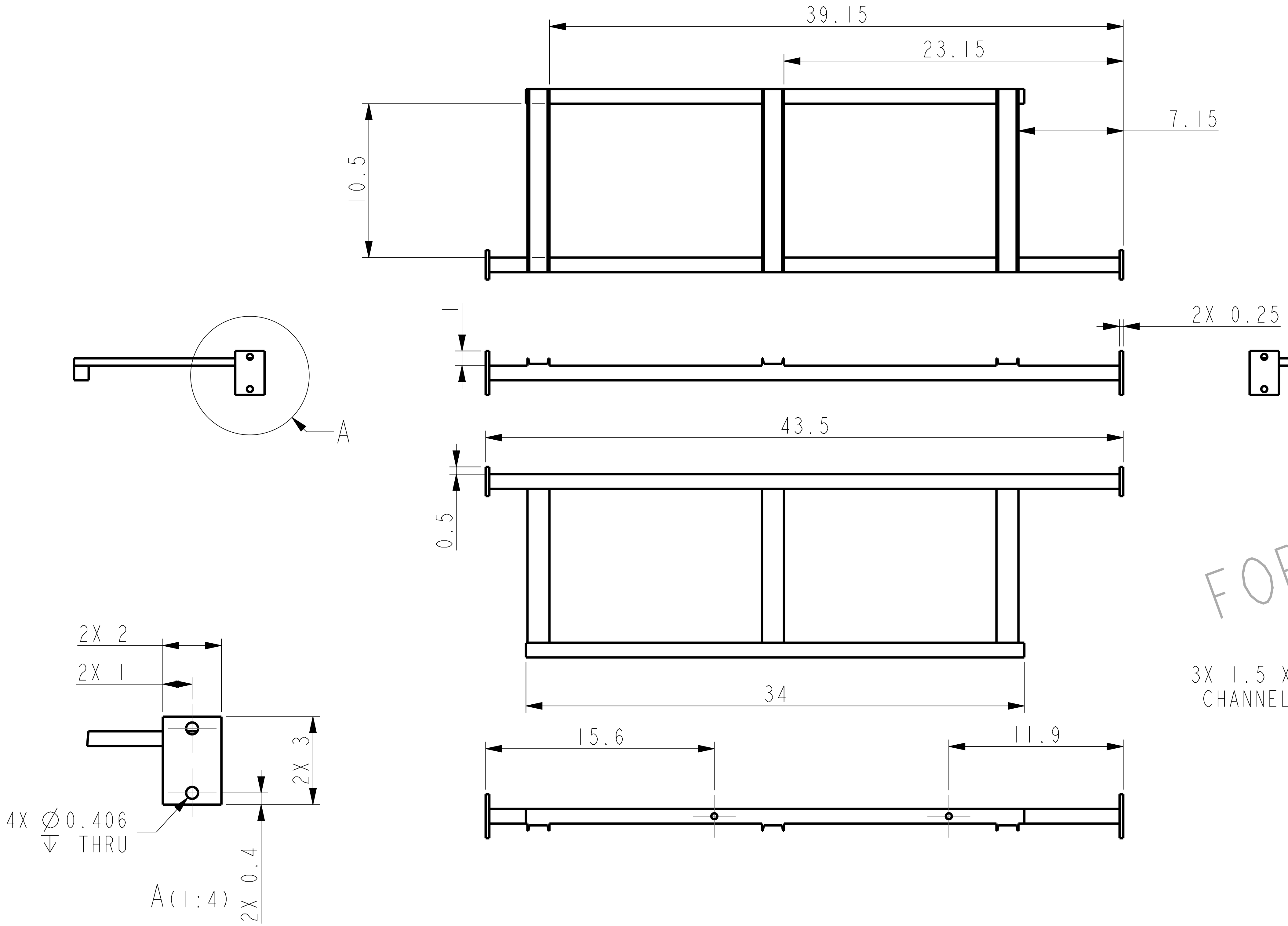
OFFICE of AUTOMOTIVE ENGINEERING
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238

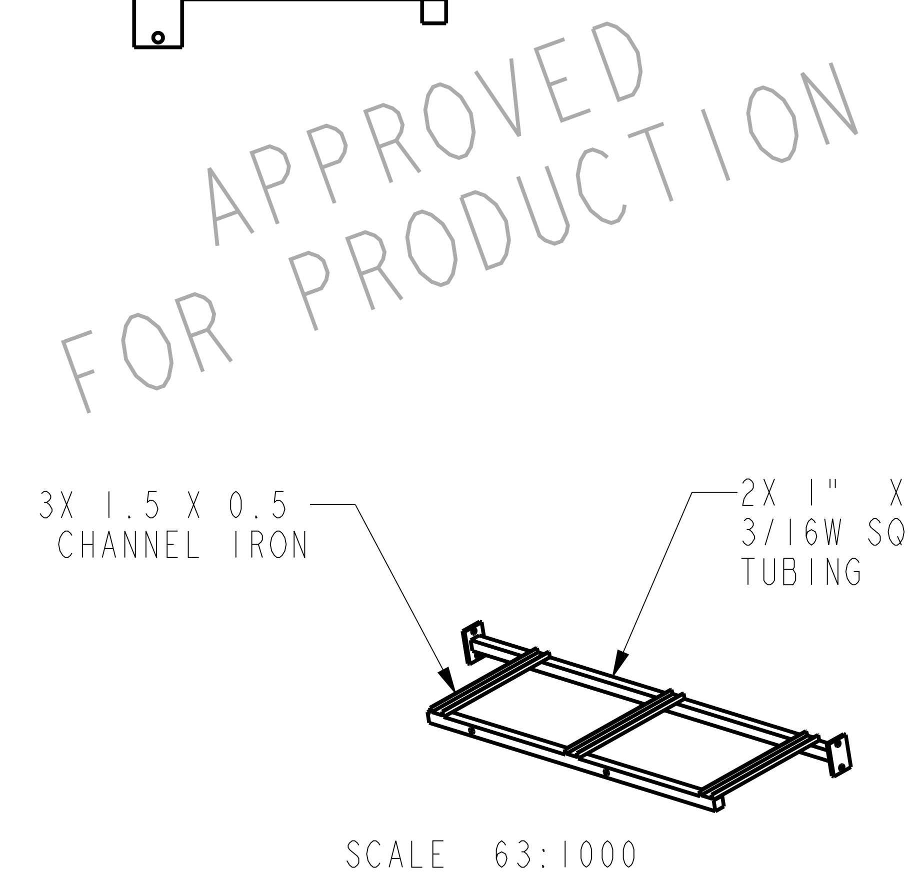
CONSUMABLE MODULE FRAME 4

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-1000-401	A

SCALE 1:8 | UNIT WEIGHT = LBS | SHEET 1 OF 1

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14





GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

BILL OF MATERIAL/PARTS LIST			
-1	MOUNTING BRACKET	STEEL WELDMENT, SEE CALLOUTS	1
P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 12-16-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: BRACKET_CM_4
THIRD ANGLE PROJECTION	EXCEPT AS MAY OTHERWISE BE PROVIDED BY CONTRACT THESE DRAWINGS AND SPECIFICATIONS ARE THE PROPERTY OF SOUTHWEST RESEARCH INSTITUTE, ARE ISSUED IN STRICT CONFIDENCE, AND SHALL NOT BE REPRODUCED, OR COPIED, OR USED AS THE BASIS FOR MANUFACTURE OR SALE OF ANY APPARATUS SHOWN HEREON WITHOUT PERMISSION

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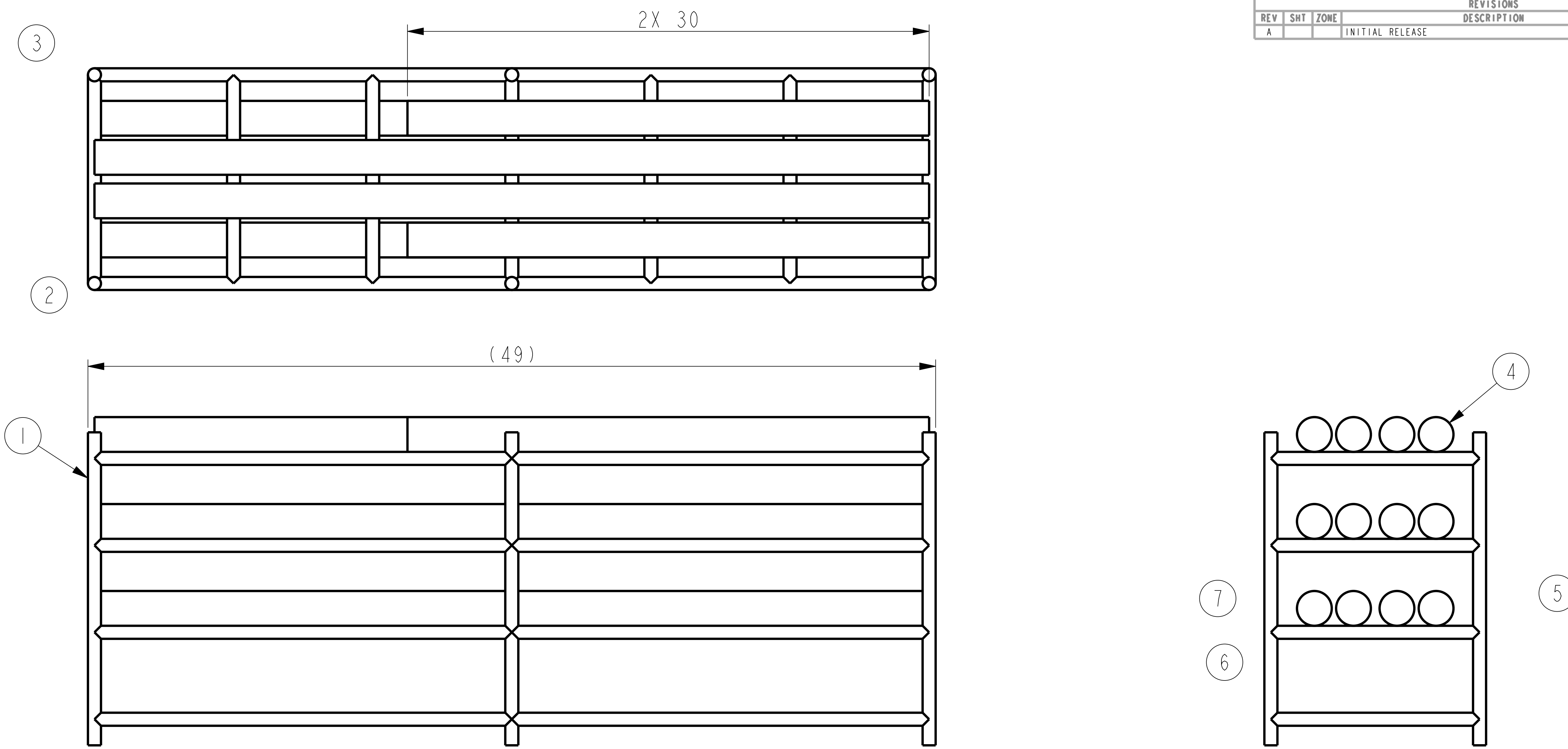
BRACKET CM-4

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-1000-402	A
SCALE 1:8	UNIT WEIGHT = LBS	SHEET 1 OF 1	

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14

REVISIONS



2	CONDUIT W/ WIRE	3/4"DIAMETER PVC CONDUIT, McMASTER CARR #8067K122 W/ MULTI CONDUCTOR WIRE, (OMITTED FROM TEST)	7
2	CONDUIT W/ WIRE	1/2" DIAMETER PVC CONDUIT, McMASTER CARR #8067K111 W/ 3 CONDUCTOR WIRE, (OMITTED FROM TEST)	6
2	INSULATION	FOAM PIPE INSULATION 1-3/4" OD X 3/4" ID, (OMITTED FROM TEST)	5
12	ROUND TUBING	2" THIN WALL STEEL TUBING, CAPPED	4
1	HOSE	EPDM HOSE, 3/4" DIAMETER (OMITTED FROM TEST)	3
1	CONDUIT	3/4" DIAMETER PVC CONDUIT, (OMITTED FROM TEST)	2
1	FRAME	SEE DRAWING: 17914-1000-501	1
QTY	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 01-10-14
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: CM_5

THIRD ANGLE PROJECTION

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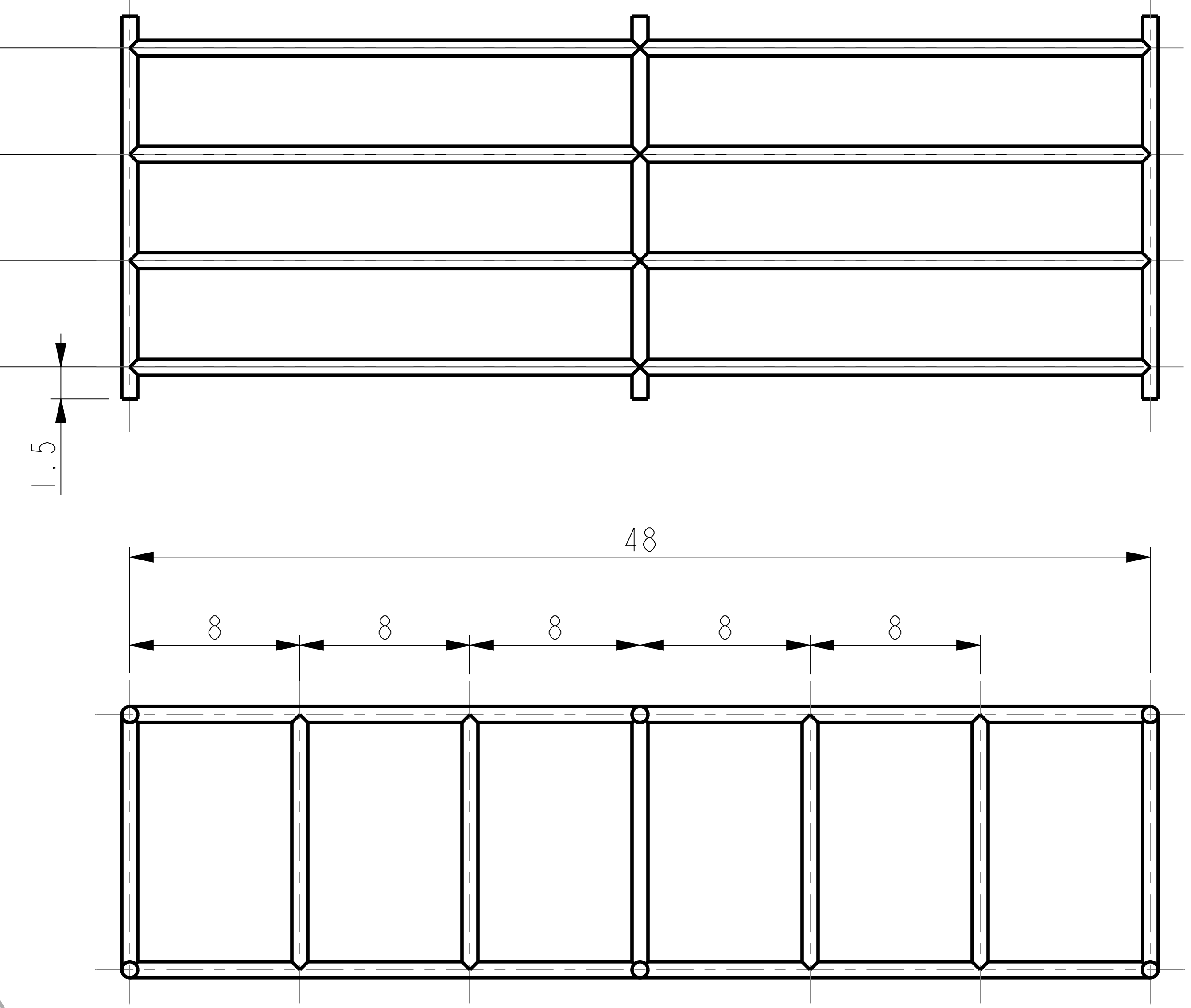
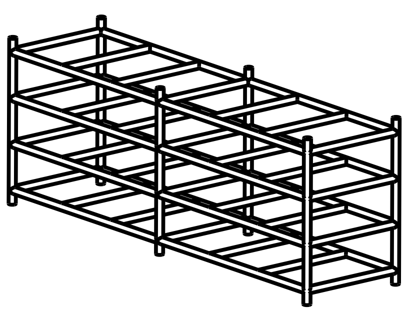
CONSUMABLE MODULE 5

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-1000-500	A

SCALE 3:20 | UNIT WEIGHT : LBS | SHEET 1 OF 1

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14





SCALE 1:20

APPROVED FOR PRODUCTION

QTY: 2 EACH

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	RACK / FRAME	3/4" X .120 W STEEL ROUND TUBING WELDENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 12-23-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: CM_5_FRAME
THIRD ANGLE PROJECTION	EXCEPT AS MAY OTHERWISE BE PROVIDED BY CONTRACT THESE DRAWINGS AND SPECIFICATIONS ARE THE PROPERTY OF SOUTHWEST RESEARCH INSTITUTE, ARE ISSUED IN STRICT CONFIDENCE, AND SHALL NOT BE REPRODUCED, OR COPIED, OR USED AS THE BASIS FOR MANUFACTURE OR SALE OF ANY APPARATUS SHOWN THEREON WITHOUT PERMISSION

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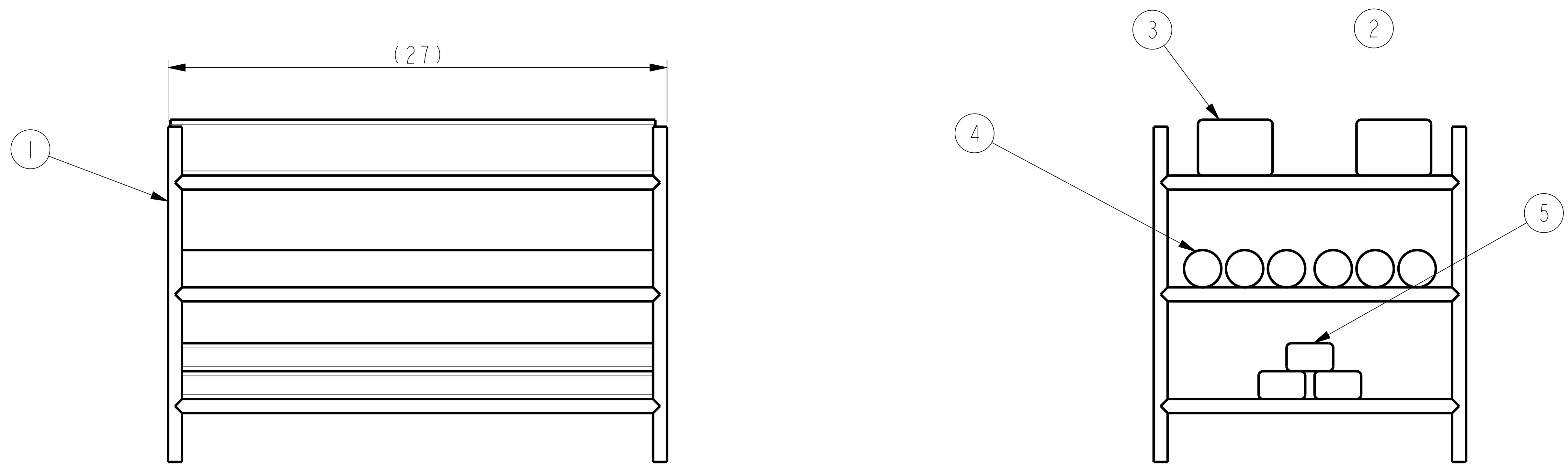
CONSUMABLE MODULE FRAME 5

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-1000-501	A
SCALE 1:8	UNIT WEIGHT = LBS	SHEET 1 OF 1	

GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14



APPROVED FOR PRODUCTION

3	RECTANGULAR TUBING	1-1/2" X 2-1/2" THIN WALL STEEL TUBING, CAPPED	5
6	ROUND TUBING	2" THIN WALL STEEL TUBING, CAPPED	4
2	RECTANGULAR TUBING	3" X 4" THIN WALL STEEL TUBING, CAPPED	3
3	HOSE	EPDM HOSE, 3" DIAMETER ABBOTT RUBBER (OMITTED FROM TEST)	2
1	FRAME	SEE DRAWING 17914-1000-601	1
P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 01-10-14
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: CM_6_A

THIRD ANGLE PROJECTION

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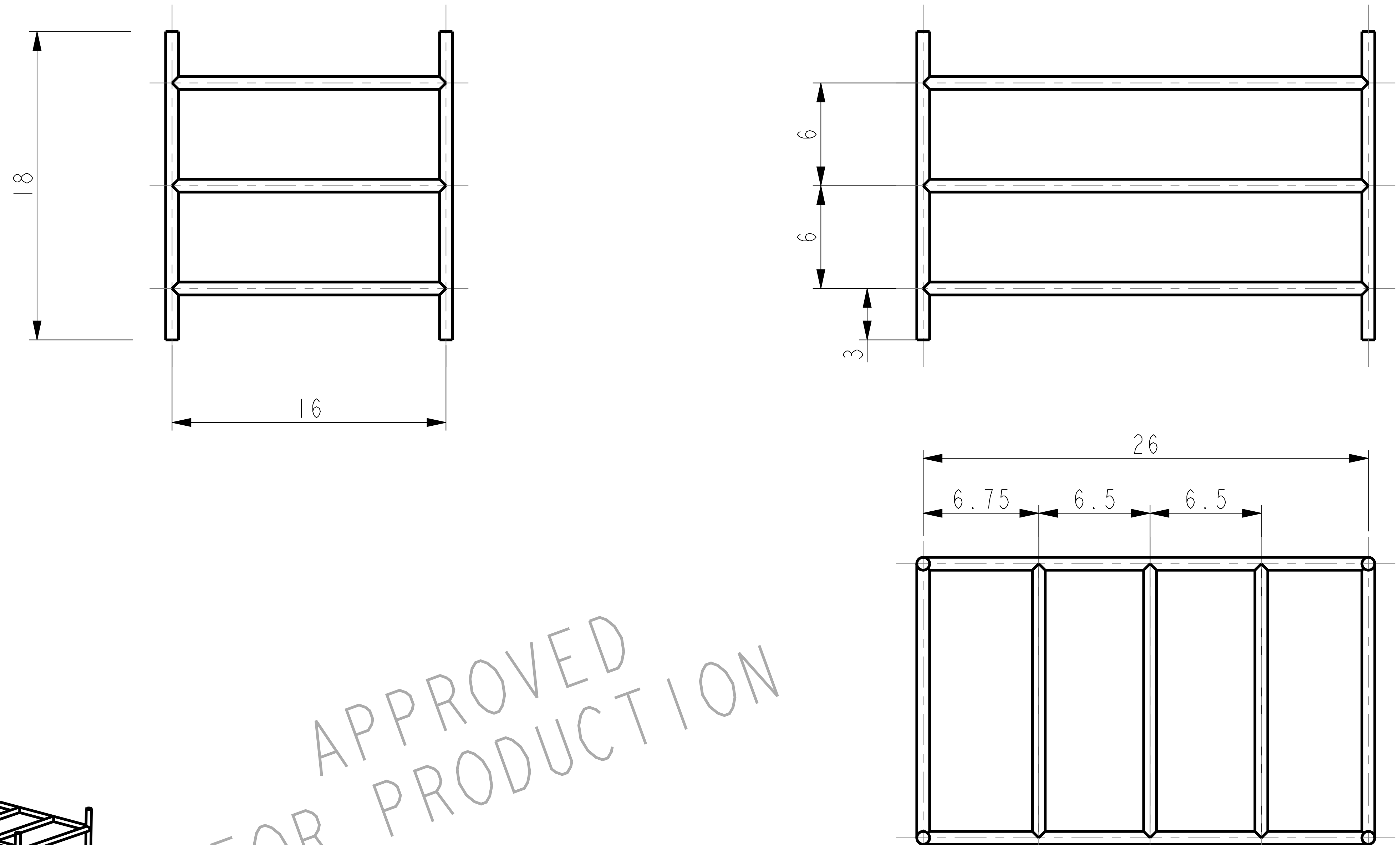
CONSUMABLE MODULE 6

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-1000-600	A

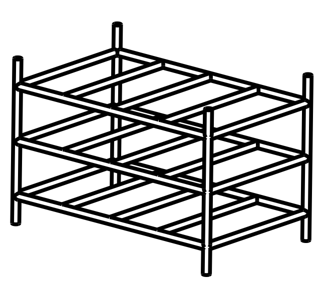
SCALE 3:20 | UNIT WEIGHT = LBS | SHEET 1 OF 1

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14

REVISIONS



APPROVED FOR PRODUCTION



SCALE 1:20

QTY: 4 EACH

GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	RACK / FRAME	3/4" X .120 W STEEL ROUND TUBING WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 12-23-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: CM_6_FRAME

THIRD ANGLE PROJECTION

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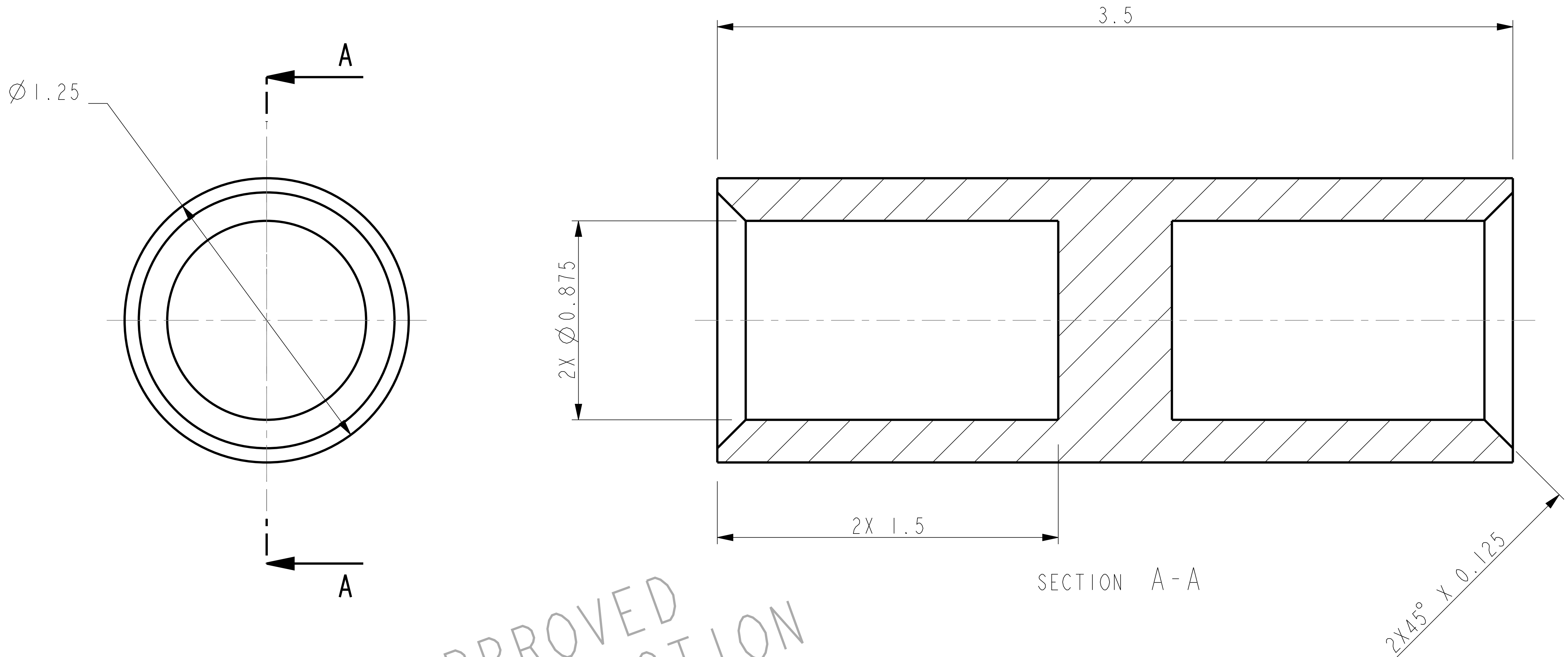
CONSUMABLE MODULE FRAME 6

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-1000-601	A

SCALE 1:8 | UNIT WEIGHT : LBS | SHEET 1 OF 1

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14



APPROVED FOR PRODUCTION

QTY: 8 EACH

GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	STANDOFF	STEEL 1018 OR EQ	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 12-30-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: CM_6_STANDOFF

THIRD ANGLE PROJECTION

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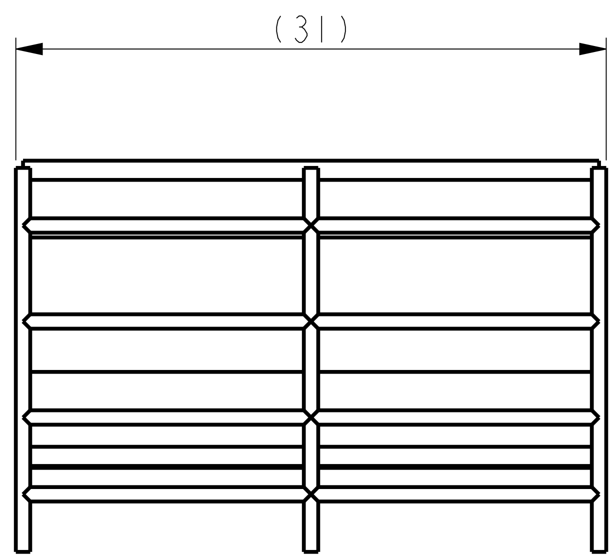
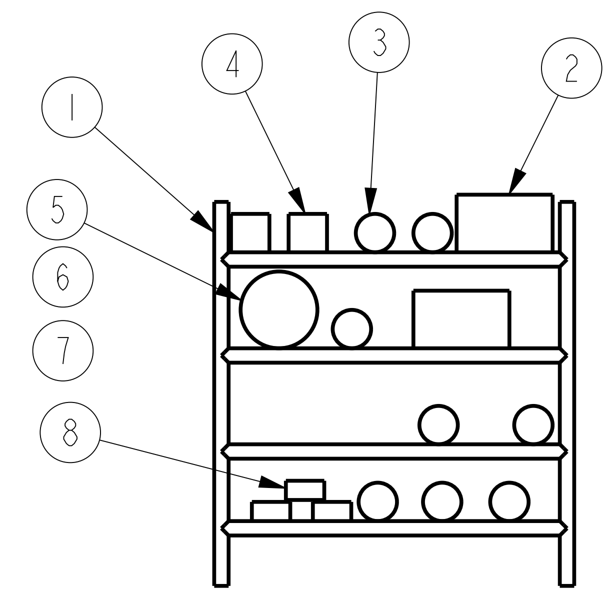
CM-6 STAND OFF

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-1000-602	A

SCALE 2:1 | UNIT WEIGHT = LBS | SHEET 1 OF 1

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14





APPROVED
FOR PRODUCTION

QTY	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
3	RECTANGULAR TUBING	1" X 2" THIN WALL STEEL TUBING, CAPPED	8
3	HOSE	1" EPDM HOSE, MCMASTER CARR #5282K65 (OMITTED FROM TEST)	7
1	INSULATION	1-3/4" OD X 1" ID FOAM PIPE INSULATION, (OMITTED FROM TEST)	6
1	ROUND TUBING	4" THIN WALL STEEL TUBING, CAPPED	5
2	SQUARE TUBING	2" THIN WALL STEEL TUBING CAPPED	4
8	ROUND TUBING	2" THIN WALL STEEL TUBING, CAPPED	3
2	RECTANGULAR TUBING	3" X 5" THIN WALL STEEL TUBING, CAPPED	2
1	FRAME	SEE DRAWING 17914-1000-701	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 01-13-14
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: CM_7
THIRD ANGLE PROJECTION	EXCEPT AS MAY OTHERWISE BE PROVIDED BY CONTRACT THESE DRAWINGS AND SPECIFICATIONS ARE THE PROPERTY OF SOUTHWEST RESEARCH INSTITUTE, ARE ISSUED IN STRICT CONFIDENCE, AND SHALL NOT BE REPRODUCED, OR COPIED, OR USED AS THE BASIS FOR MANUFACTURE OR SALE OF ANY APPARATUS SHOWN THEREON WITHOUT PERMISSION

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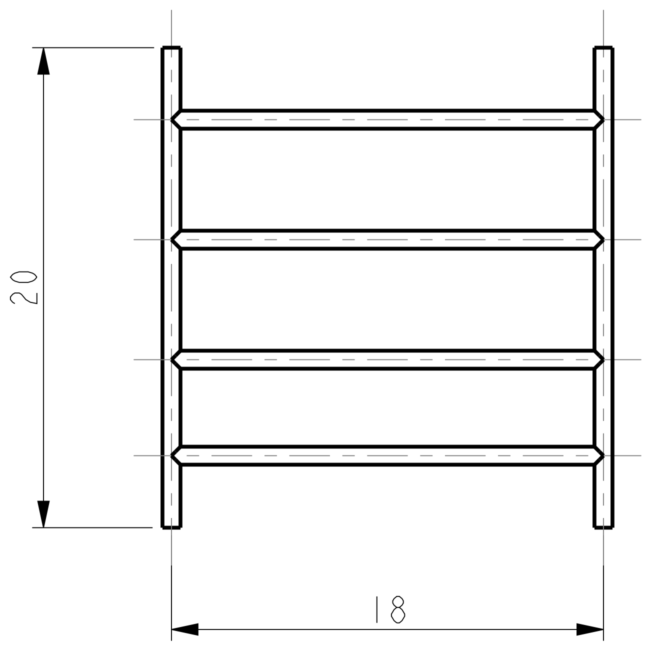
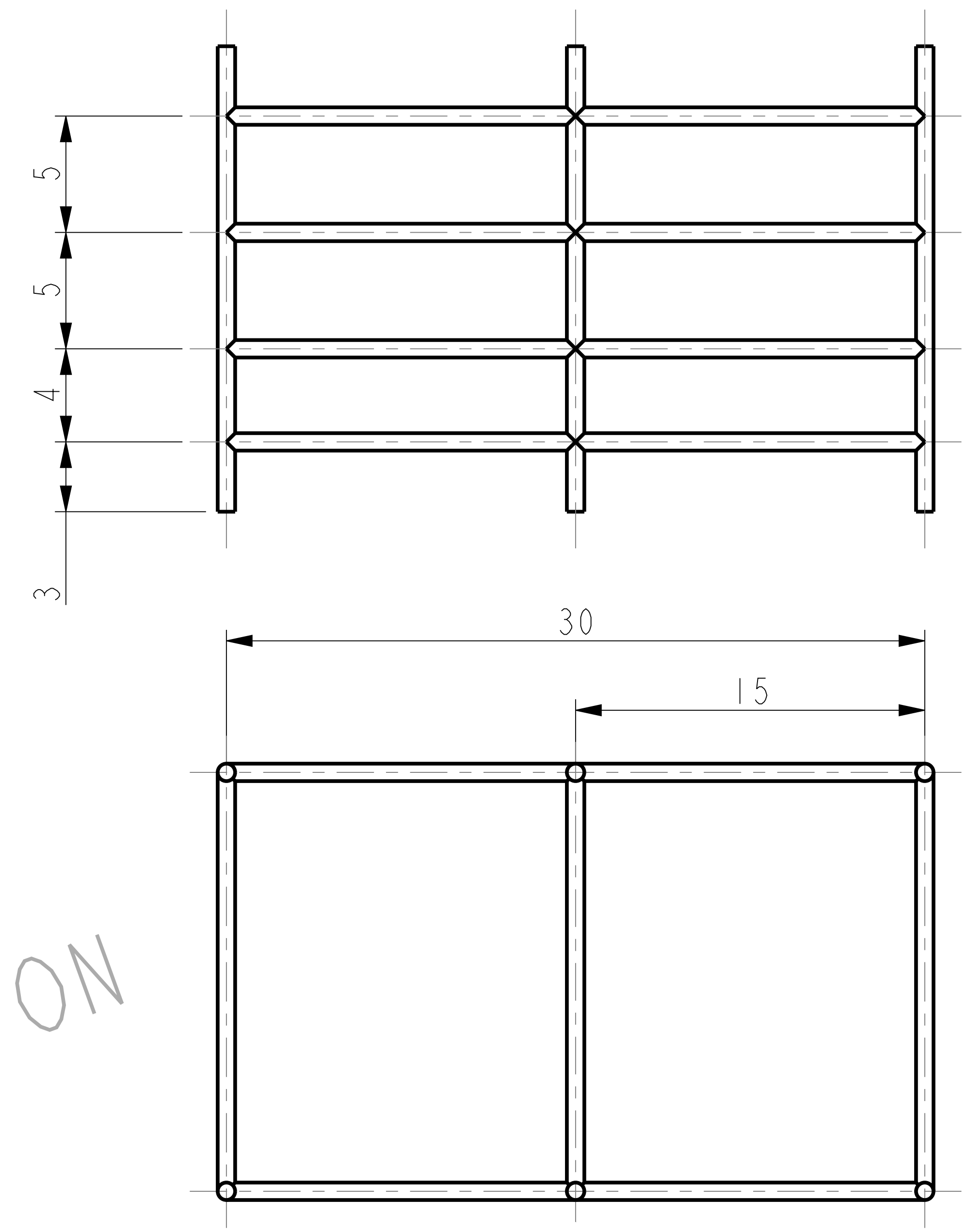
CONSUMABLE MODULE 7

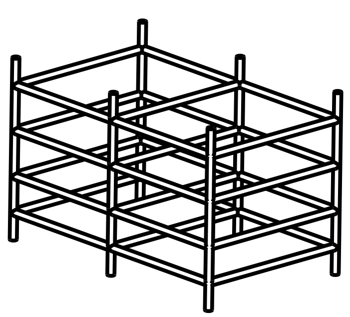
SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-1000-700	A

SCALE 1:10 | UNIT WEIGHT = LBS | SHEET 1 OF 1

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-05-14







SCALE 1:20

APPROVED FOR PRODUCTION

GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	FRAME / RACK	3/4" X .120 W ROUND STEEL TUBING WELDMENT	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	C WRAY
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 12-23-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: CM_7_FRAME
THIRD ANGLE PROJECTION	EXCEPT AS MAY OTHERWISE BE PROVIDED BY CONTRACT THESE DRAWINGS AND SPECIFICATIONS ARE THE PROPERTY OF SOUTHWEST RESEARCH INSTITUTE, ARE ISSUED IN STRICT CONFIDENCE, AND SHALL NOT BE REPRODUCED, OR COPIED, OR USED AS THE BASIS FOR MANUFACTURE OR SALE OF ANY APPARATUS SHOWN THEREON WITHOUT PERMISSION

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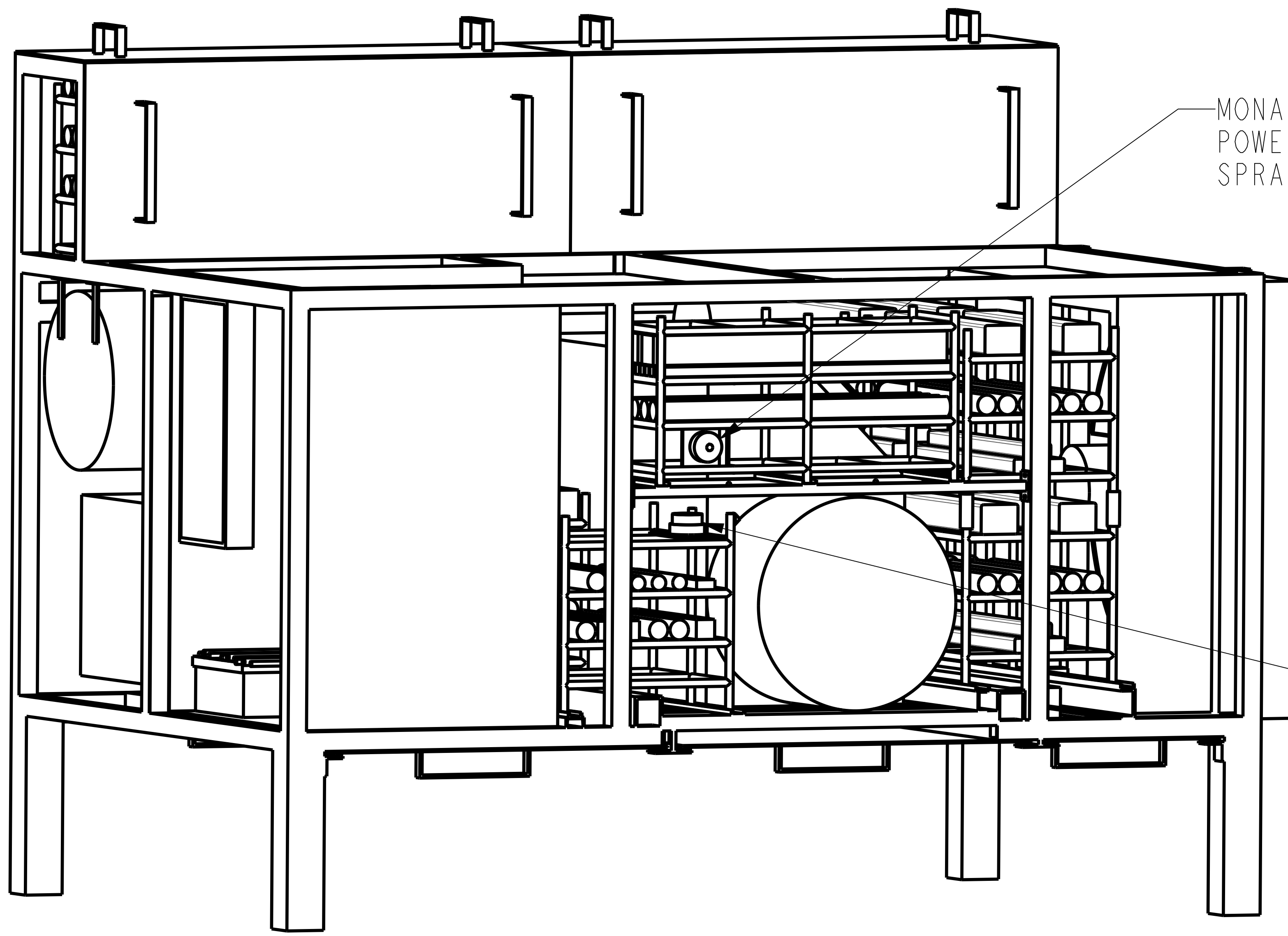
CONSUMABLE MODULE FRAME 7

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-1000-701	A
SCALE 1:8	UNIT WEIGHT : LBS	SHEET 1 OF 1	

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	07-31-14



APPROVED FOR PRODUCTION

BILL OF MATERIAL/PARTS LIST

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1			1

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	J HUCZEK
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 07-29-14
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: POWER_STEERING_FLUID

THIRD ANGLE PROJECTION

EXCEPT AS MAY OTHERWISE BE PROVIDED BY CONTRACT THESE DRAWINGS AND SPECIFICATIONS ARE THE PROPERTY OF SOUTHWEST RESEARCH INSTITUTE, ARE ISSUED IN STRICT CONFIDENCE, AND SHALL NOT BE REPRODUCED, OR COPIED, OR USED AS THE BASIS FOR MANUFACTURE OR SALE OF ANY APPARATUS SHOWN THEREON WITHOUT PERMISSION

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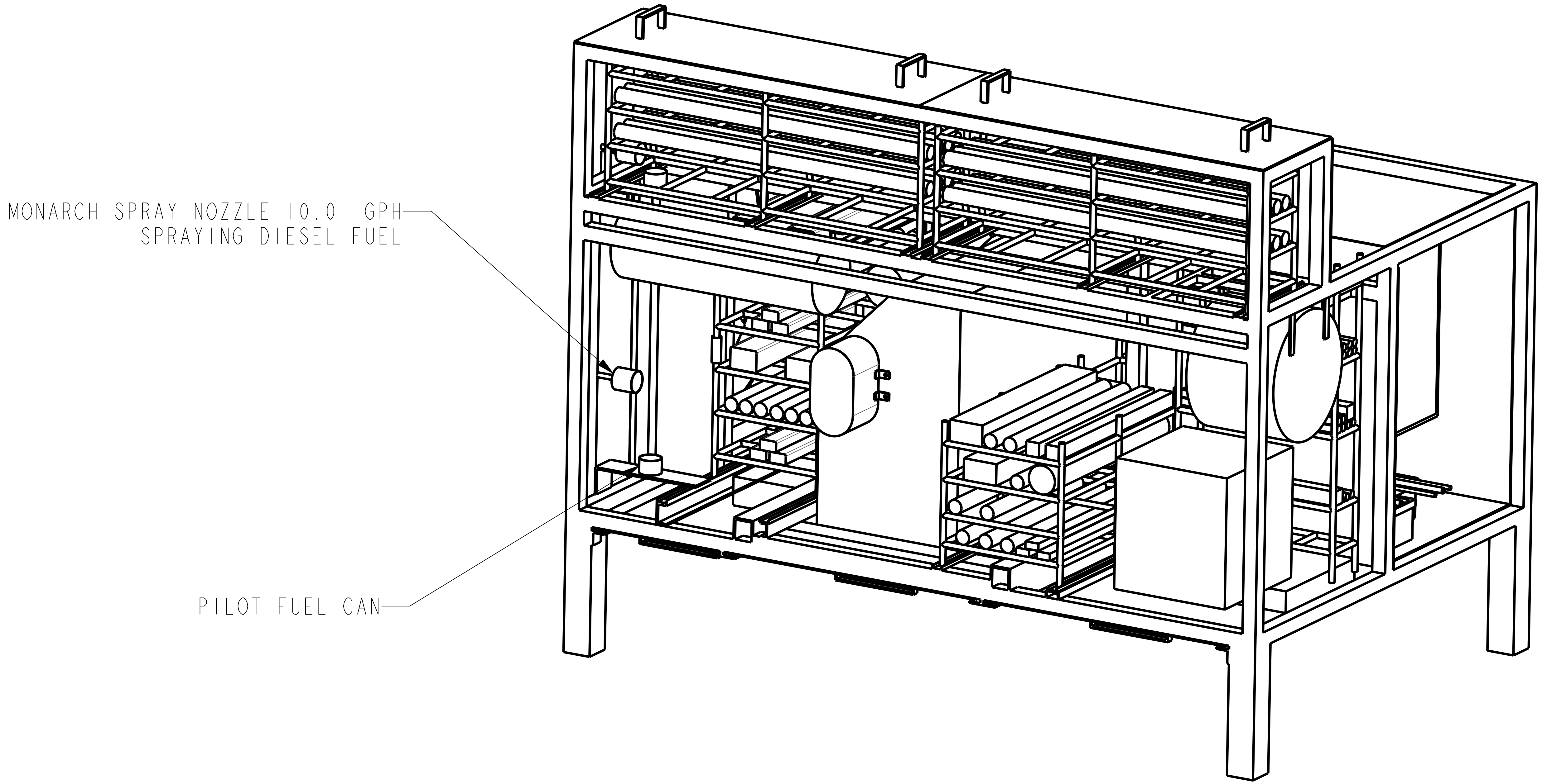
POWER STEERING FLUID SPRAY FIRE SCENARIO

SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-1000-FS1	A

SCALE 63:1000 | UNIT WEIGHT = LBS | SHEET 1 OF 1

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-04-14



P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1			1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	J HUCZEK
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 07-29-14
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: DIESEL_SPRAY_FIRE

THIRD ANGLE PROJECTION

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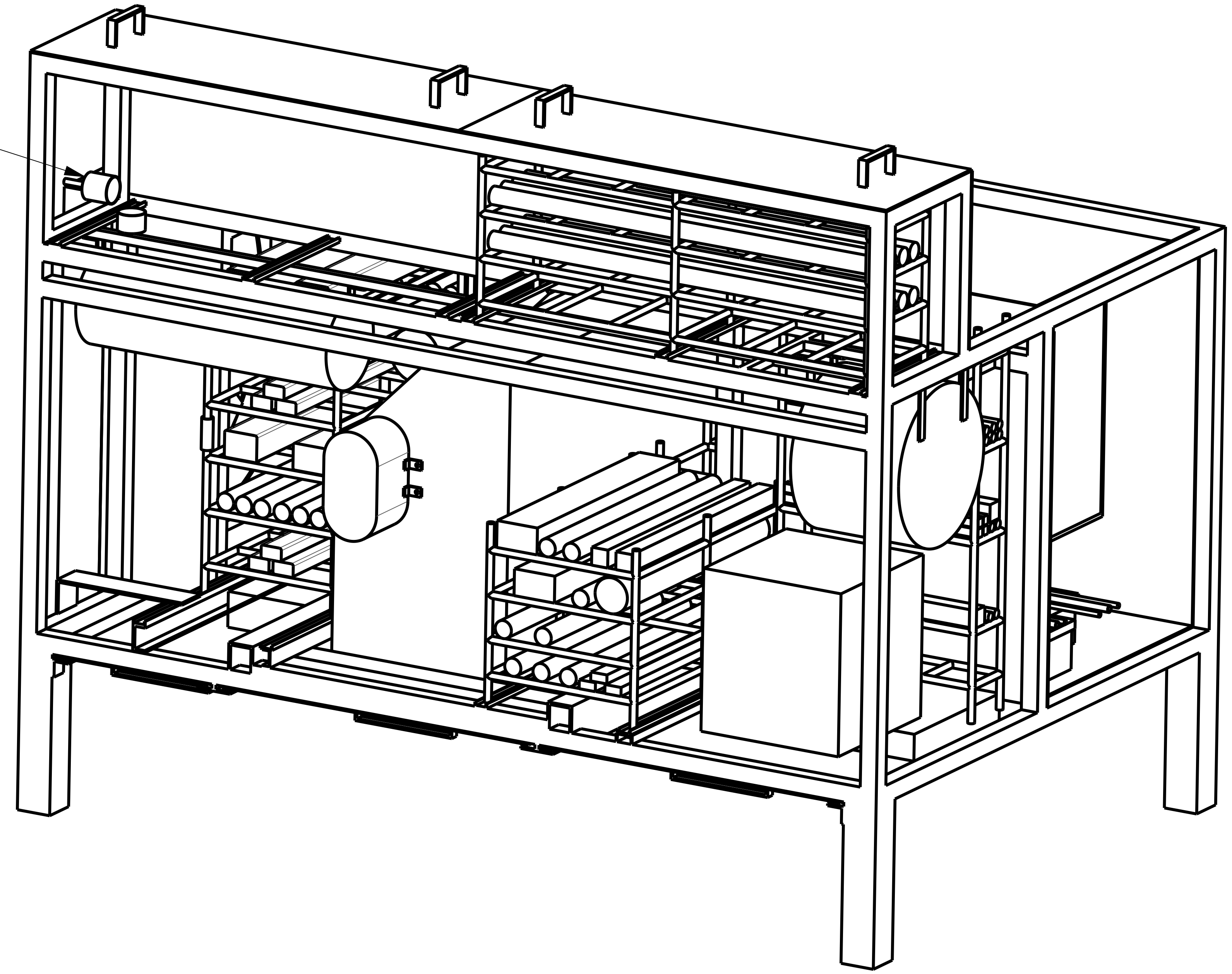
DIESEL SPRAY FIRE SCENARIO

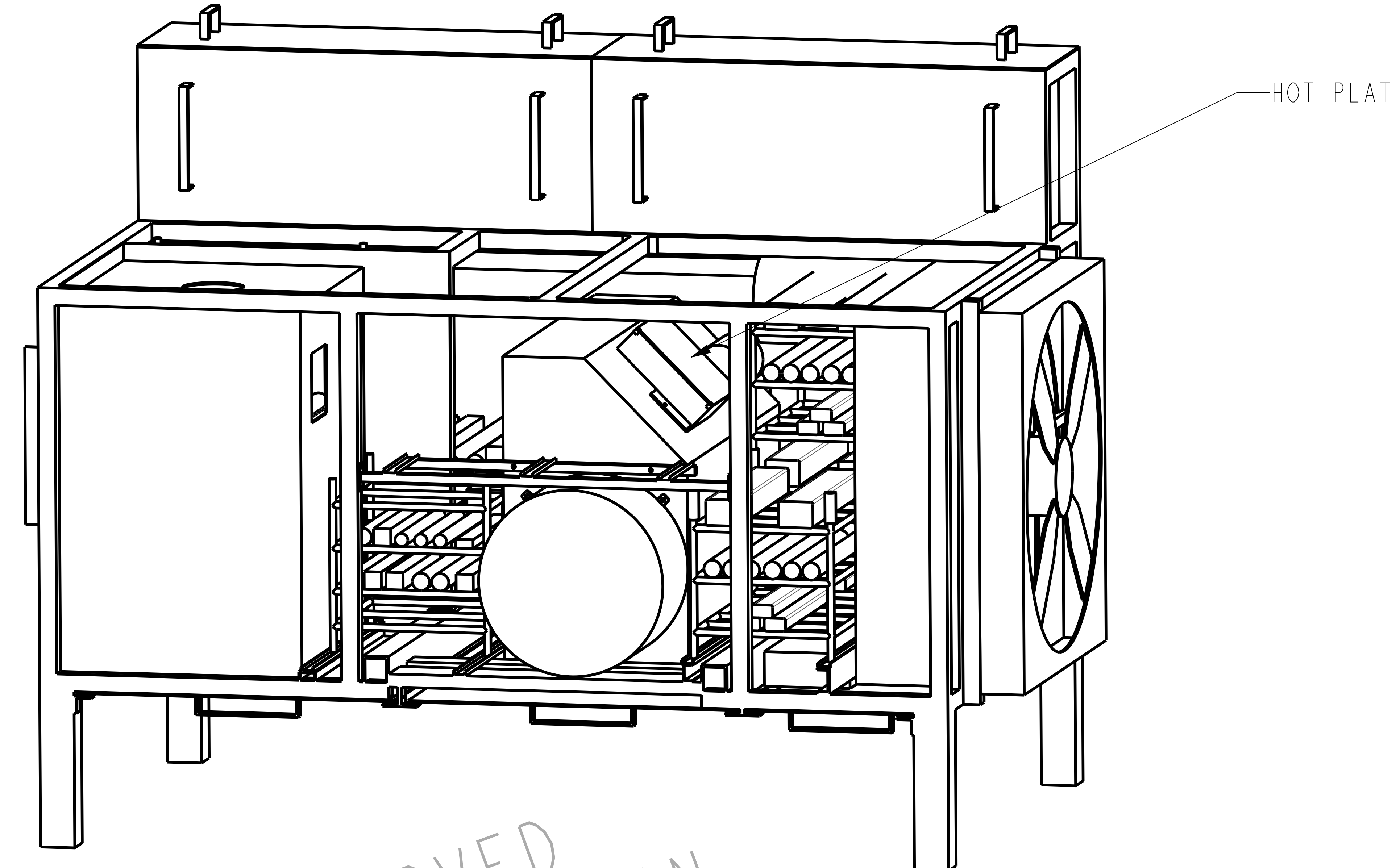
SIZE	CODE	DRAWING NUMBER	REV
B	26401	17914-1000-FS2	A

SCALE 63:1000 | UNIT WEIGHT = LBS | SHEET 1 OF 2



B	26401	17914-1000-FS2	
SCALE 63:1000			SHEET 2 OF 2

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-04-14



APPROVED FOR PRODUCTION

-1			1
P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	J HUCZEK
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 07-30-14
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: OIL_DRIP_FIRE

THIRD ANGLE PROJECTION

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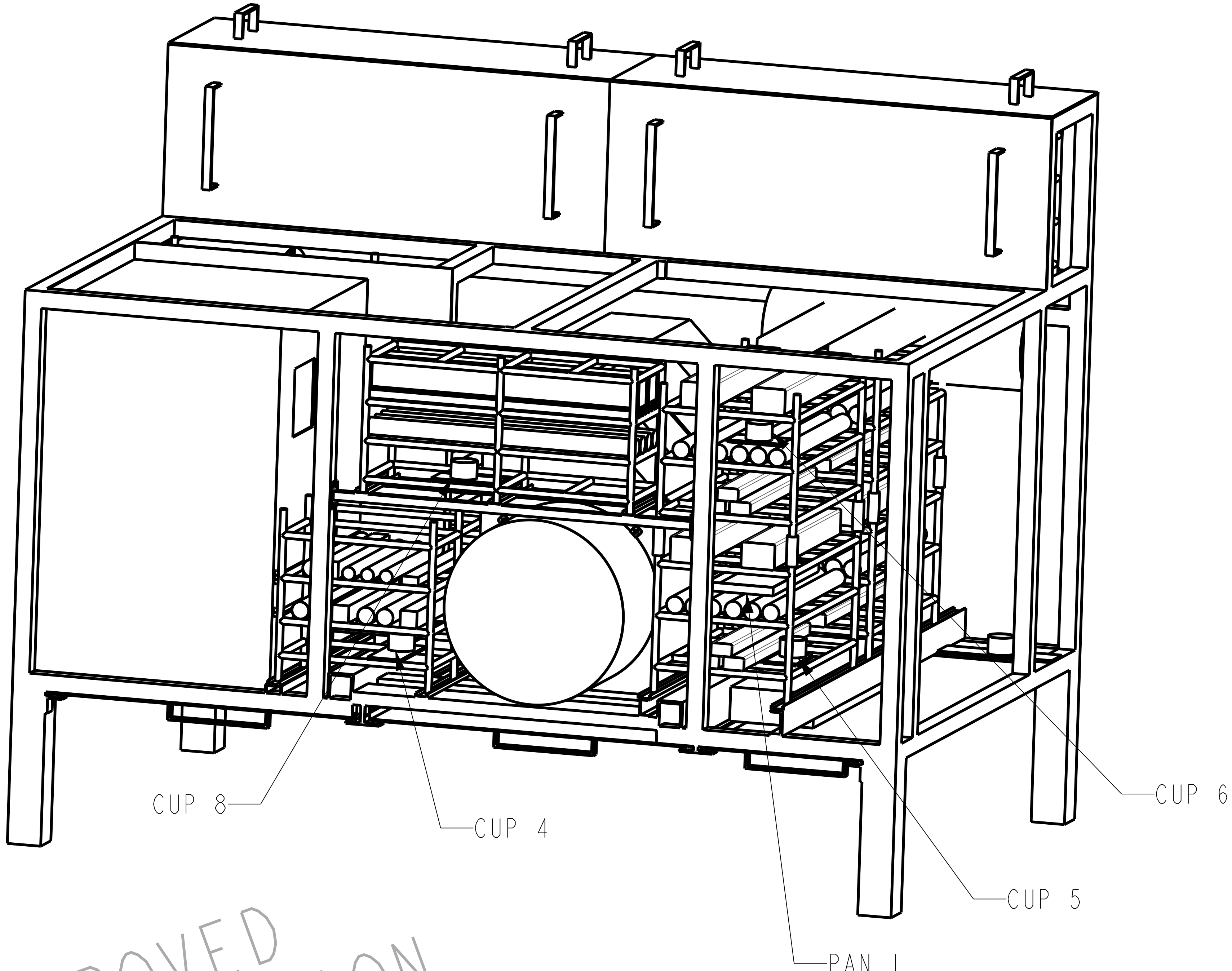
HOT SURFACE RE-IGNITION FIRE SCENARIO

SIZE	CAGE	DWG NO	REV
B	26401	17914-1000-FS3	A
SCALE 63:1000	UNIT WEIGHT = LBS	SHEET 1 OF 1	



REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	07-31-14

APPROVED FOR PRODUCTION

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1			1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	J HUCZEK
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 07-30-14
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: POOL_FIRE

THIRD ANGLE PROJECTION

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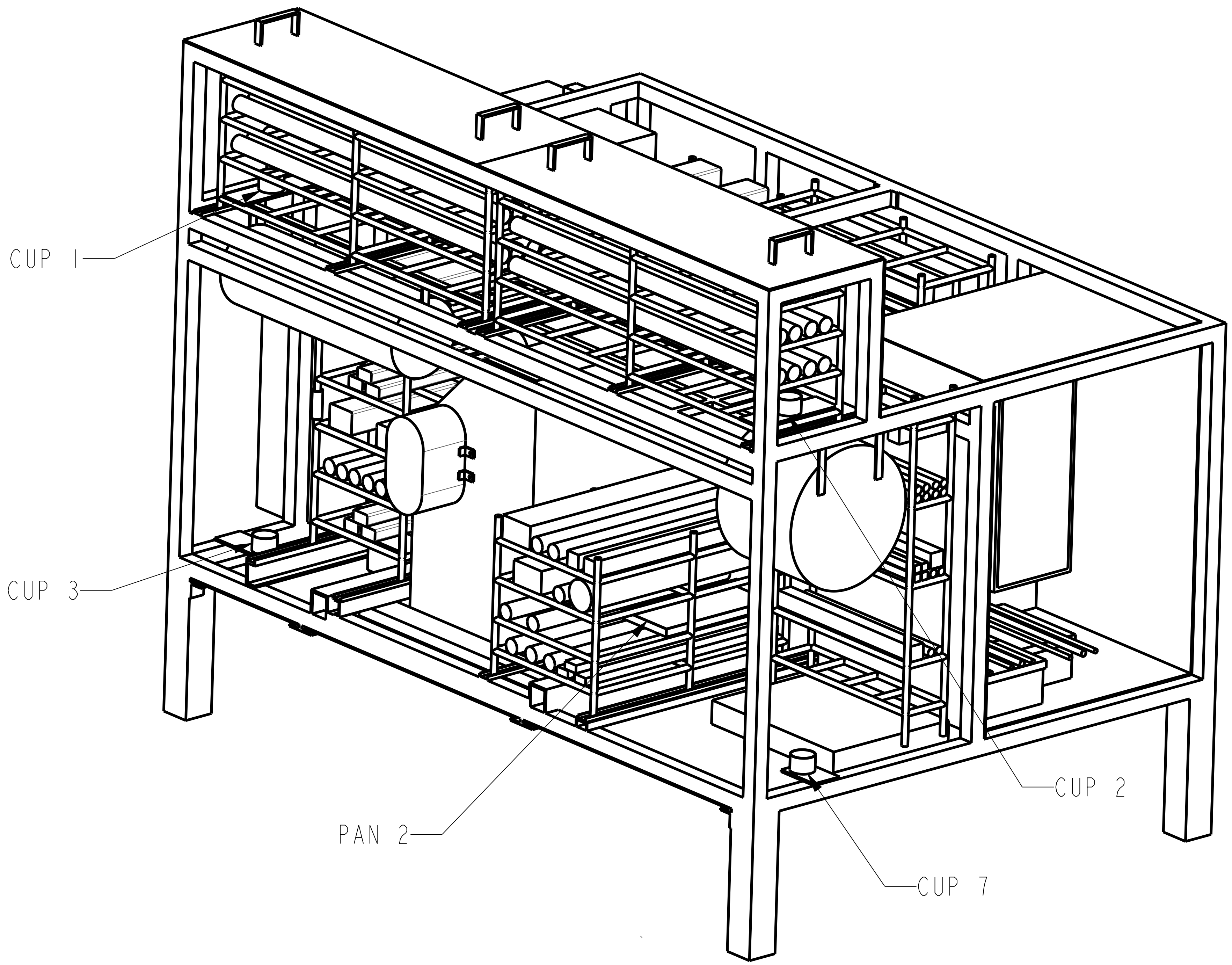
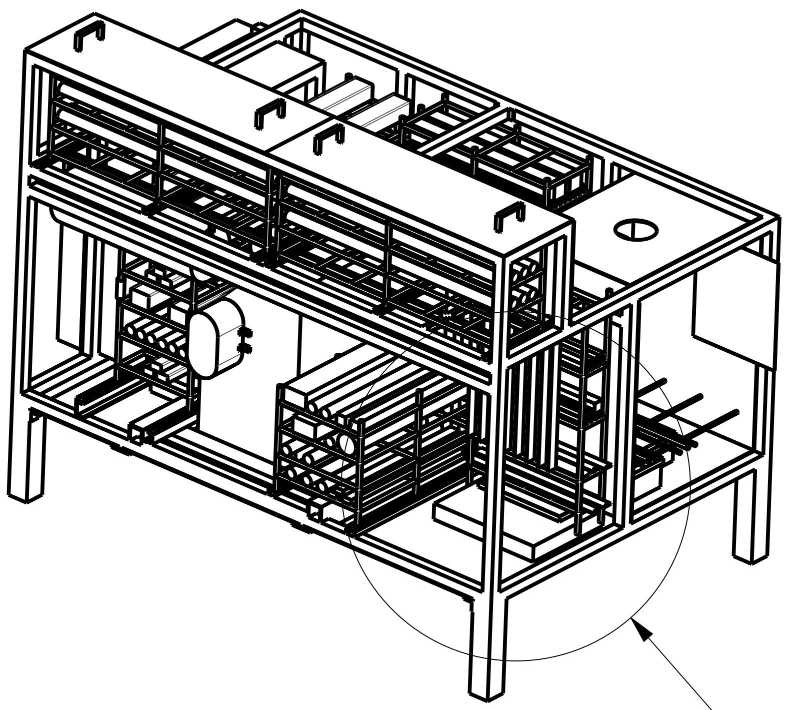
DISTRIBUTED POOL FIRE SCENARIO

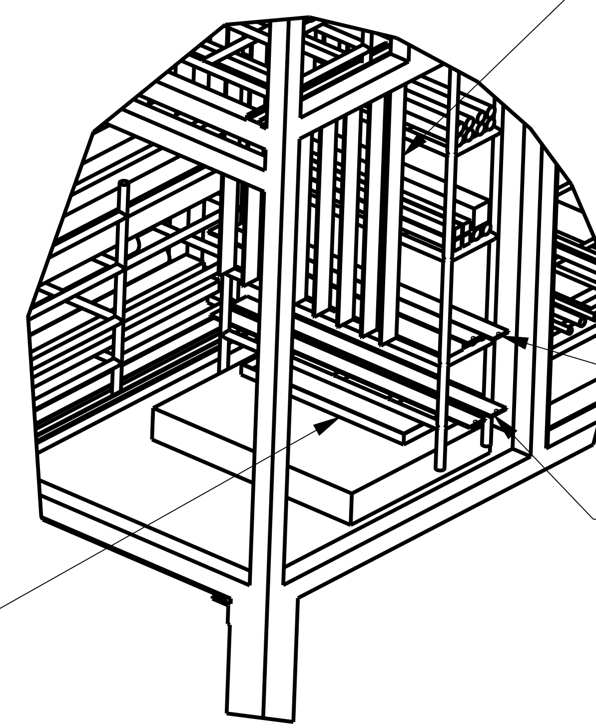
SIZE	CAGE	DRAWING NUMBER	REV
B	26401	17914-1000-FS4	A
SCALE 63:1000	UNIT WEIGHT = LBS	SHEET 1 OF 2	



B	26401	17914-1000-FS4	
SCALE 63:1000			SHEET 2 OF 2

REV	SHT	ZONE	DESCRIPTION	DATE
			REVISIONS	
A			INITIAL RELEASE	08-04-14





A(31:500)

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1			1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	B SCHULTZ
TWO PLACES (X.XX) = ± 0.01	J HUCZEK
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 07-30-14
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: PLASTICS_FIRE
THIRD ANGLE PROJECTION	EXCEPT AS MAY OTHERWISE BE PROVIDED BY CONTRACT THESE DRAWINGS AND SPECIFICATIONS ARE THE PROPERTY OF SOUTHWEST RESEARCH INSTITUTE, ARE ISSUED IN STRICT CONFIDENCE, AND SHALL NOT BE REPRODUCED, OR COPIED, OR USED AS THE BASIS FOR MANUFACTURE OR SALE OF ANY APPARATUS SHOWN THEREON WITHOUT PERMISSION

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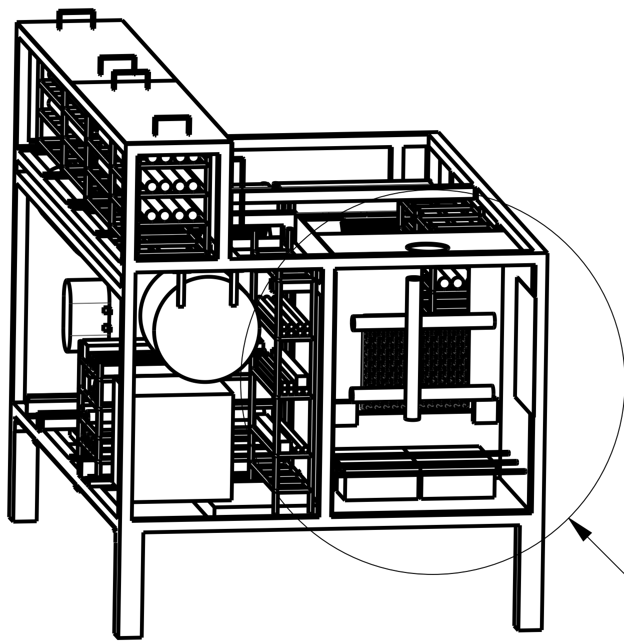
OFFICE of AUTOMOTIVE ENGINEERING
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238

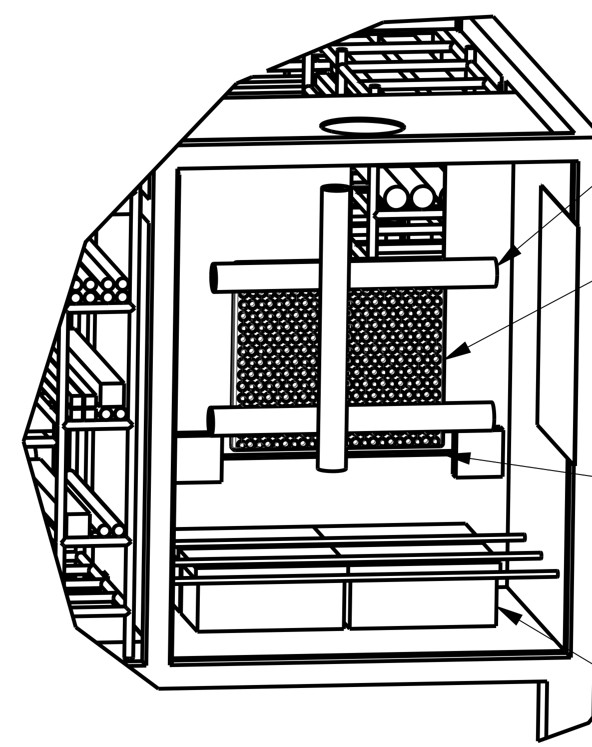
PLASTICS FIRE SCENERIO

SIZE	CAGE	DRAWING NO.	REV
B	26401	17914-1000-FS5	A

SCALE 31:1000 UNIT WEIGHT = LBS SHEET 1 OF 1

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-04-14





A(31:500)

APPROVED
FOR PRODUCTION

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1			1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) = ± 0.1	
TWO PLACES (X.XX) = ± 0.01	J HUCZEK
THREE PLACES (X.XXX) = ± 0.005	B SCHULTZ
FOUR PLACES (X.XXXX) = ± 0.0005	J HUCZEK
ANGLES = ± 0.5 DEGREE	COMPLETION DATE: 07-30-14
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: CABLE_FOAM_FIRE

THIRD ANGLE PROJECTION

SOUTHWEST RESEARCH INSTITUTE
OFFICE of AUTOMOTIVE ENGINEERING
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238

BATTERY COMPARTMENT FIRE SCENERIO

SIZE	CODE	DRAWING NUMBER	REV
B	26401	17914-1000-FS6	A

SCALE 31:1000 | UNIT WEIGHT = LBS | SHEET 1 OF 1

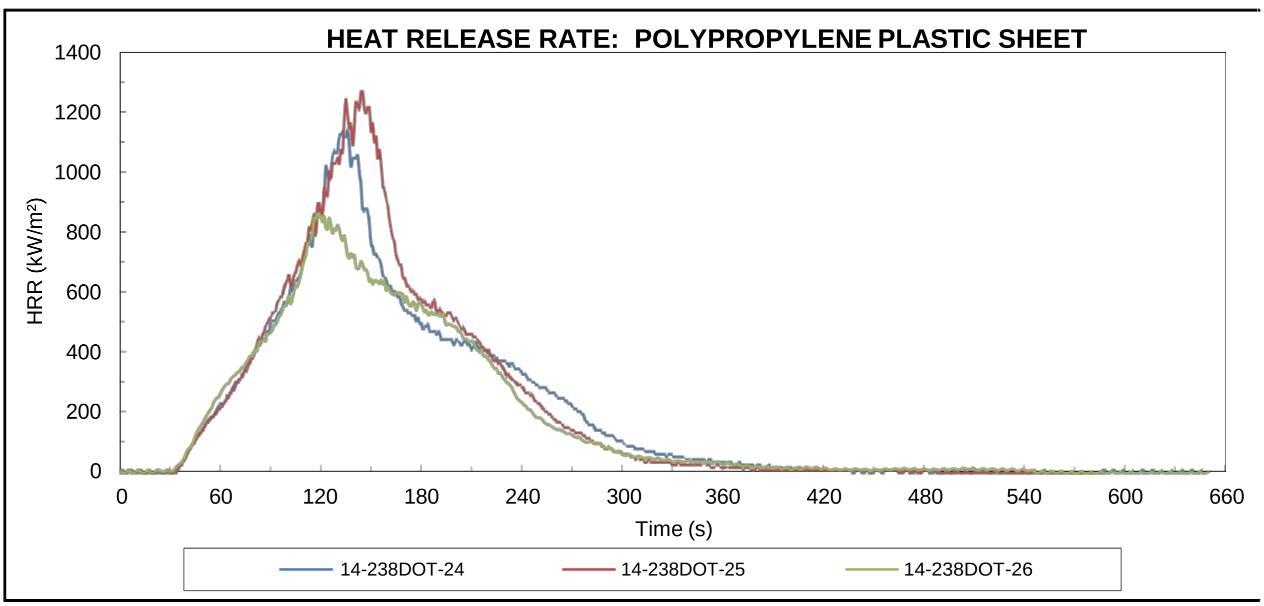
APPENDIX C
BENCH-SCALE MATERIAL FLAMMABILITY DATA FOR ENGINE COMPARTMENT SOURCES
(CONSISTING OF 15 PAGES)

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Polypropylene Plastic Sheet
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²
		Duct Flow:	24 l/s
Orientation:	Horizontal	*Sample Area:*	0.00884 m²
Frame:	Yes	*Distance:*	25 mm
Spark Igniter:	Yes	*Operator:*	Abe Mata

Test ID	Test Date	t_{ig} (s)	Test Duration (s)	C-Factor (SI Units)	HRR_{peak} (kW/m²)	THR (MJ/m²)	HRR_{60s} (kW/m²)	HRR_{180s} (kW/m²)	HRR_{300s} (kW/m²)	$HRR_{30s, max}$ (kW/m²)
14-238DOT-24	08/26/14	33	540	0.0419	1144	124.9	251	536	407	1013
14-238DOT-25	08/26/14	32	481	0.0419	1271	130.7	247	602	430	1141
14-238DOT-26	08/26/14	32	537	0.0419	861	110.8	257	500	361	793
Average		32	519	---	1092	122.2	252	546	399	982

Initial Mass (g)	Mass at Ignition (g)	Final Mass (g)	Mass Loss (g/m^2)	MLR (g/m^2-s)	10-90 MLR (g/m^2-s)	EHC (MJ/kg)	$S_{A,1}$ (m²/m²)	$S_{A,2}$ (m²/m²)	S_A (m²/m²)	SEA (m²/kg)
30.2	30.1	2.8	3095	5.7	12.6	40.4	7	1773	1780	573
30.1	30.1	2.0	3177	6.5	15.9	41.1	0	1770	1771	557
30.1	30.8	4.0	2948	5.5	13.3	37.6	0	1575	1575	534
30.1	30.3	3.0	3073	5.9	13.9	39.7	3	1706	1709	555

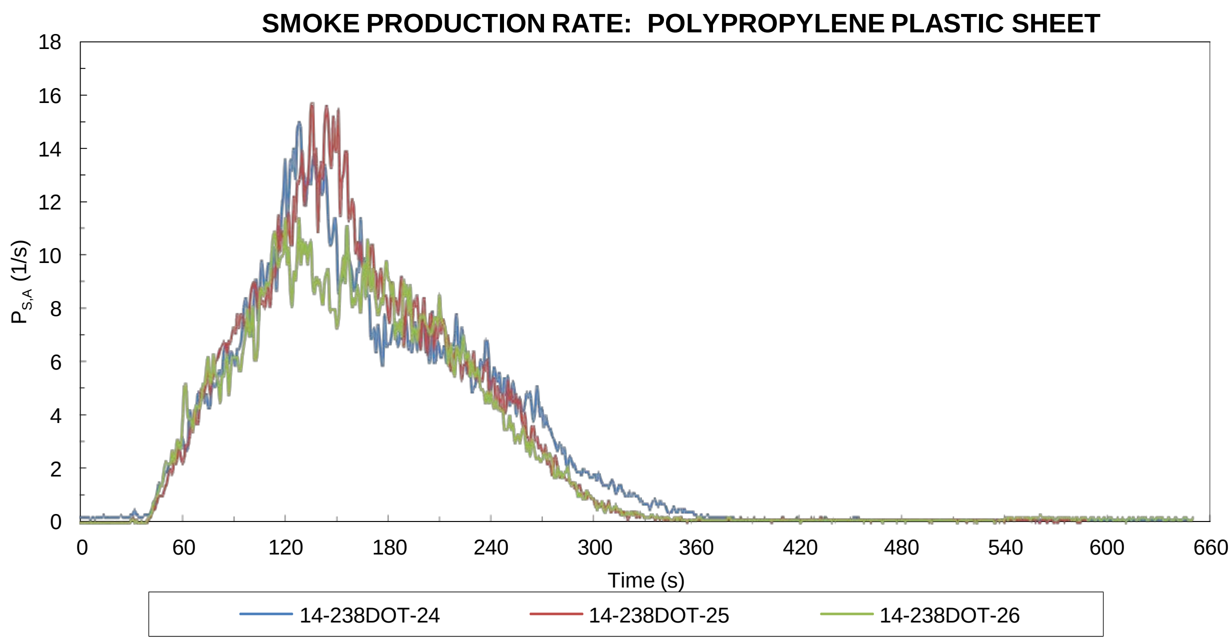


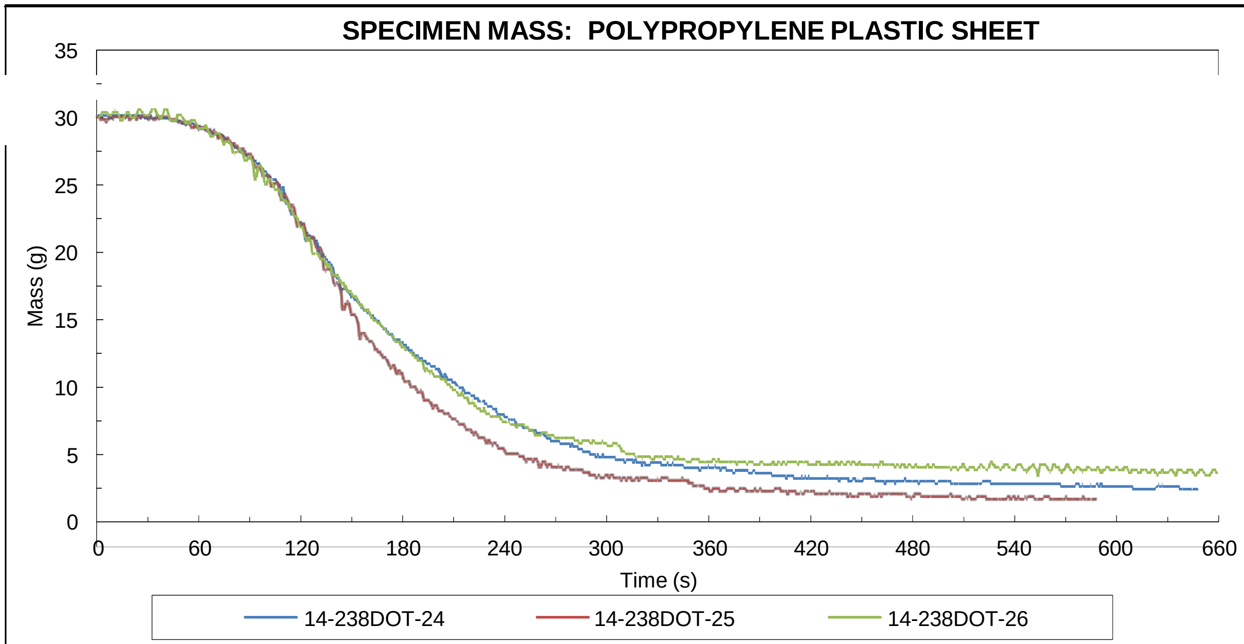
SOUTHWEST RESEARCH INSTITUTE

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Polypropylene Plastic Sheet
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²

(Page 2)





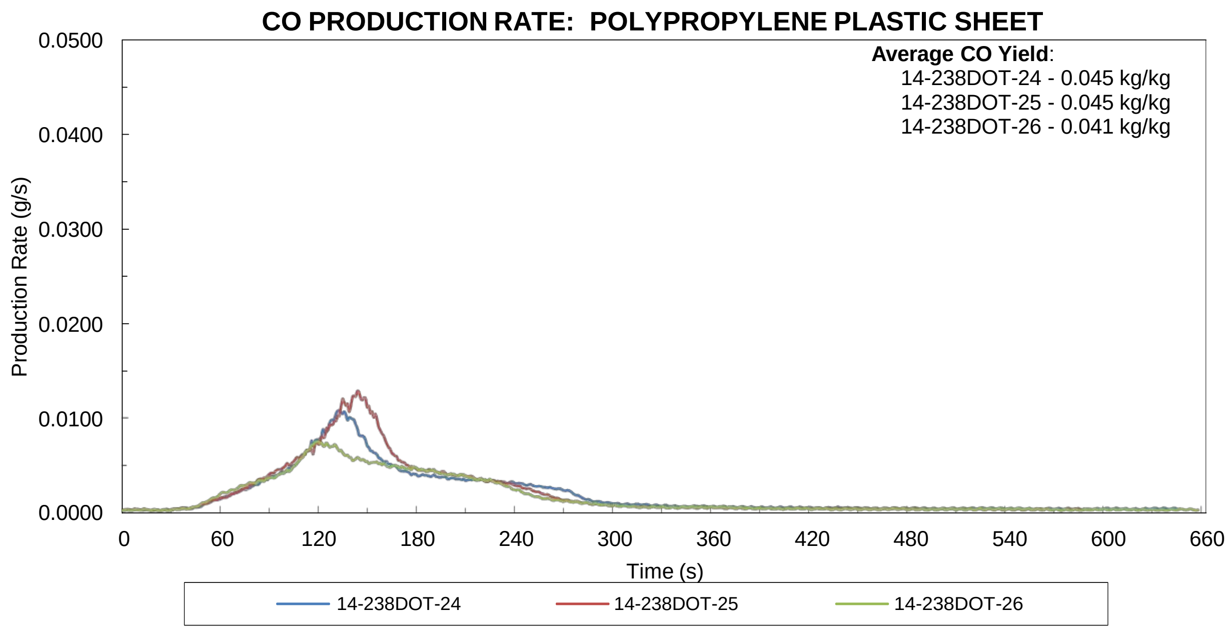
Notes & Observations:

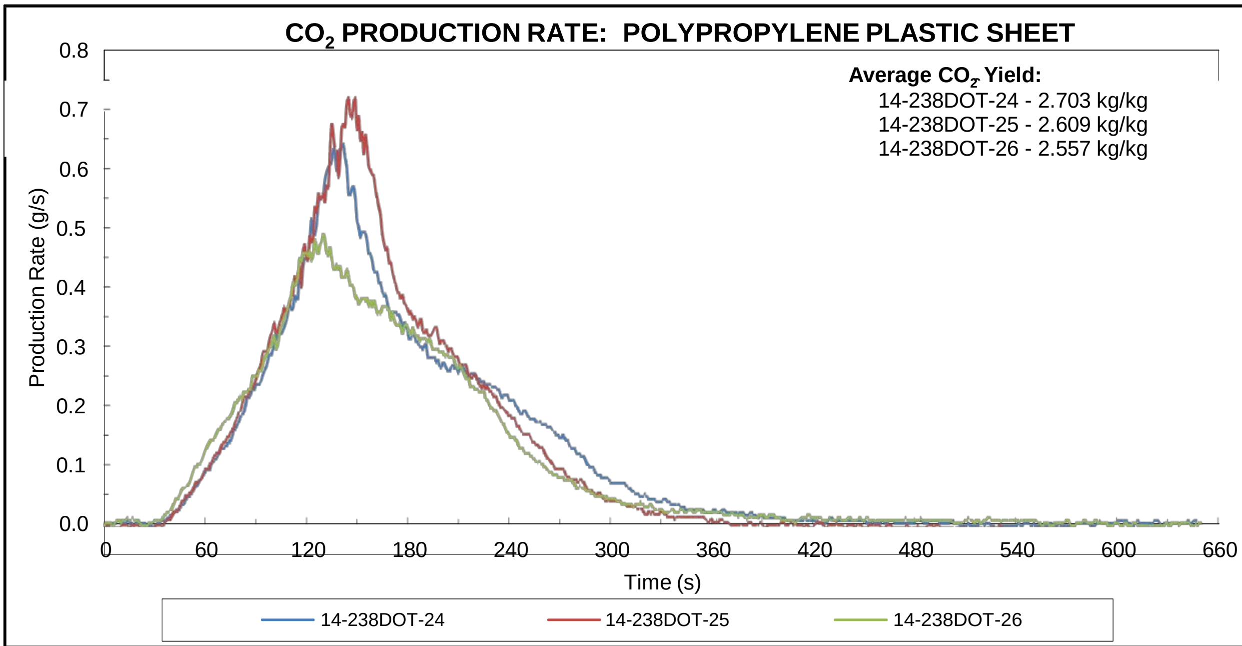
SOUTHWEST RESEARCH INSTITUTE

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Polypropylene Plastic Sheet
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²

(Page 3)





Notes & Observations:

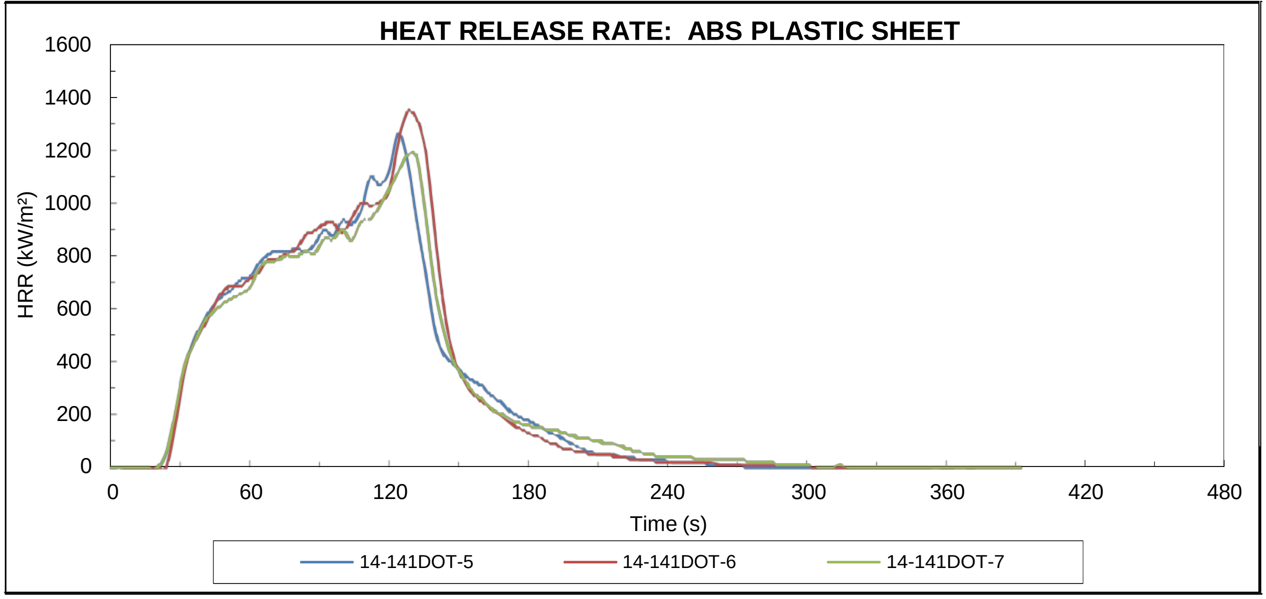
SOUTHWEST RESEARCH INSTITUTE

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	ABS Plastic Sheet
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²
		Duct Flow:	24 l/s
Orientation:	Horizontal	*Sample Area:*	0.00884 m²
Frame:	Yes	*Distance:*	25 mm
Spark Igniter:	Yes	*Operator:*	Abe Mata

Test ID	Test Date	t_{ig} (s)	Test Duration (s)	C-Factor (SI Units)	HRR_{peak} (kW/m²)	THR (MJ/m²)	HRR_{60s} (kW/m²)	HRR_{180s} (kW/m²)	HRR_{300s} (kW/m²)	$HRR_{30s, max}$ (kW/m²)
14-141DOT-5	05/21/14	19	264	0.0449	1267	109.8	580	597		1091
14-141DOT-6	05/21/14	21	286	0.0449	1350	112.7	621	614		1155
14-141DOT-7	05/21/14	20	316	0.0449	1188	110.4	560	586		1060
Average		20	289	---	1268	111.0	587	599	N/A	1102

Initial Mass (g)	Mass at Ignition (g)	Final Mass (g)	Mass Loss (g/m^2)	MLR (g/m^2-s)	10-90 MLR (g/m^2-s)	EHC (MJ/kg)	$S_{A,1}$ (m²/m²)	$S_{A,2}$ (m²/m²)	S_A (m²/m²)	SEA (m²/kg)
32.7	32.7	0.6	3628	13.6	29.0	30.3	1	5587	5588	1540
33.0	33.2	0.9	3633	12.5	29.1	31.0	6	5598	5604	1541
32.8	32.8	0.6	3640	11.5	27.0	30.3	0	5555	5555	1526
32.8	32.9	0.7	3634	12.5	28.4	30.5	2	5580	5582	1536

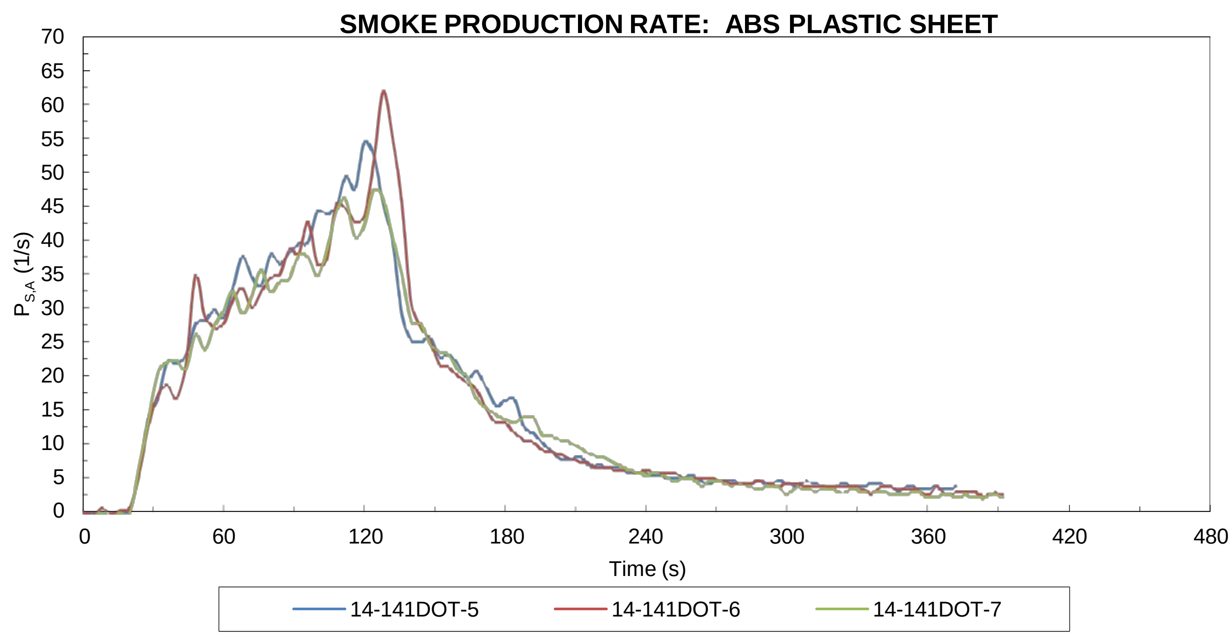


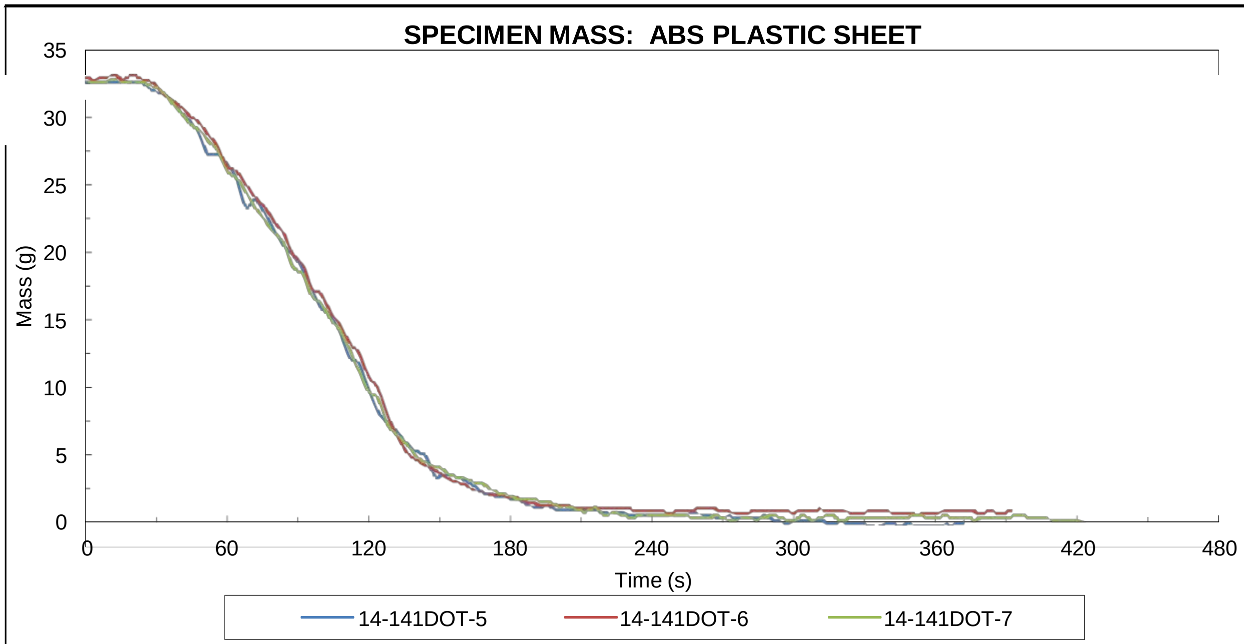
SOUTHWEST RESEARCH INSTITUTE

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	ABS Plastic Sheet
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²

(Page 2)



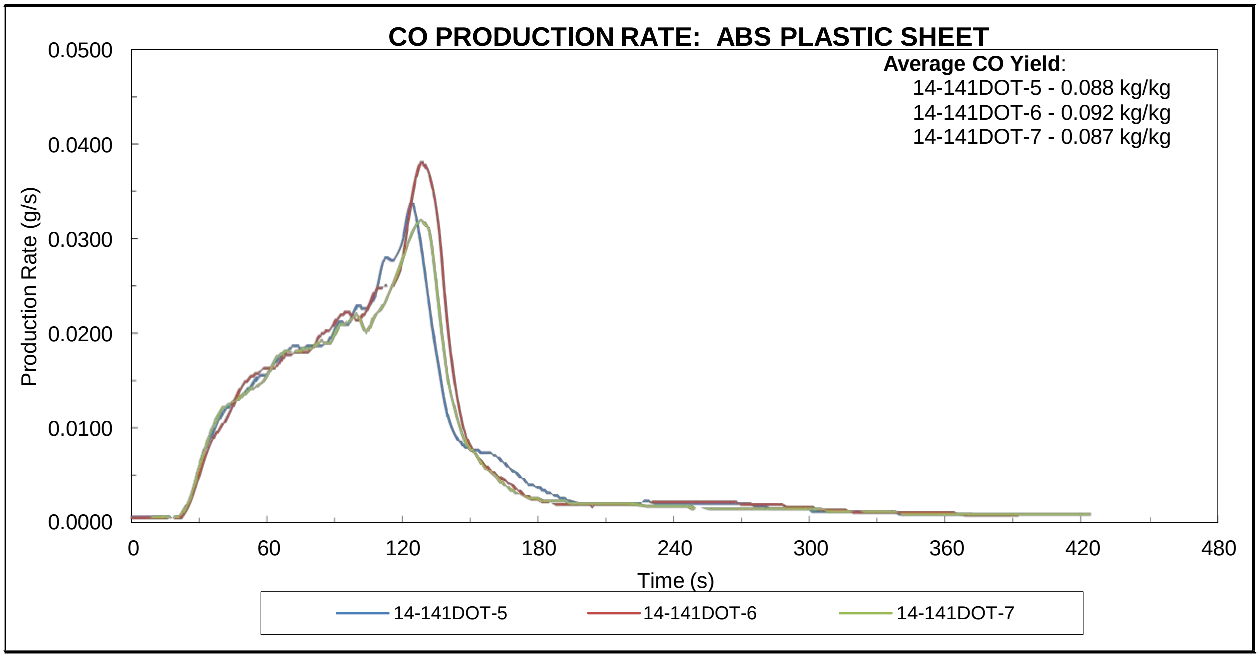


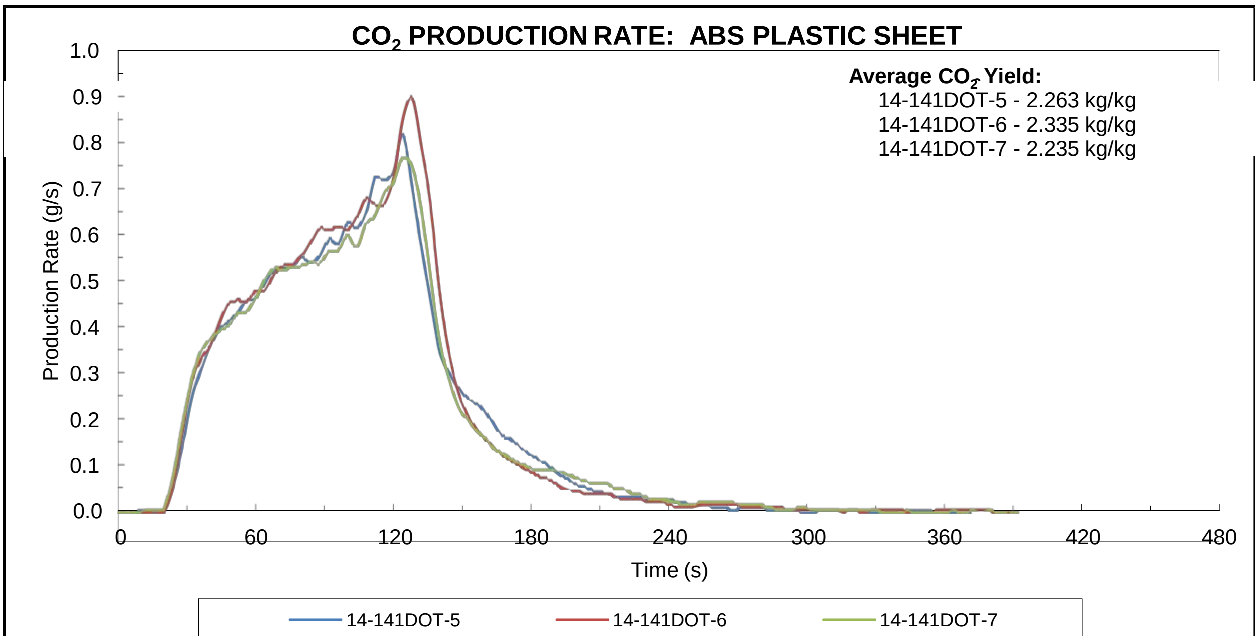
Notes & Observations:

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	ABS Plastic Sheet
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²

(Page 3)





Notes & Observations:

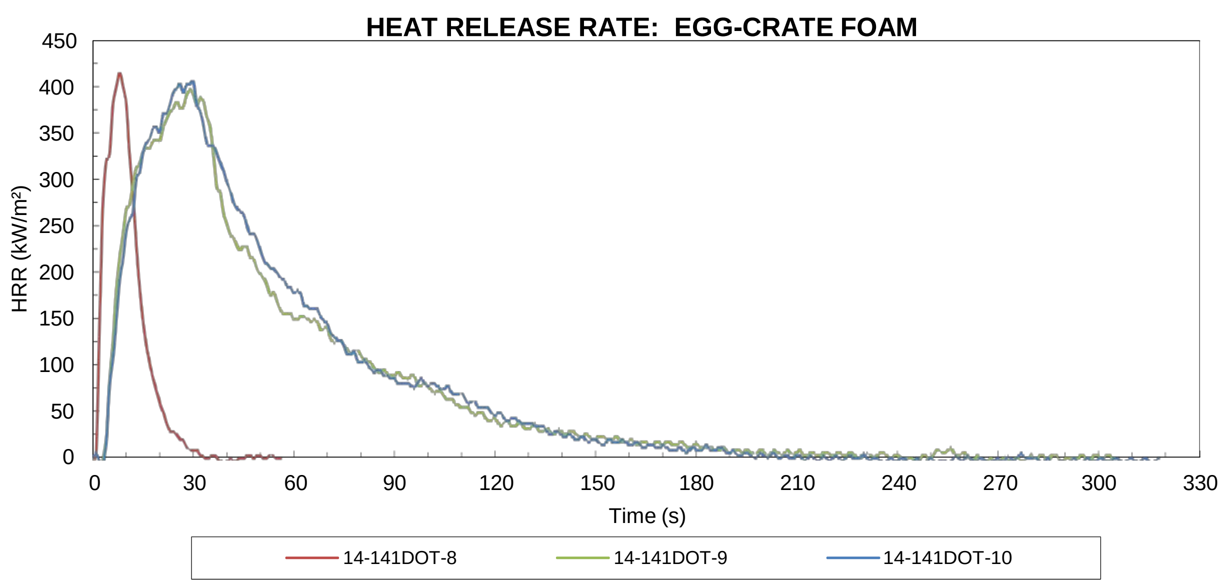
SOUTHWEST RESEARCH INSTITUTE

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA		*Material ID:*	Egg-Crate Foam
SwRI Project No:	01.17914		*Heat Flux:*	50 kW/m²
			Duct Flow:	24 l/s
Orientation:	Horizontal		*Sample Area:*	0.00884 m²
Frame:	Yes		*Distance:*	25 mm
Spark Igniter:	Yes		*Operator:*	Abe Mata

Test ID	Test Date	t_{ig} (s)	Test Duration (s)	C-Factor (SI Units)	HRR_{peak} (kW/m²)	THR (MJ/m²)	HRR_{60s} (kW/m²)	HRR_{180s} (kW/m²)	HRR_{300s} (kW/m²)	$HRR_{30s, max}$ (kW/m²)
14-141DOT-10	05/21/14	2	211	0.0449	406	23.5	272	130		352
14-141DOT-8	05/21/14	2	117	0.0449	416	19.8	286	109		352
14-141DOT-9	05/21/14	2	198	0.0449	397	22.7	260	125		345
Average		2	175	---	407	22.0	273	121	N/A	350

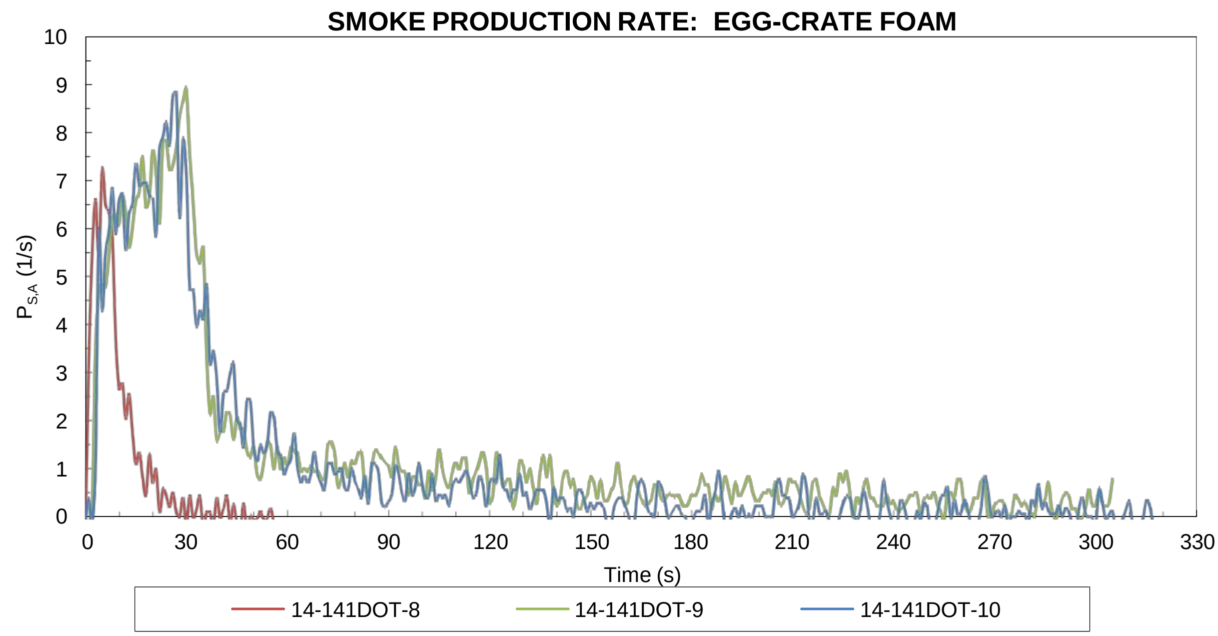
Initial Mass (g)	Mass at Ignition (g)	Final Mass (g)	Mass Loss (g/m²)	MLR (g/m²-s)	10-90 MLR (g/m²-s)	EHC (MJ/kg)	$S_{A,1}$ (m²/m²)	$S_{A,2}$ (m²/m²)	S_A (m²/m²)	SEA (m²/kg)
8.0	8.0	0.8	817	3.7	7.9	28.7	0	334	335	409
6.6	6.0	0.0	747	3.5	11.5	26.5	24	277	301	371
7.8	7.6	0.0	882	4.5	9.4	25.7	0	365	365	414
7.5	7.2	0.3	815	3.9	9.6	27.0	8	326	334	398

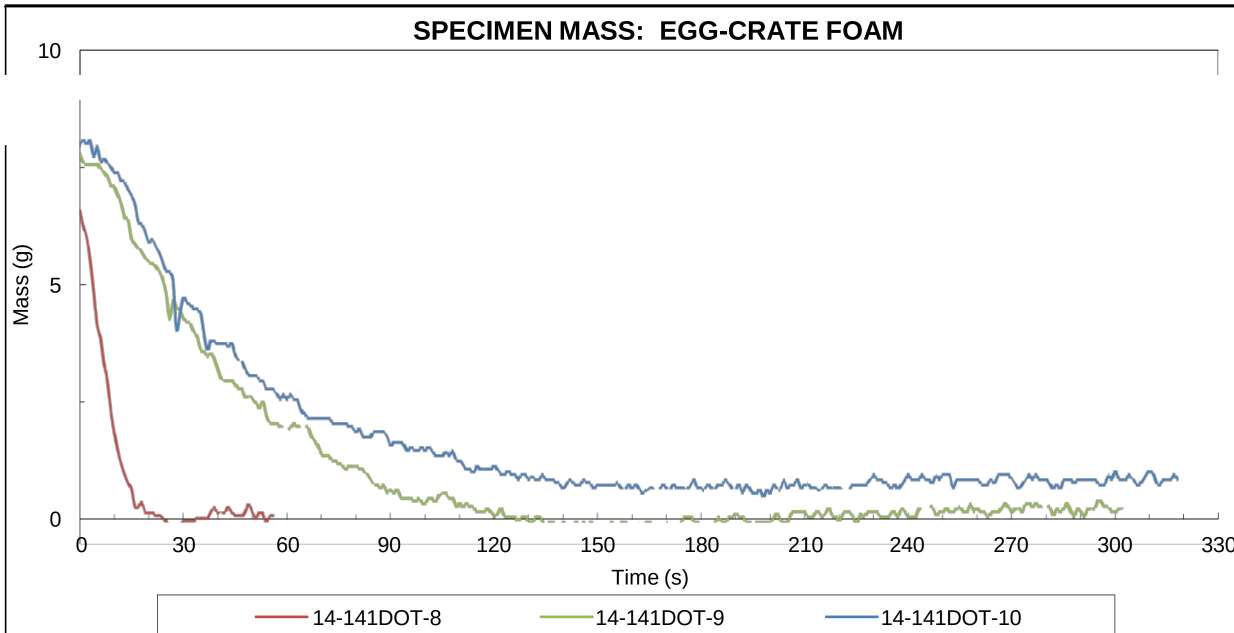


SOUTHWEST RESEARCH INSTITUTE
CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Egg-Crate Foam
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²

(Page 2)



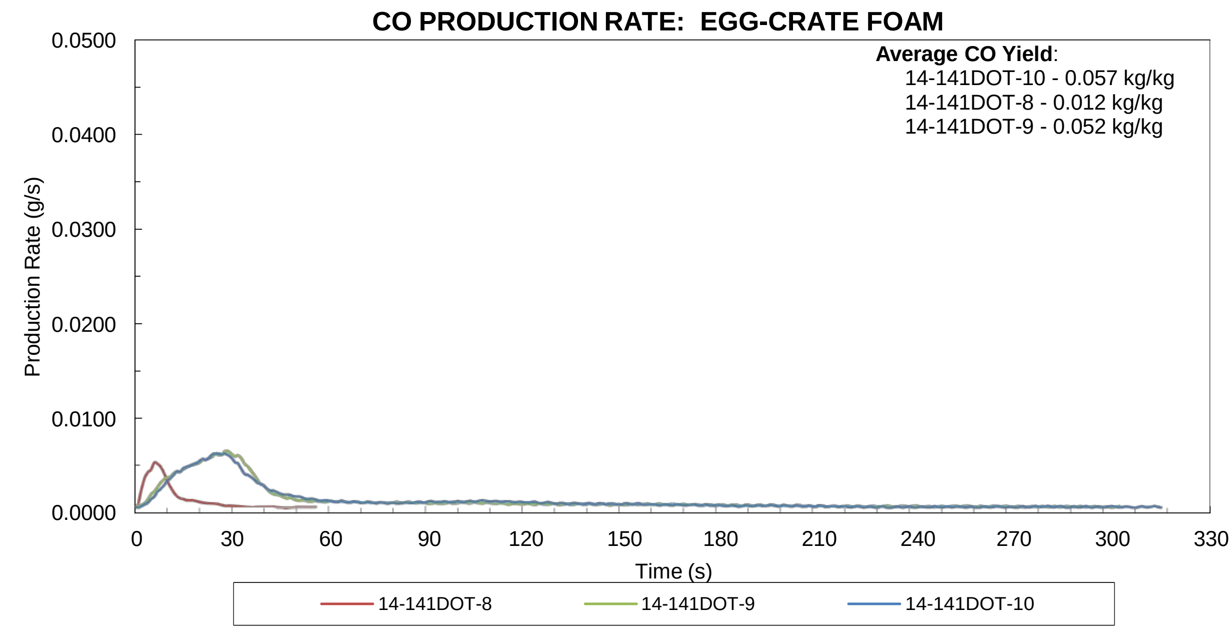


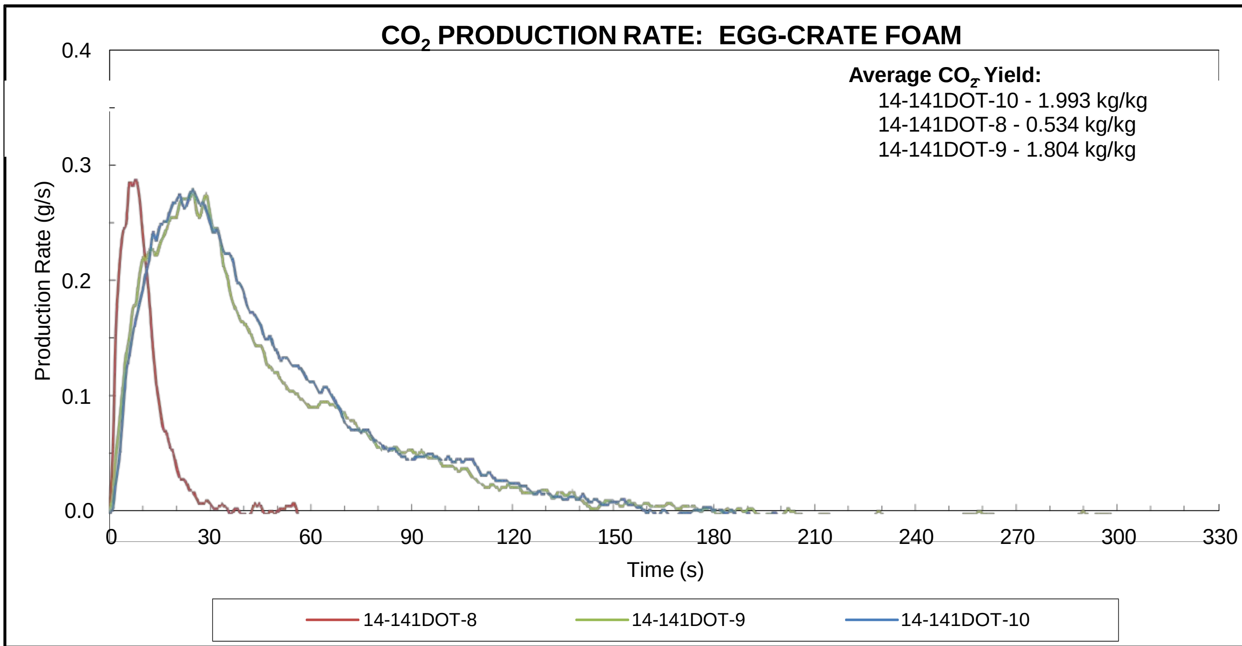
Notes & Observations:

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Egg-Crate Foam
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²

(Page 3)





Notes & Observations:

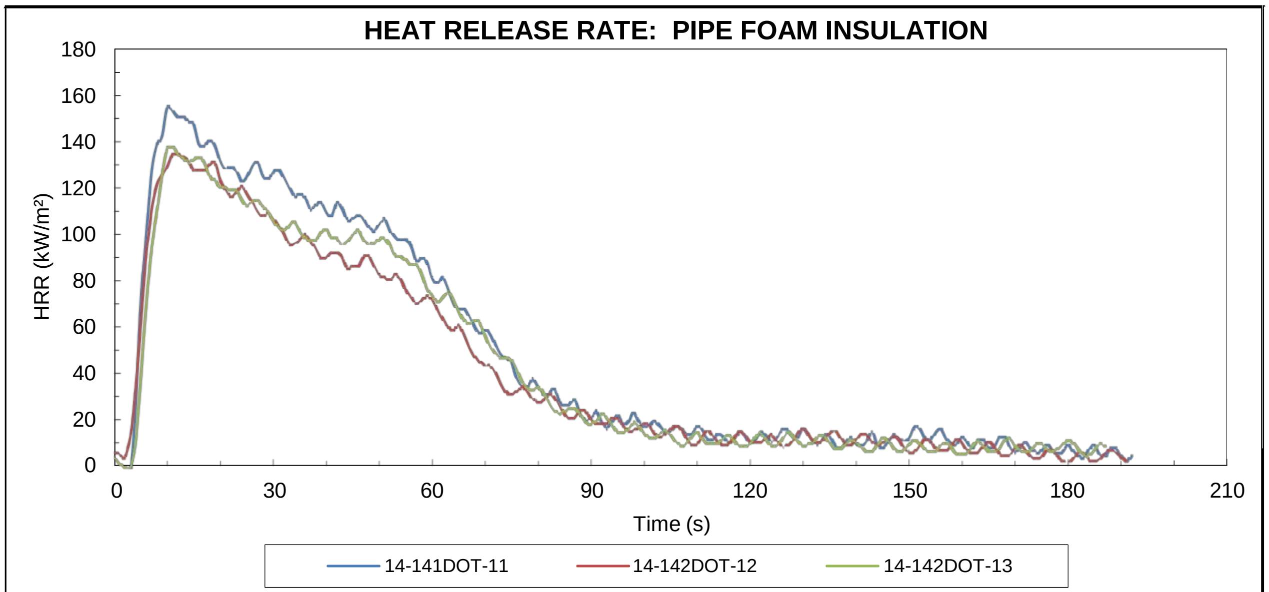
S O U T H W E S T   R E S E A R C H   I N S T I T U T E

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Pipe Foam Insulation
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²
		Duct Flow:	24 l/s
Orientation:	Horizontal	*Sample Area:*	0.00884 m²
Frame:	Yes	*Distance:*	25 mm
Spark Igniter:	Yes	*Operator:*	Abe Mata

Test ID	Test Date	t_{ig} (s)	Test Duration (s)	C-Factor (SI Units)	HRR_{peak} (kW/m²)	THR (MJ/m²)	HRR_{60s} (kW/m²)	HRR_{180s} (kW/m²)	HRR_{300s} (kW/m²)	$HRR_{30s, max}$ (kW/m²)
14-141DOT-11	05/21/14	3	85	0.0449	155	7.9	115			133
14-142DOT-12	05/22/14	2	92	0.0415	135	6.9	98			118
14-142DOT-13	05/22/14	2	80	0.0415	139	7.0	100			118
Average		2	86	---	143	7.3	104	N/A	N/A	123

Initial Mass (g)	Mass at Ignition (g)	Final Mass (g)	Mass Loss (g/m^2)	MLR (g/m^2-s)	10-90 MLR (g/m^2-s)	EHC (MJ/kg)	$S_{A,1}$ (m²/m²)	$S_{A,2}$ (m²/m²)	S_A (m²/m²)	SEA (m²/kg)
6.8	6.6	1.7	554	9.9	615.4	10.3	22	304	325	548
6.3	6.3	1.6	535	4.3	7.8	13.0	0	301	301	562
6.6	6.6	1.7	554	4.6	7.6	15.0	0	336	336	605
6.6	6.5	1.7	548	6.3	210.3	12.8	7	313	321	572

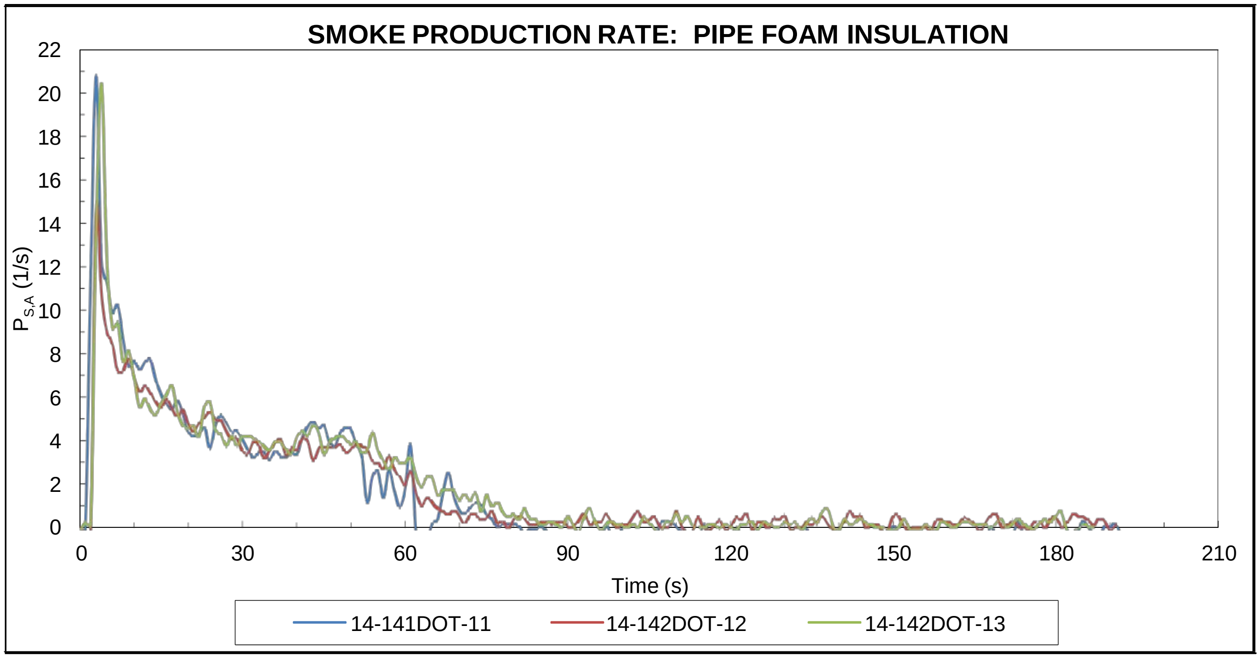


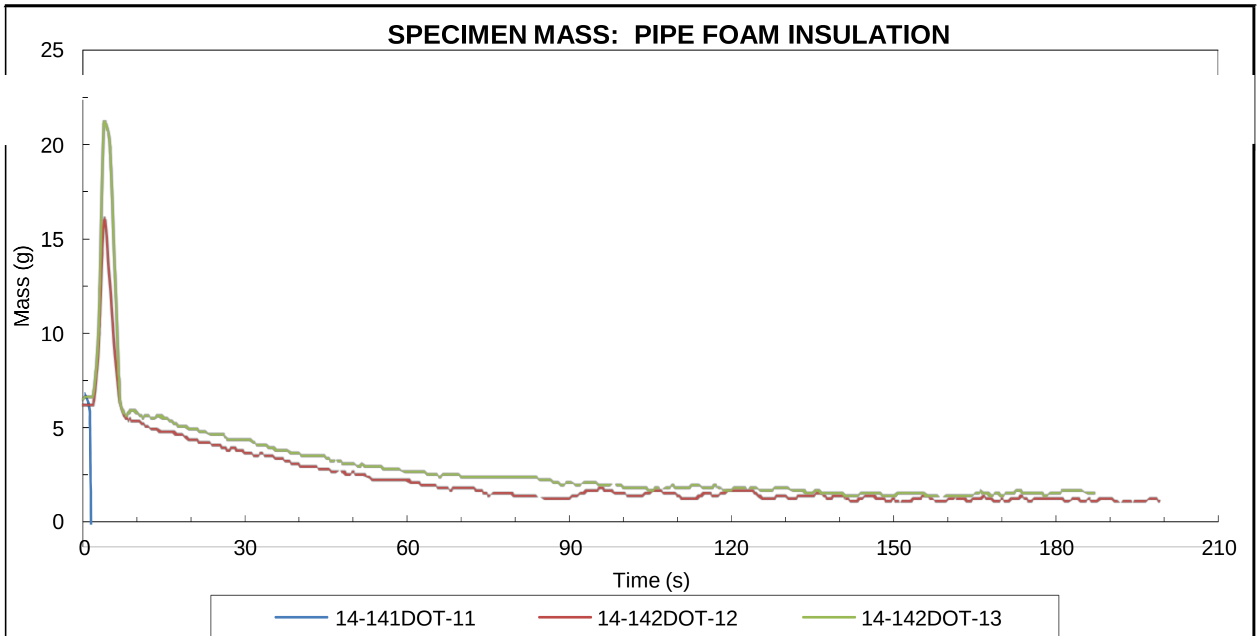
SOUTHWEST RESEARCH INSTITUTE

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Pipe Foam Insulation
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²

(Page 2)





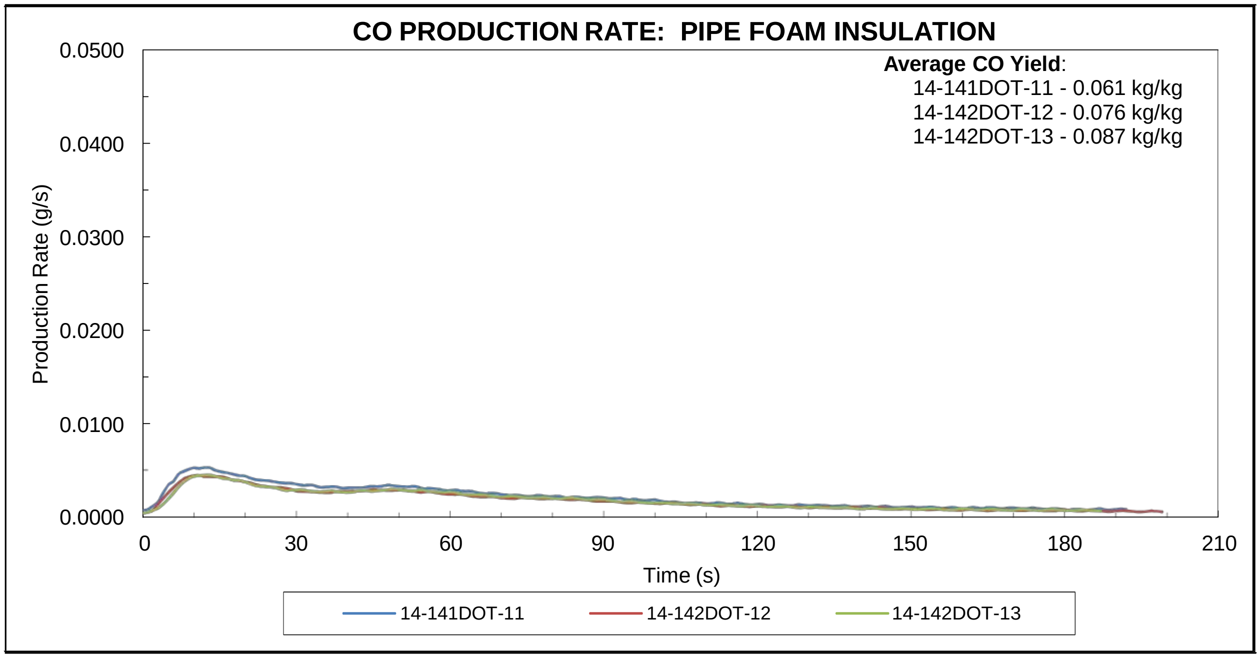
Notes & Observations:

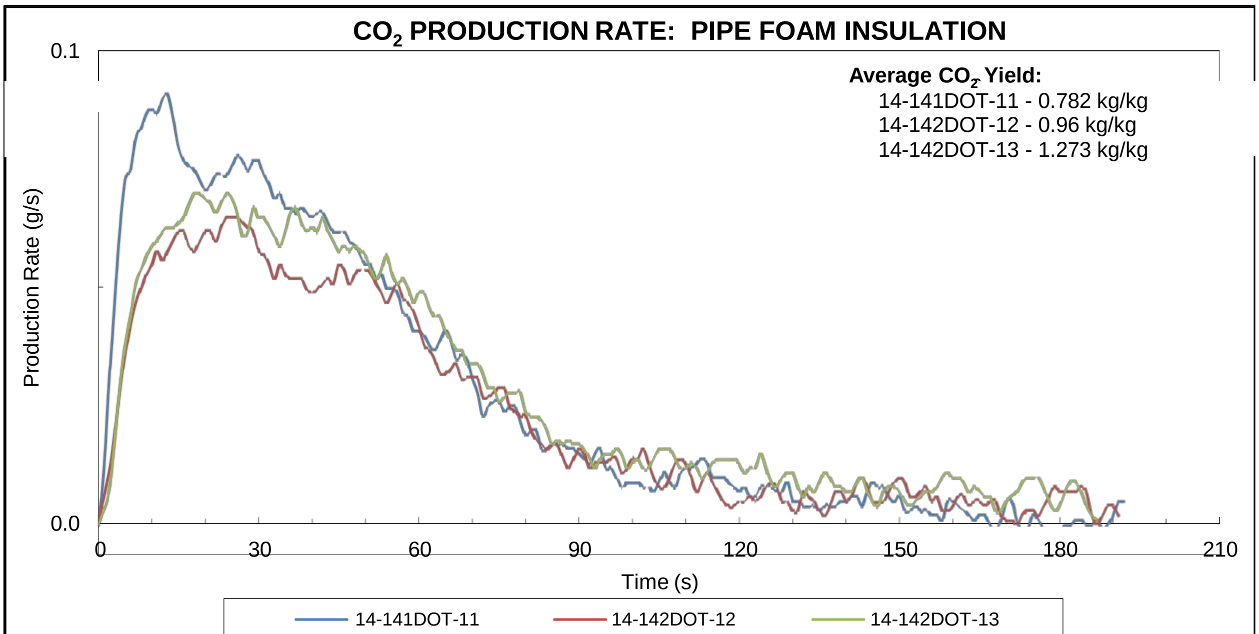
SOUTHWEST RESEARCH INSTITUTE

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Pipe Foam Insulation
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²

(Page 3)





Notes & Observations:

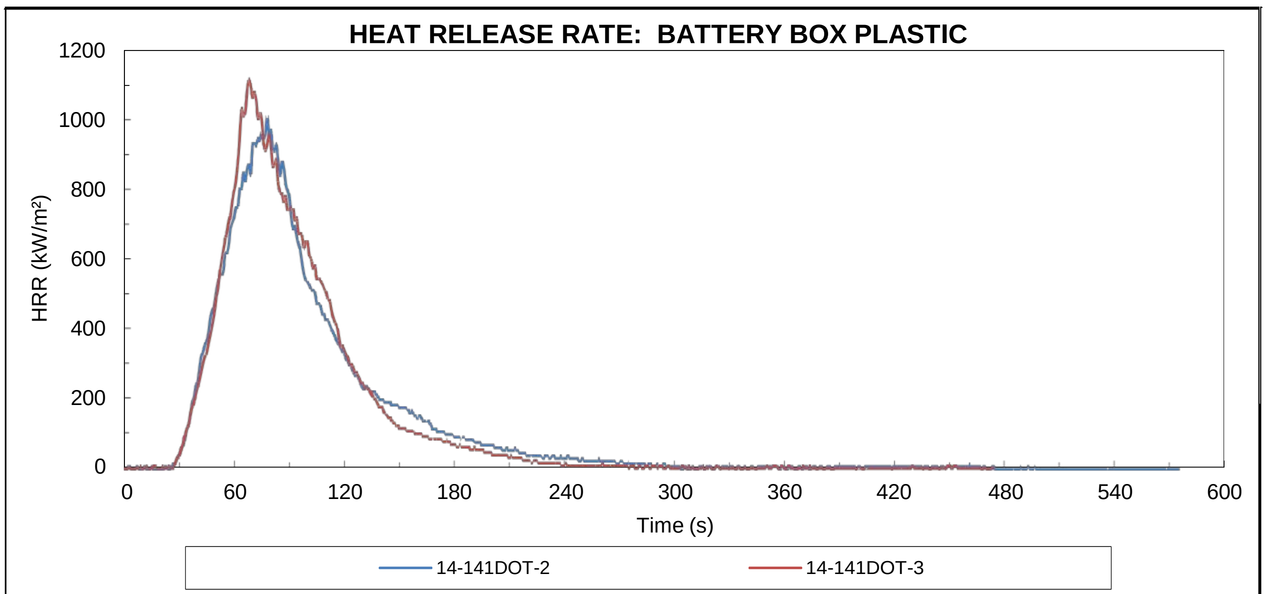
SOUTHWEST RESEARCH INSTITUTE

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Battery Box Plastic
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²
		Duct Flow:	24 l/s
Orientation:	Horizontal	*Sample Area:*	0.00884 m²
Frame:	Yes	*Distance:*	25 mm
Spark Igniter:	Yes	*Operator:*	Abe Mata

Test ID	Test Date	t_{ig} (s)	Test Duration (s)	C-Factor (SI Units)	HRR_{peak} (kW/m²)	THR (MJ/m²)	HRR_{60s} (kW/m²)	HRR_{180s} (kW/m²)	HRR_{300s} (kW/m²)	$HRR_{30s, max}$ (kW/m²)
14-141DOT-2	05/21/14	26	468	0.0449	1016	68.9	576	366	228	885
14-141DOT-3	05/21/14	26	367	0.0449	1117	68.3	606	371	227	937
Average		26	418	---	1067	68.6	591	368	227	911

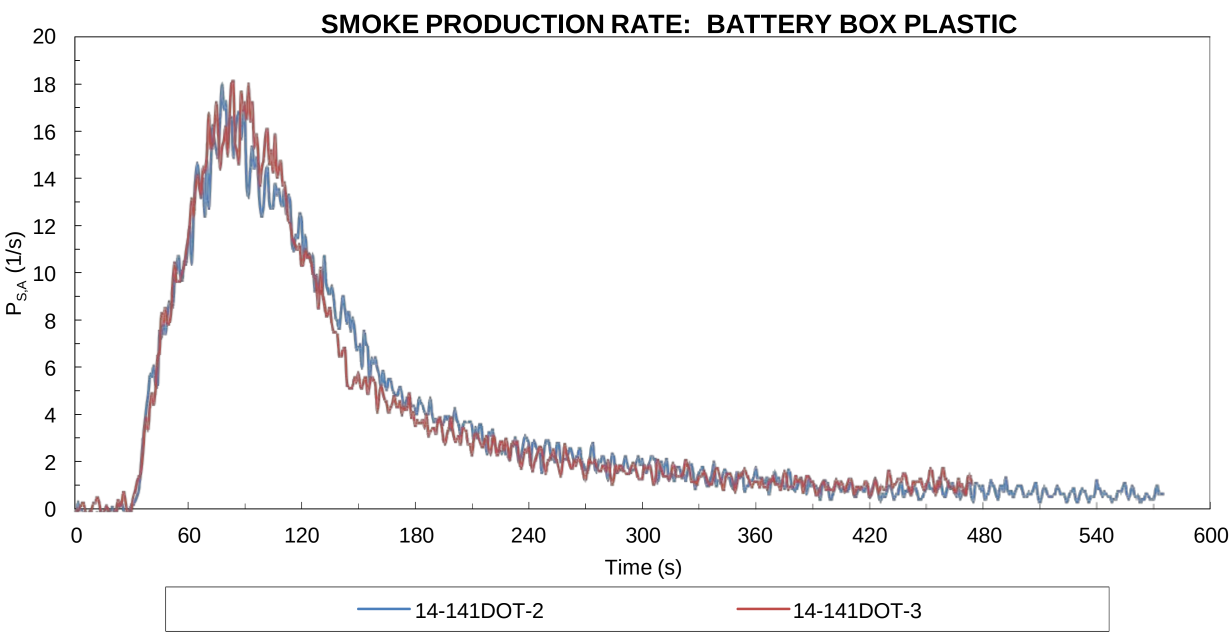
Initial Mass (g)	Mass at Ignition (g)	Final Mass (g)	Mass Loss (g/m²)	MLR (g/m²-s)	10-90 MLR (g/m²-s)	EHC (MJ/kg)	$S_{A,1}$ (m²/m²)	$S_{A,2}$ (m²/m²)	S_A (m²/m²)	SEA (m²/kg)
16.2	16.4	1.8	1634	3.5	12.2	42.2	1	2003	2005	1226
16.0	15.9	1.7	1623	4.4	14.6	42.1	4	1850	1853	1140
16.1	16.1	1.7	1628	4.0	13.4	42.1	2	1926	1929	1183

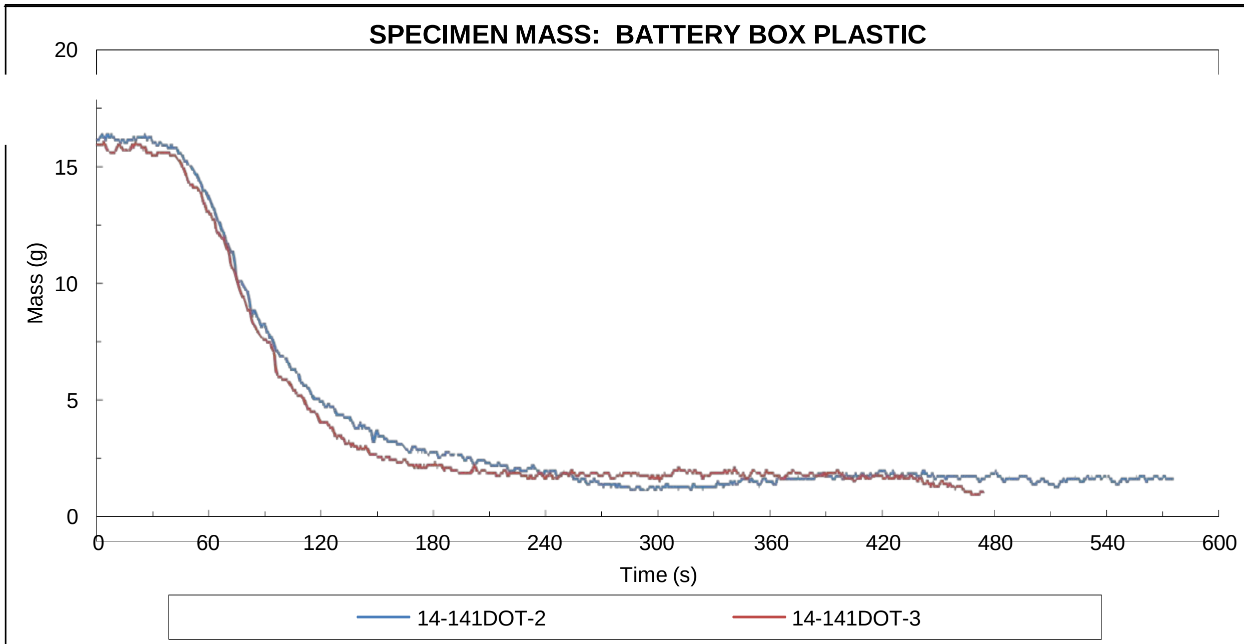


CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Battery Box Plastic
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²

(Page 2)





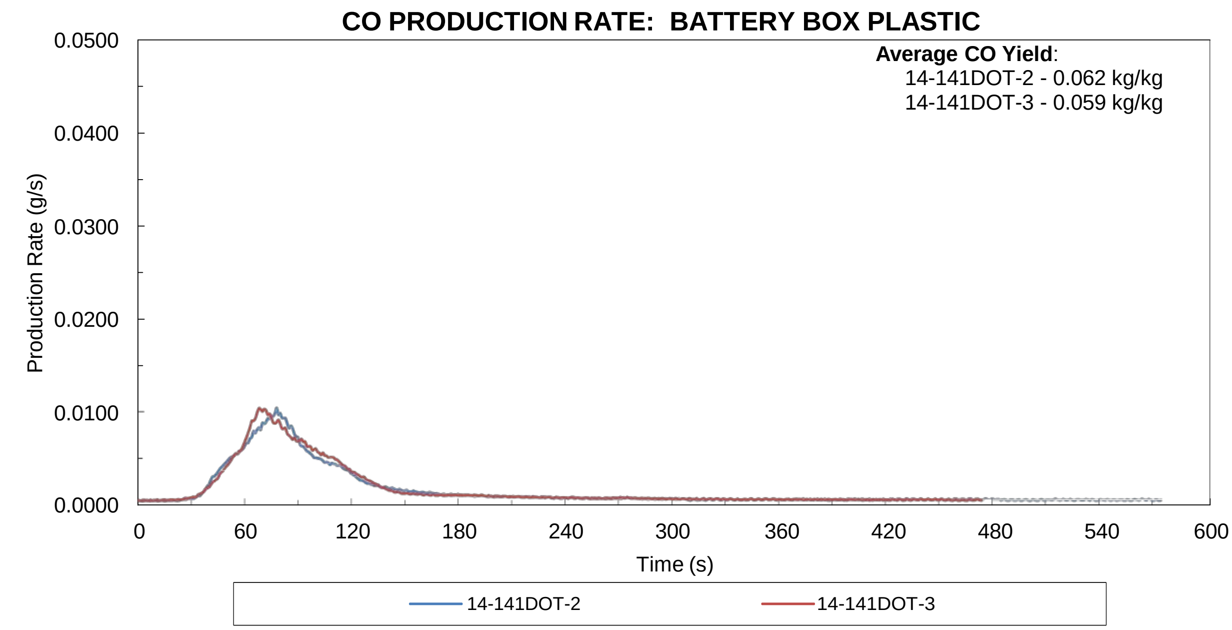
Notes & Observations:

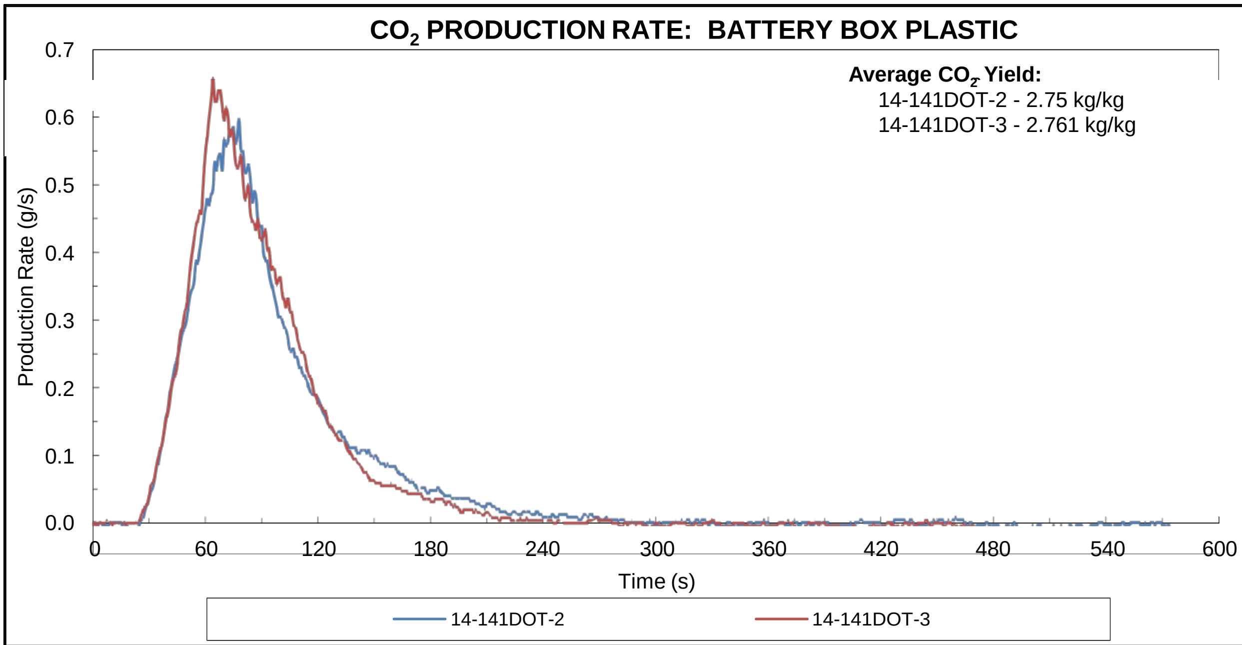
SOUTHWEST RESEARCH INSTITUTE

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Battery Box Plastic
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²

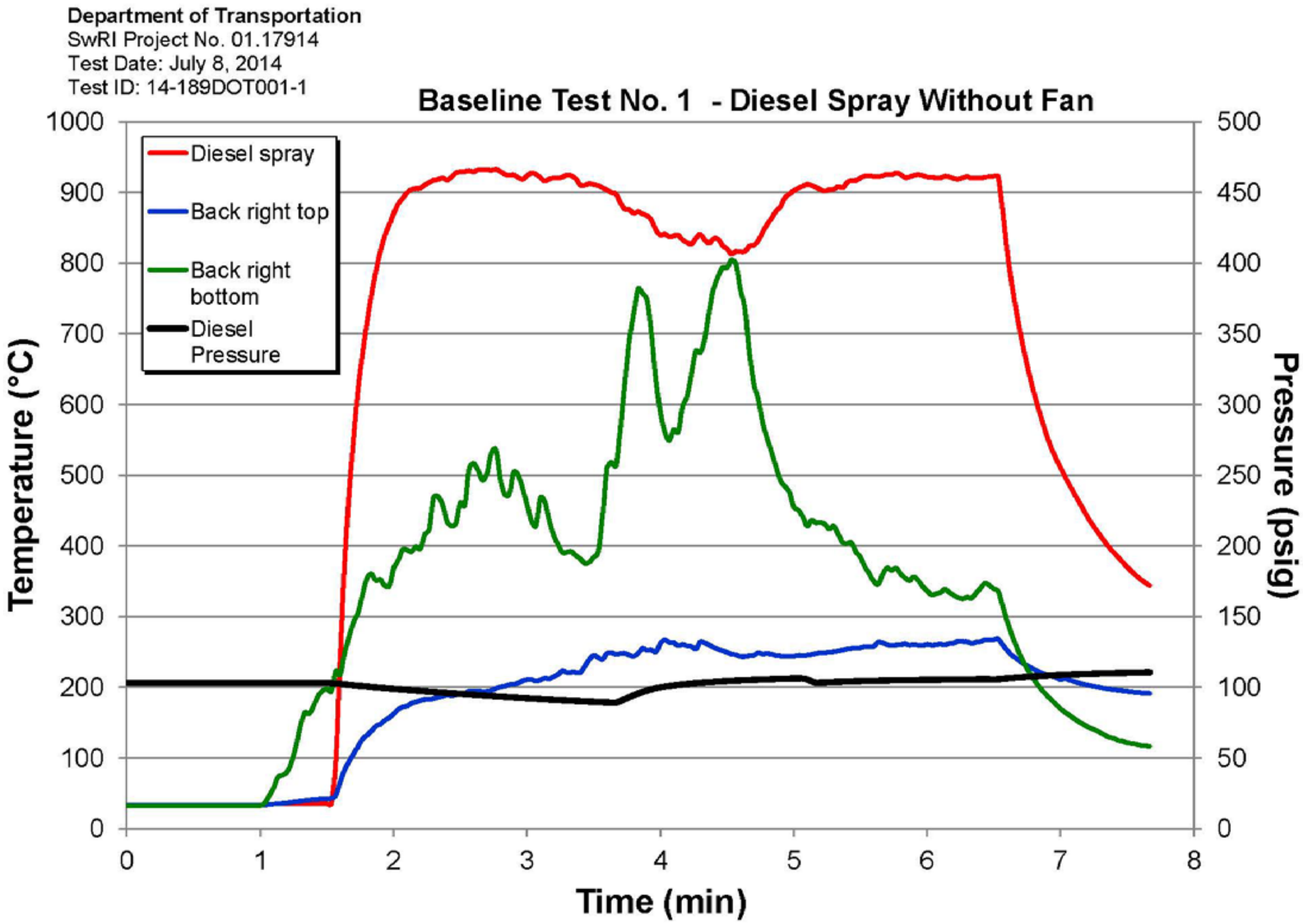
(Page 3)





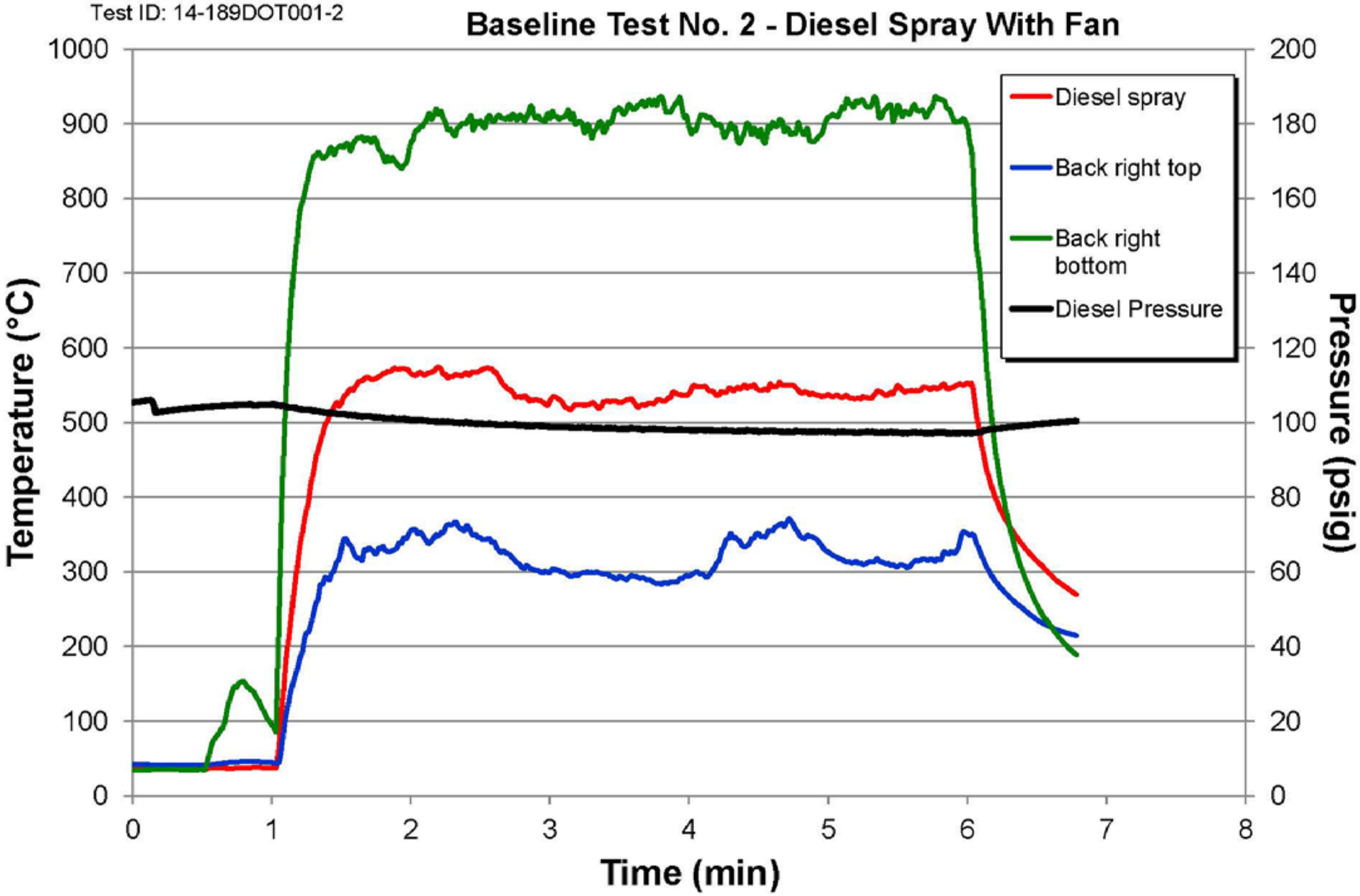
Notes & Observations:

APPENDIX D
ENGINE COMPARTMENT FIRE SCENARIO BASELINE TEMPERATURE DATA
(CONSISTING OF 10 PAGES)

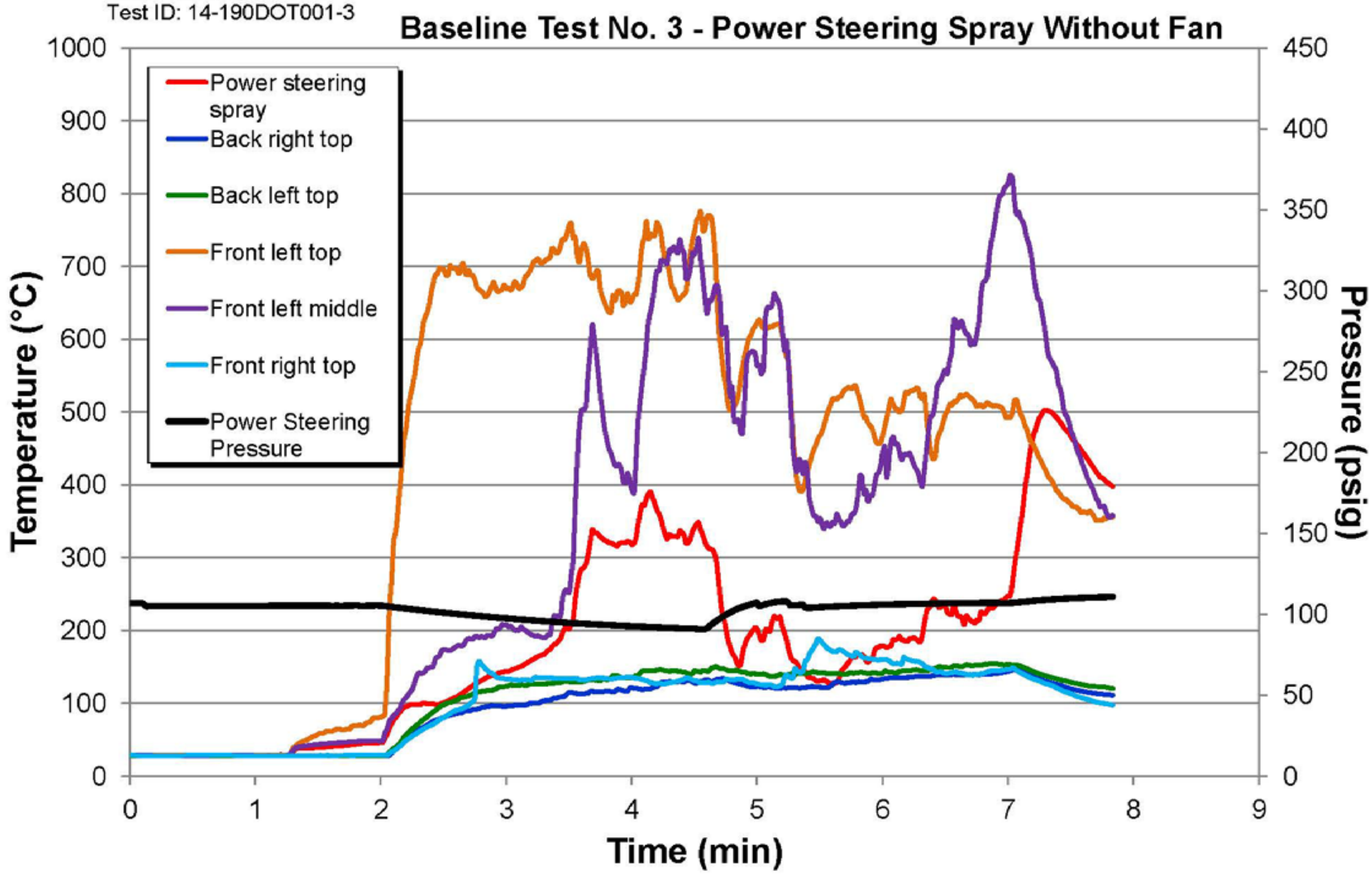


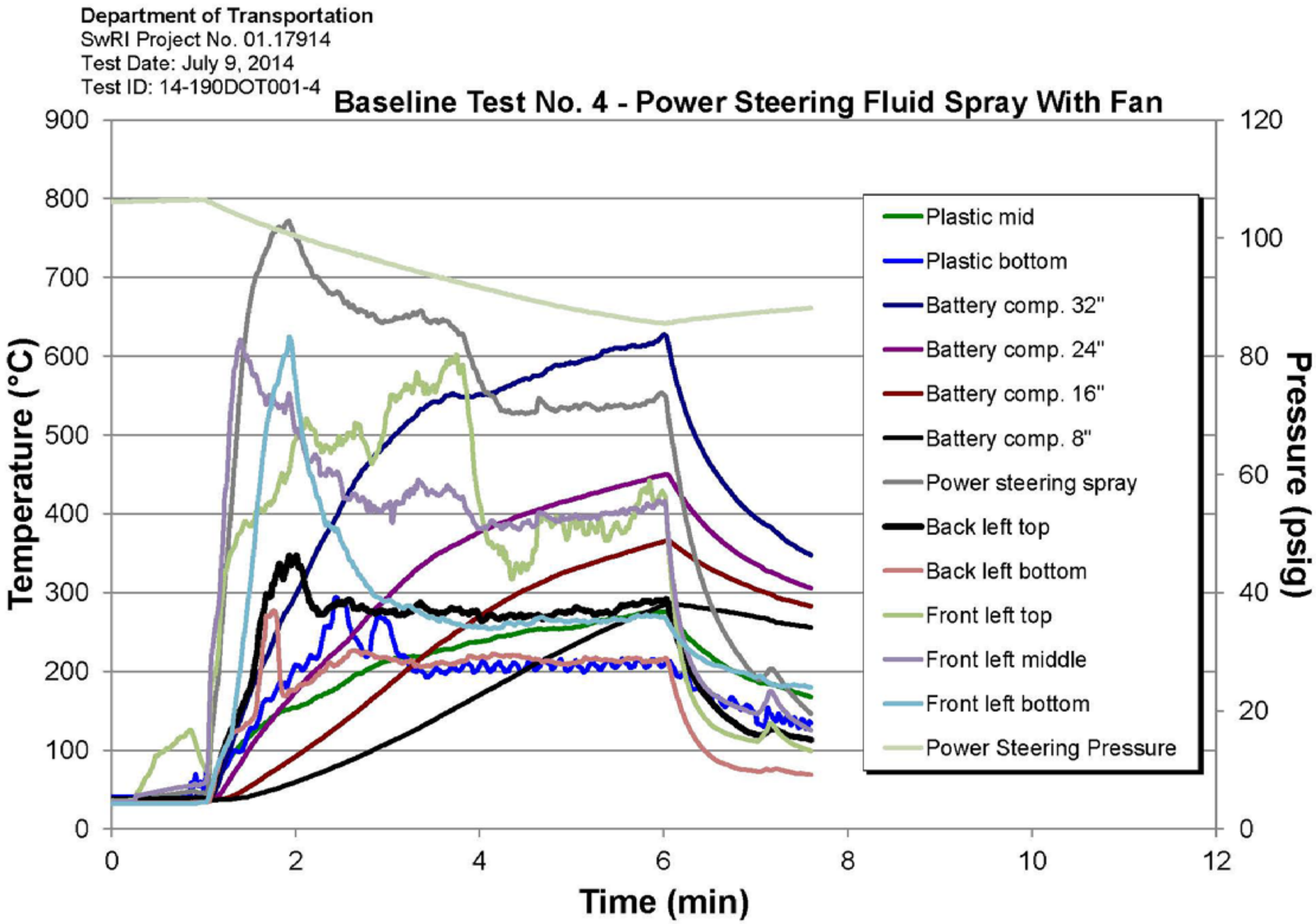
Department of Transportation
SwRI Project No. 01.17914
Test Date: July 8, 2014
Test ID: 14-189DOT001-1
Baseline Test No. 1 - Diesel Spray Without Fan
Diesel spray
Back right top
Back right bottom
Diesel Pressure
Temperature (°C)
Pressure (psig)
Time (min)
0
100
200
300
400
500
600
700
800
900
1000
0
50
100
150
200
250
300
350
400
450
500
0
1
2
3
4
5
6
7
8

Department of Transporation
SwRI Project No. 01.17914
Test Date: July 8, 2014
Test ID: 14-189DOT001-2

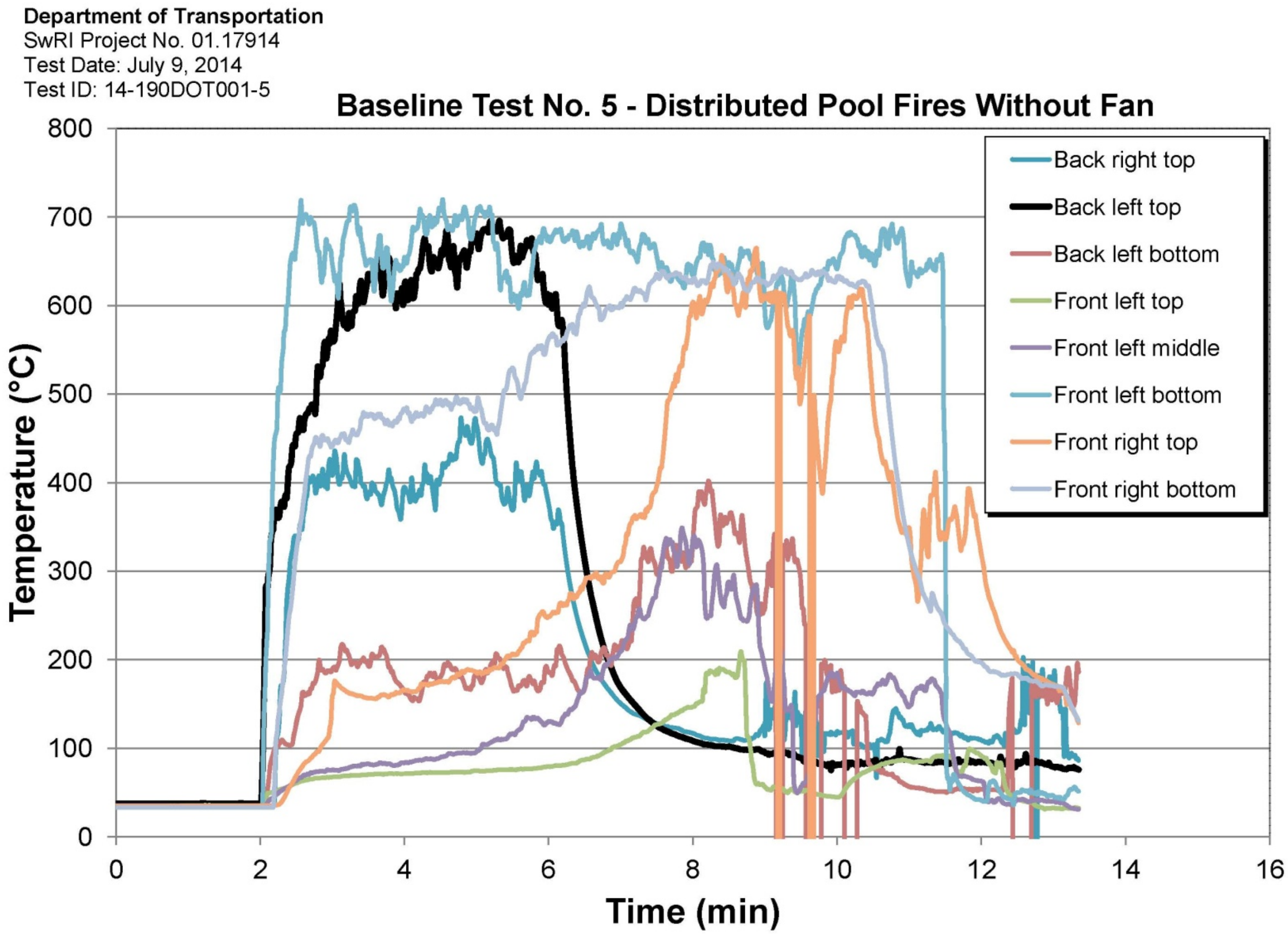


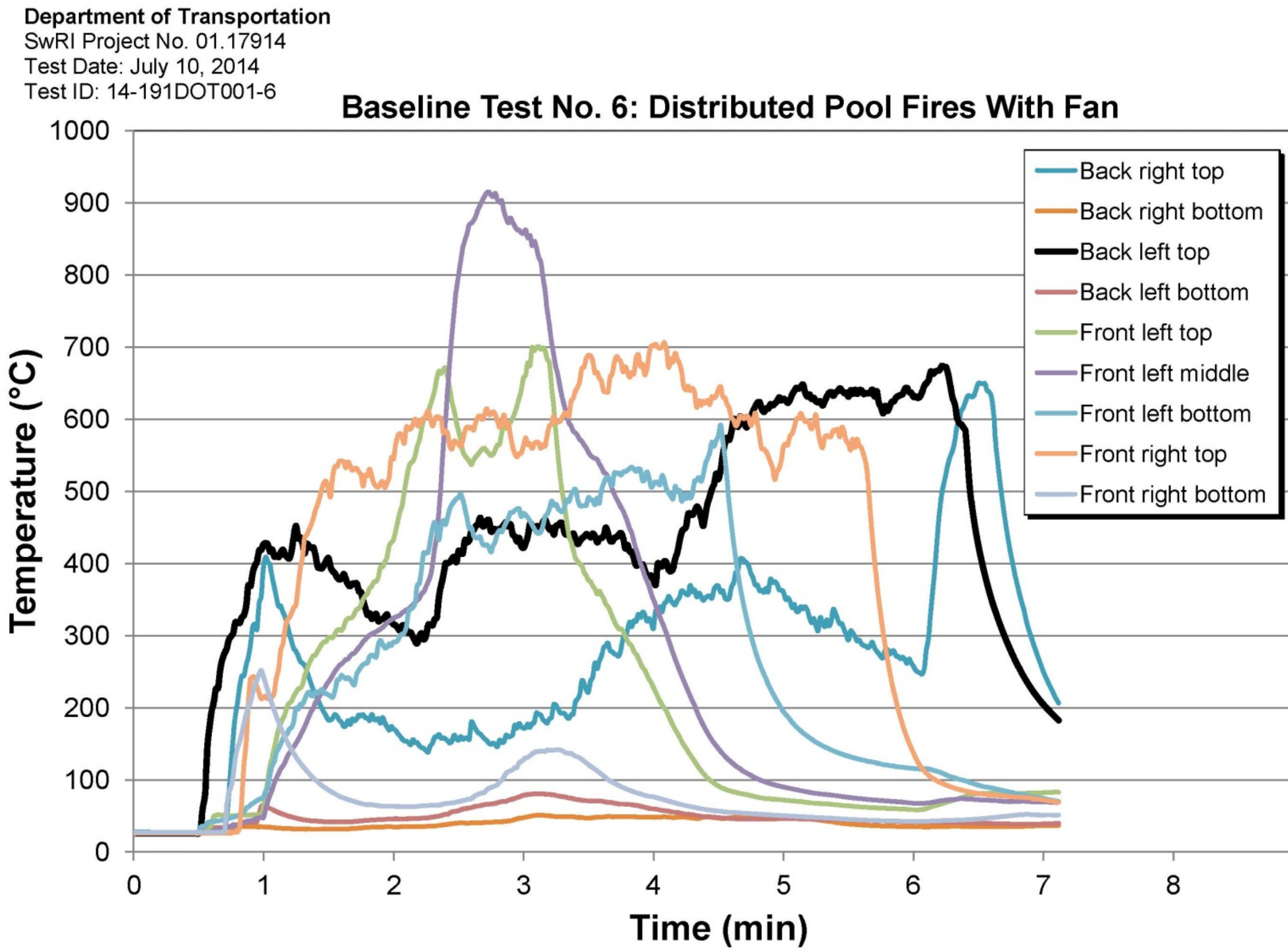
Department of Transportation
SwRI Project No. 01.17914
Test Date: July 9, 2014
Test ID: 14-190DOT001-3



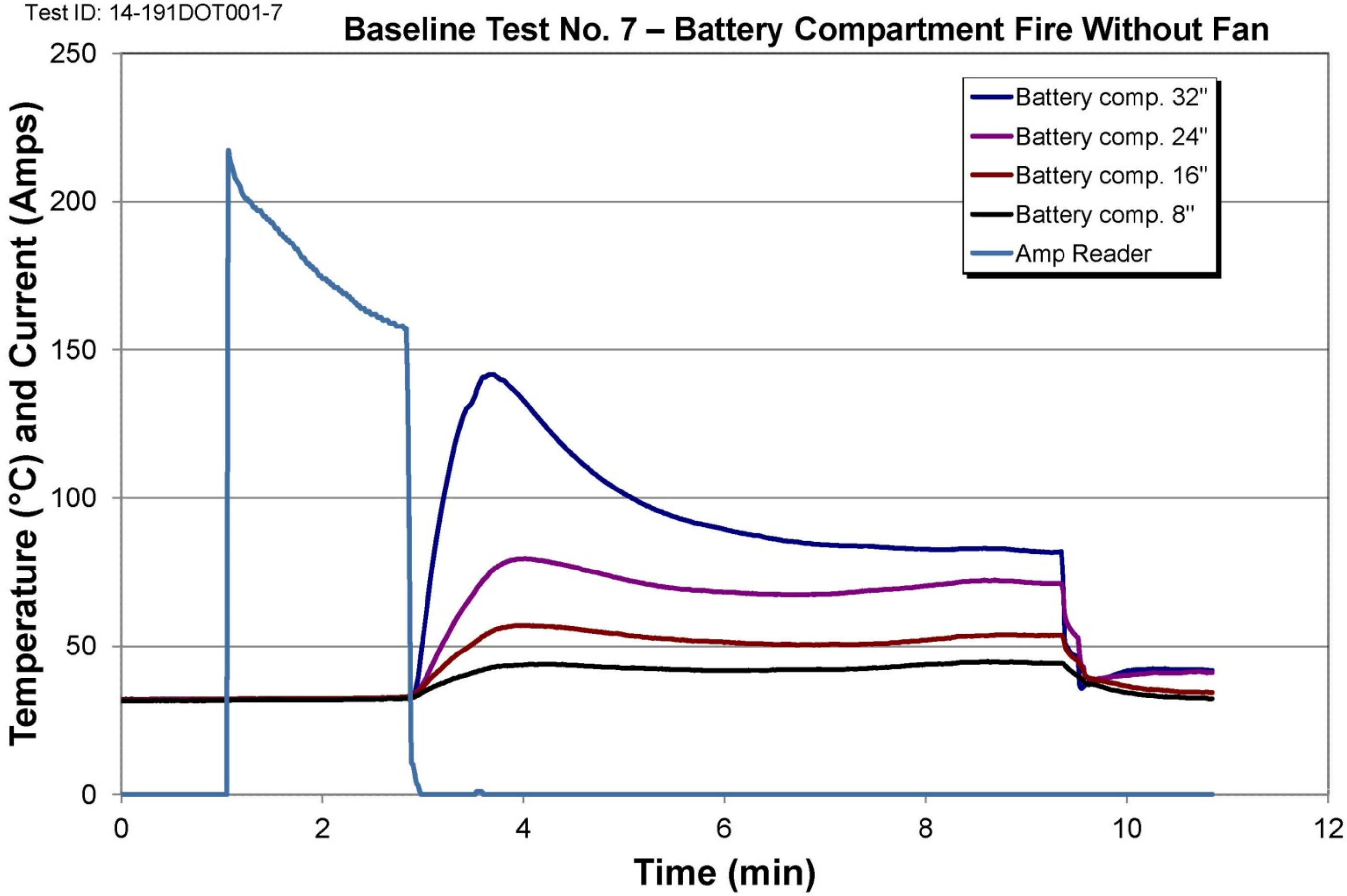


Department of Transportation
SwRI Project No. 01.17914
Test Date: July 9, 2014
Test ID: 14-190DOT001-4
Baseline Test No. 4 - Power Steering Fluid Spray With Fan
Temperature (°C)
Pressure (psig)
Time (min)
0
100
200
300
400
500
600
700
800
900
0
20
40
60
80
100
120
0
2
4
6
8
10
12
Plastic mid
Plastic bottom
Battery comp. 32"
Battery comp. 24"
Battery comp. 16"
Battery comp. 8"
Power steering spray
Back left top
Back left bottom
Front left top
Front left middle
Front left bottom
Power Steering Pressure

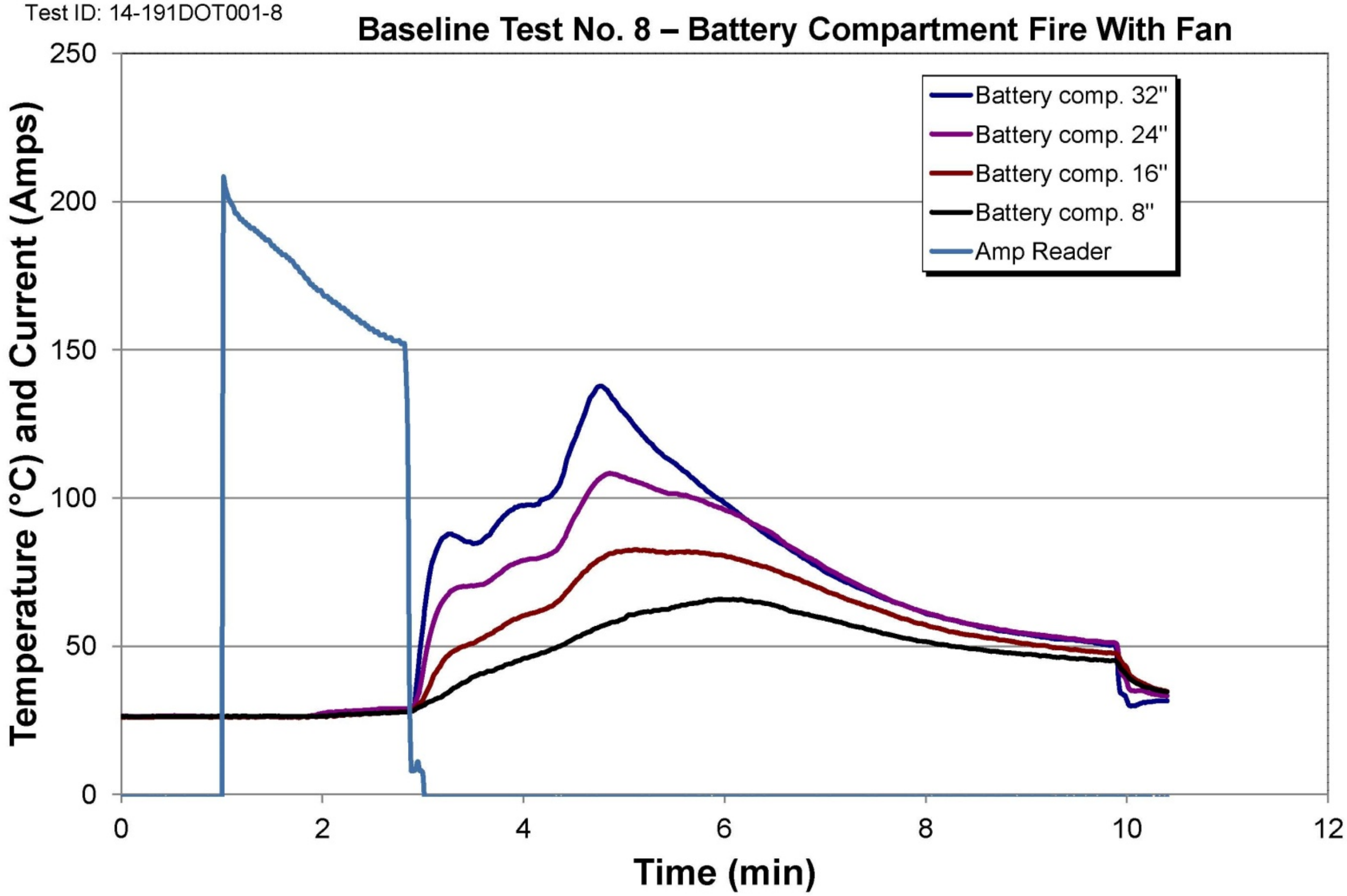

Department of Transportation
SwRI Project No. 01.17914
Test Date: July 9, 2014
Test ID: 14-190DOT001-5
Baseline Test No. 5 - Distributed Pool Fires Without Fan
Temperature (°C)
Time (min)
0
100
200
300
400
500
600
700
800
0
2
4
6
8
10
12
14
16
Back right top
Back left top
Back left bottom
Front left top
Front left middle
Front left bottom
Front right top
Front right bottom


Department of Transportation
SwRI Project No. 01.17914
Test Date: July 10, 2014
Test ID: 14-191DOT001-6
Baseline Test No. 6: Distributed Pool Fires With Fan
Temperature (°C)
Time (min)
Back right top
Back right bottom
Back left top
Back left bottom
Front left top
Front left middle
Front left bottom
Front right top
Front right bottom
0
100
200
300
400
500
600
700
800
900
1000
0
1
2
3
4
5
6
7
8
9

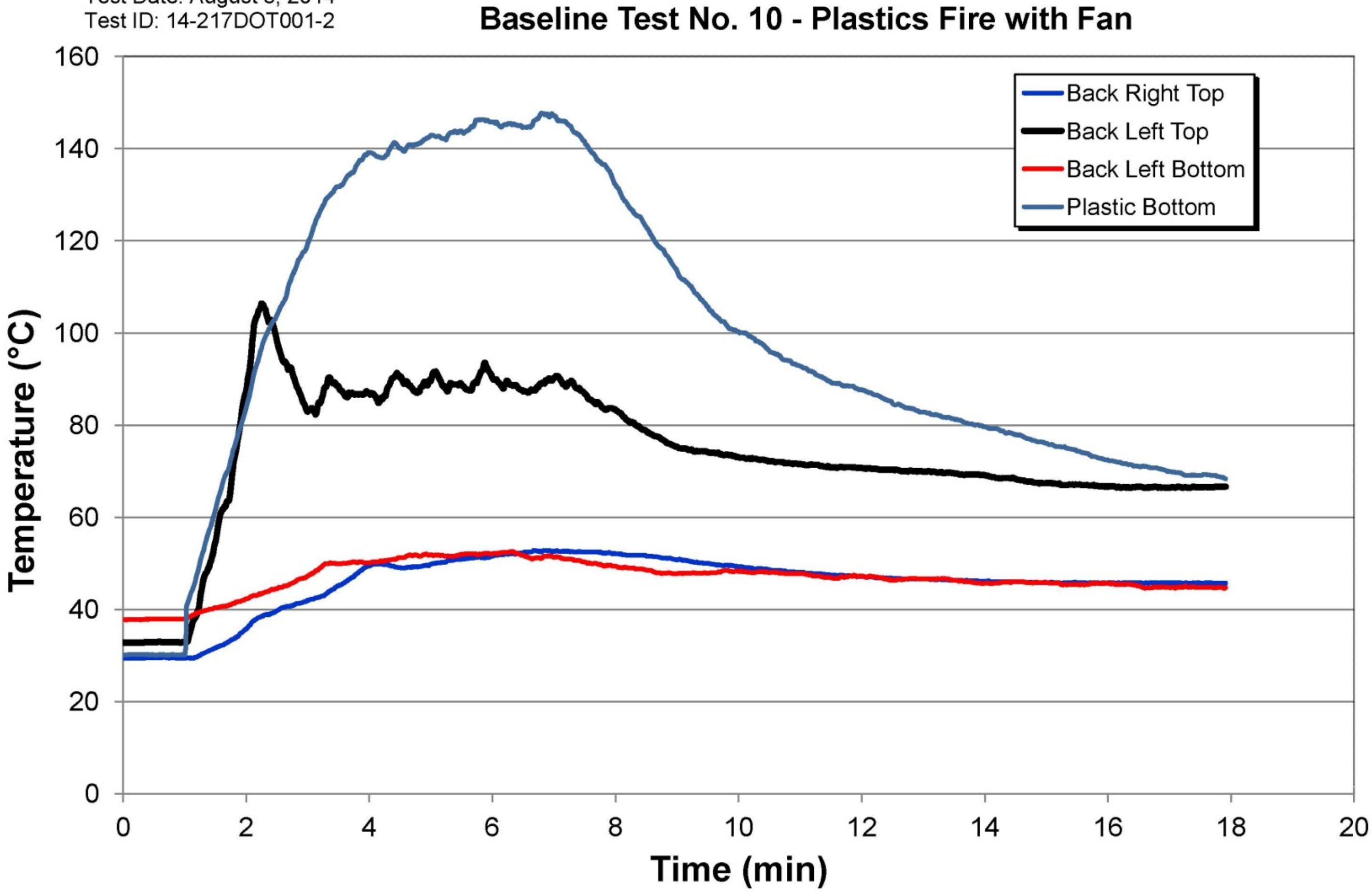
Department of Transportation
SwRI Project No. 01.17914
Test Date: July 10, 2014
Test ID: 14-191DOT001-7



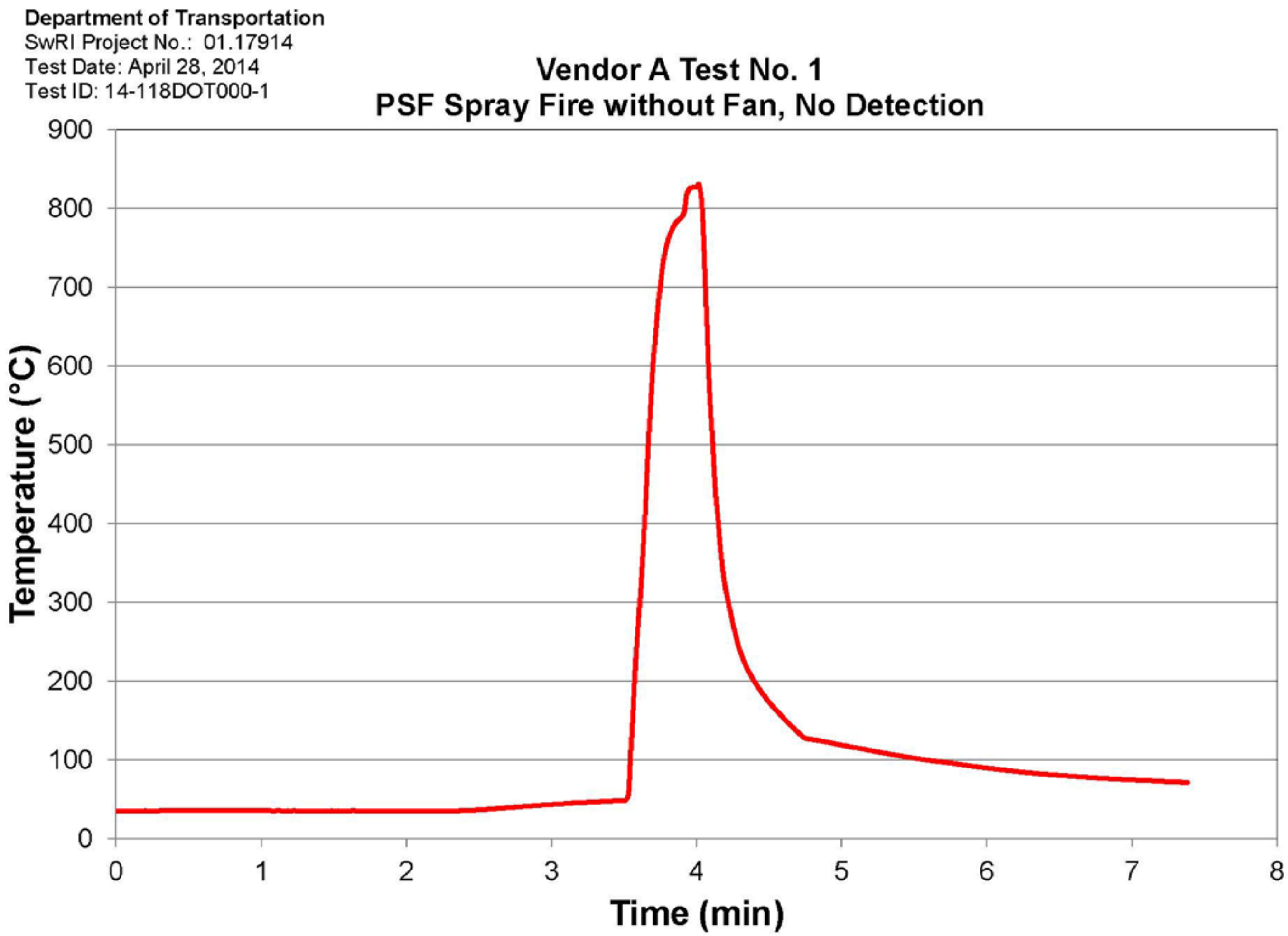
Department of Transportation
SwRI Project No. 01.17914
Test Date: July 10, 2014
Test ID: 14-191DOT001-8

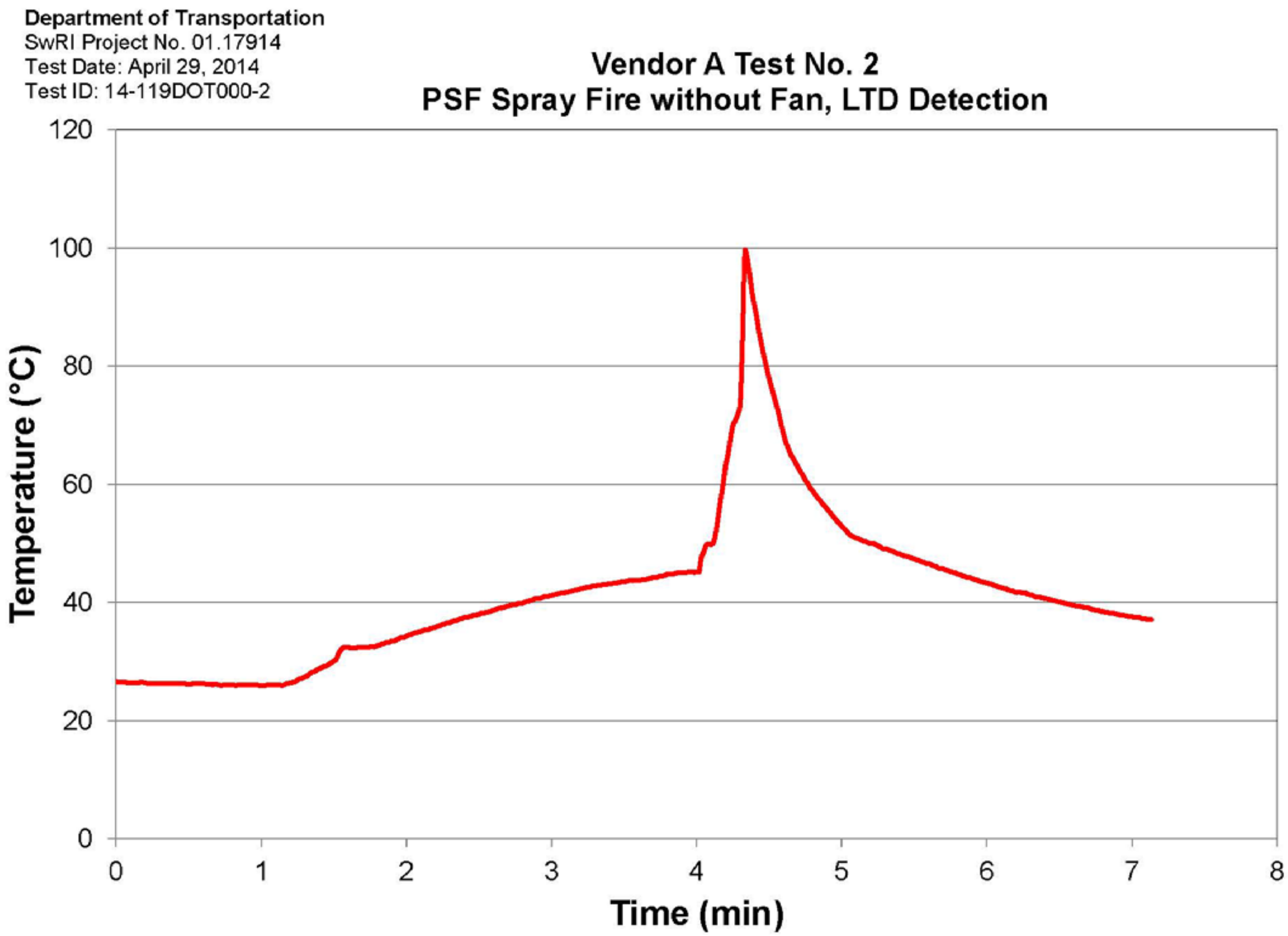


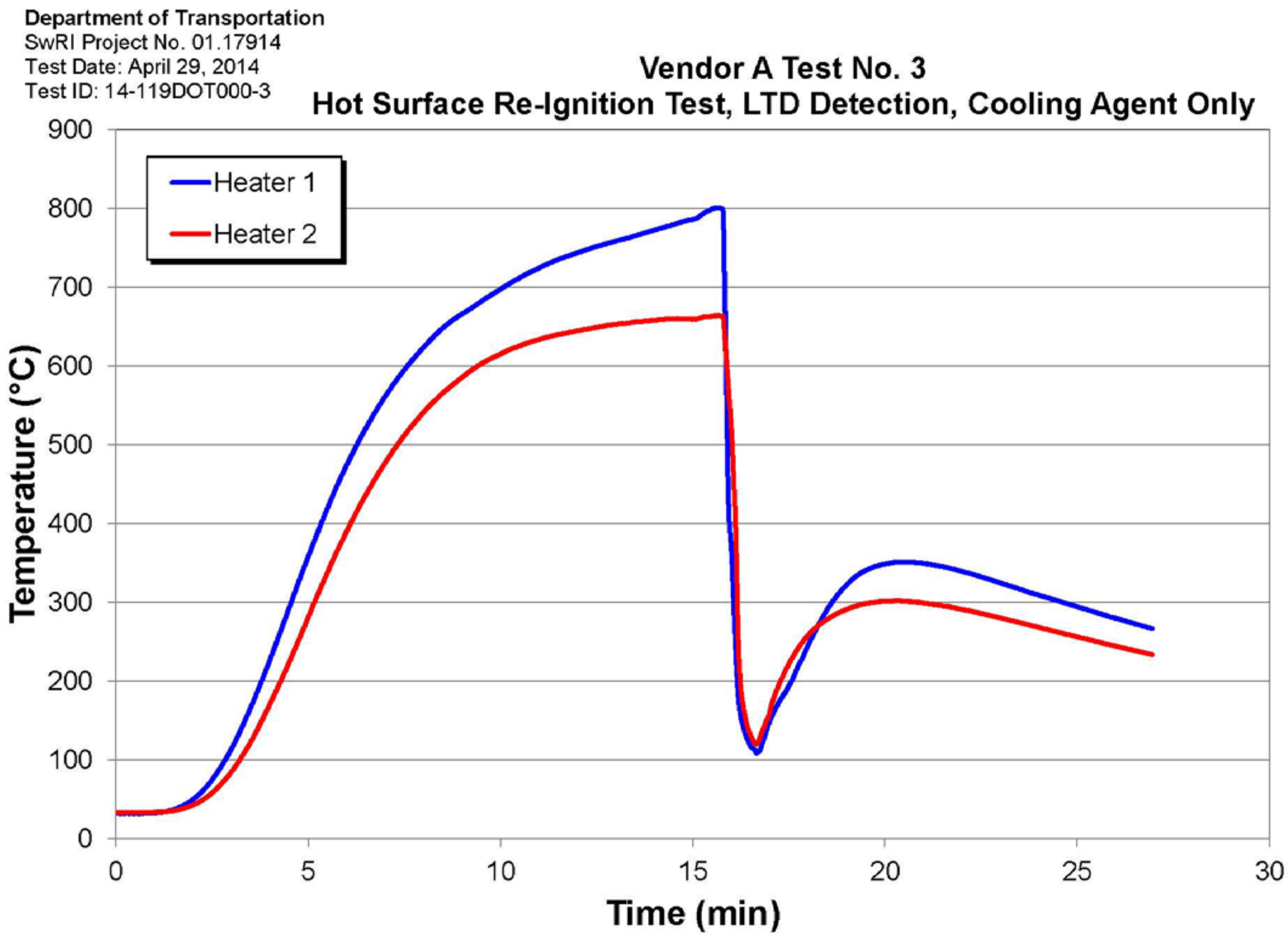
Department of Transportation
SwRI Project No. 01.17914
Test Date: August 5, 2014
Test ID: 14-217DOT001-2



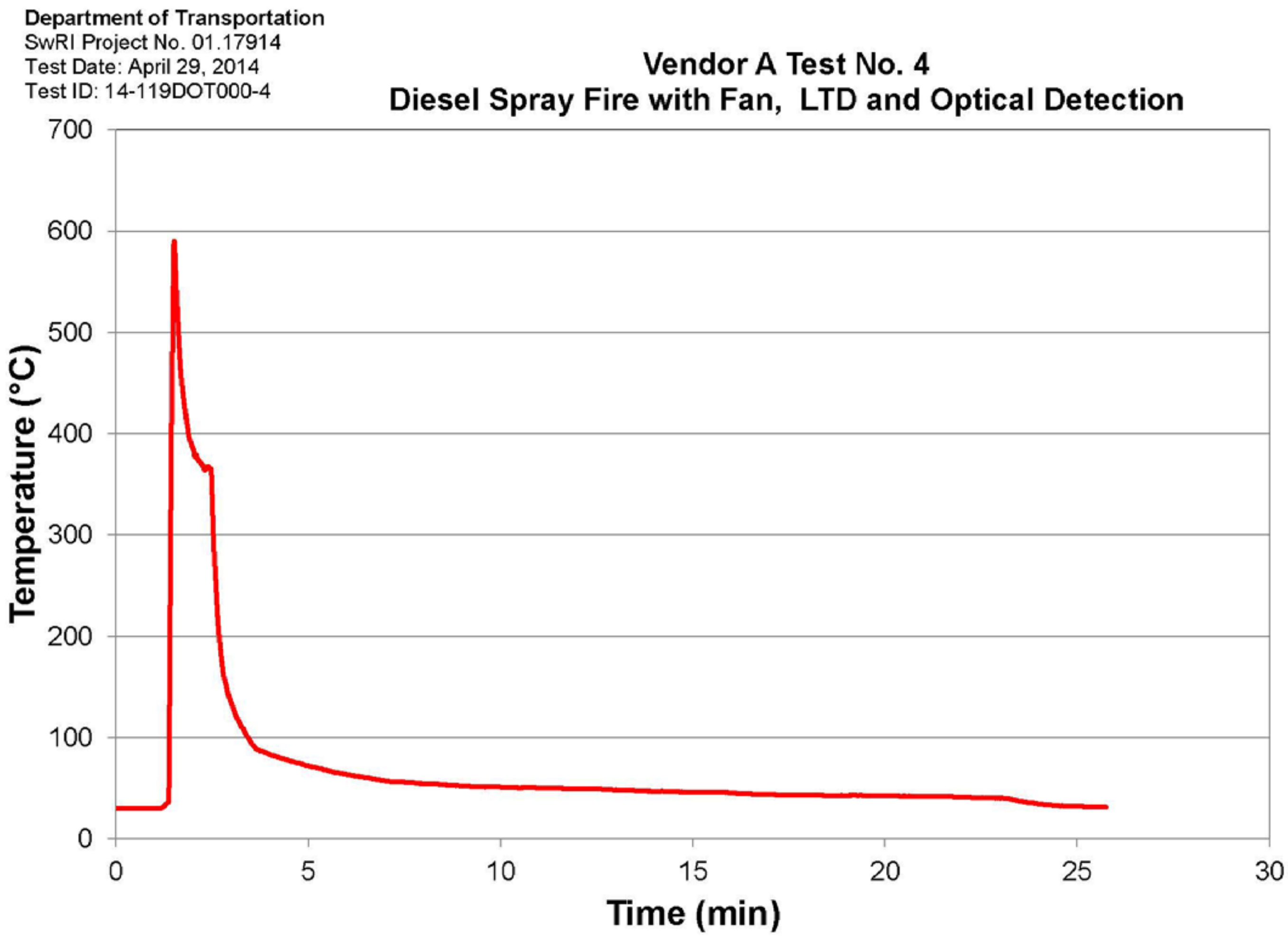
APPENDIX E
ENGINE COMPARTMENT VENDOR A TEST DATA
(CONSISTING OF 14 PAGES)

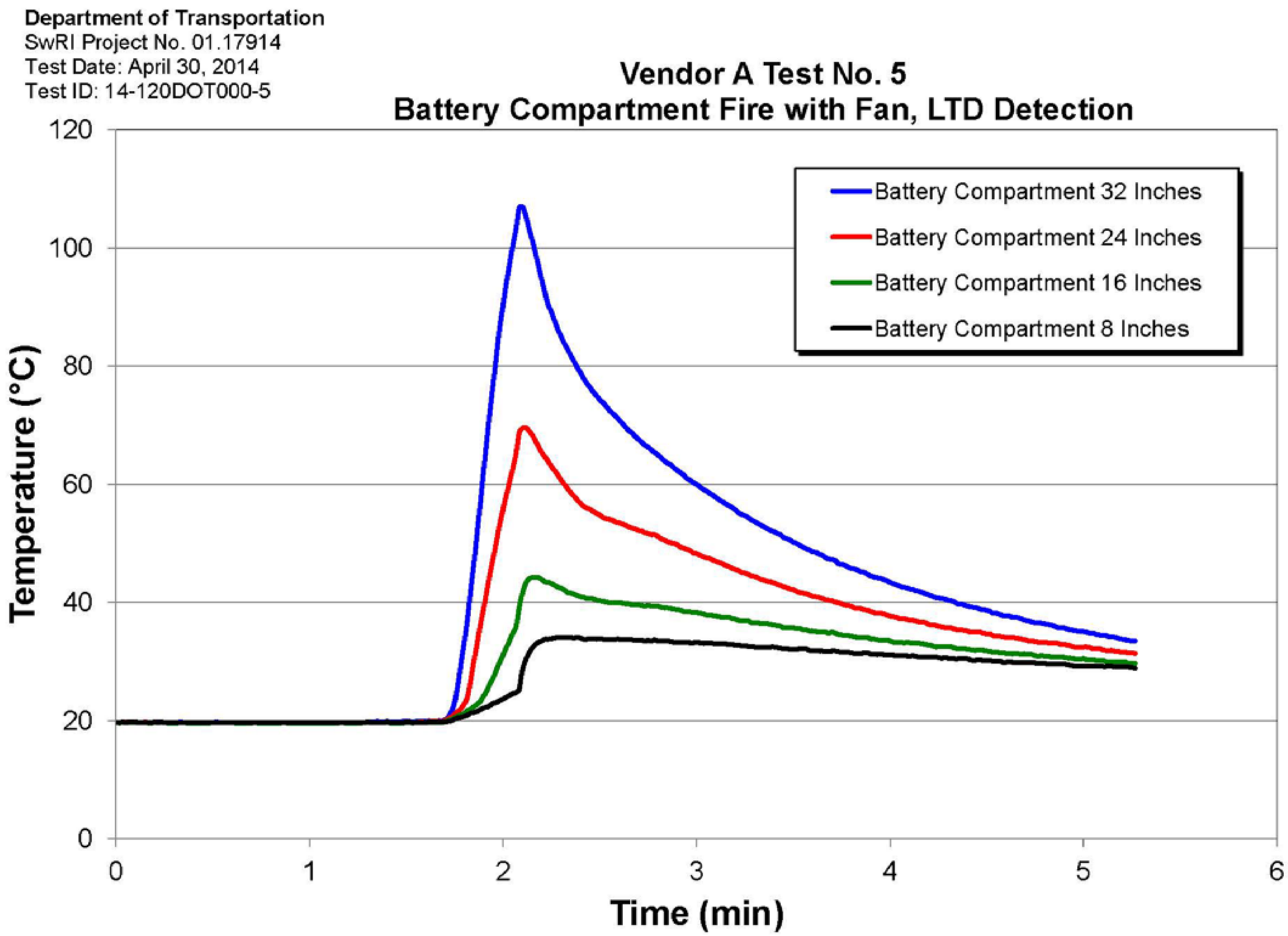

Department of Transportation
SwRI Project No.: 01.17914
Test Date: April 28, 2014
Test ID: 14-118DOT000-1
Vendor A Test No. 1
PSF Spray Fire without Fan, No Detection
Temperature (°C)
Time (min)
0
100
200
300
400
500
600
700
800
900
0
1
2
3
4
5
6
7
8

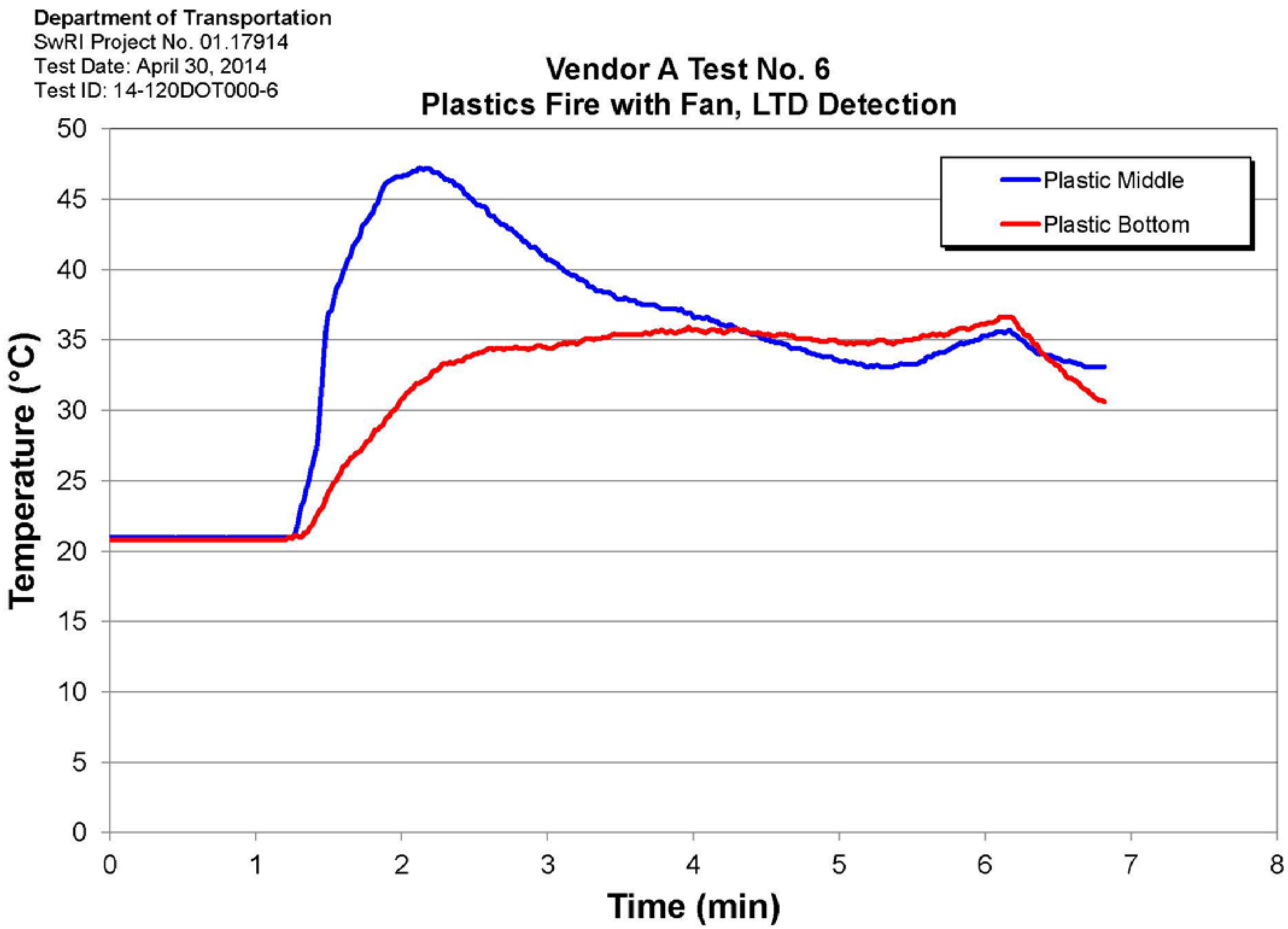

Department of Transportation
SwRI Project No. 01.17914
Test Date: April 29, 2014
Test ID: 14-119DOT000-2
Vendor A Test No. 2
PSF Spray Fire without Fan, LTD Detection
Temperature (°C)
Time (min)
120
100
80
60
40
20
0
0
1
2
3
4
5
6
7
8



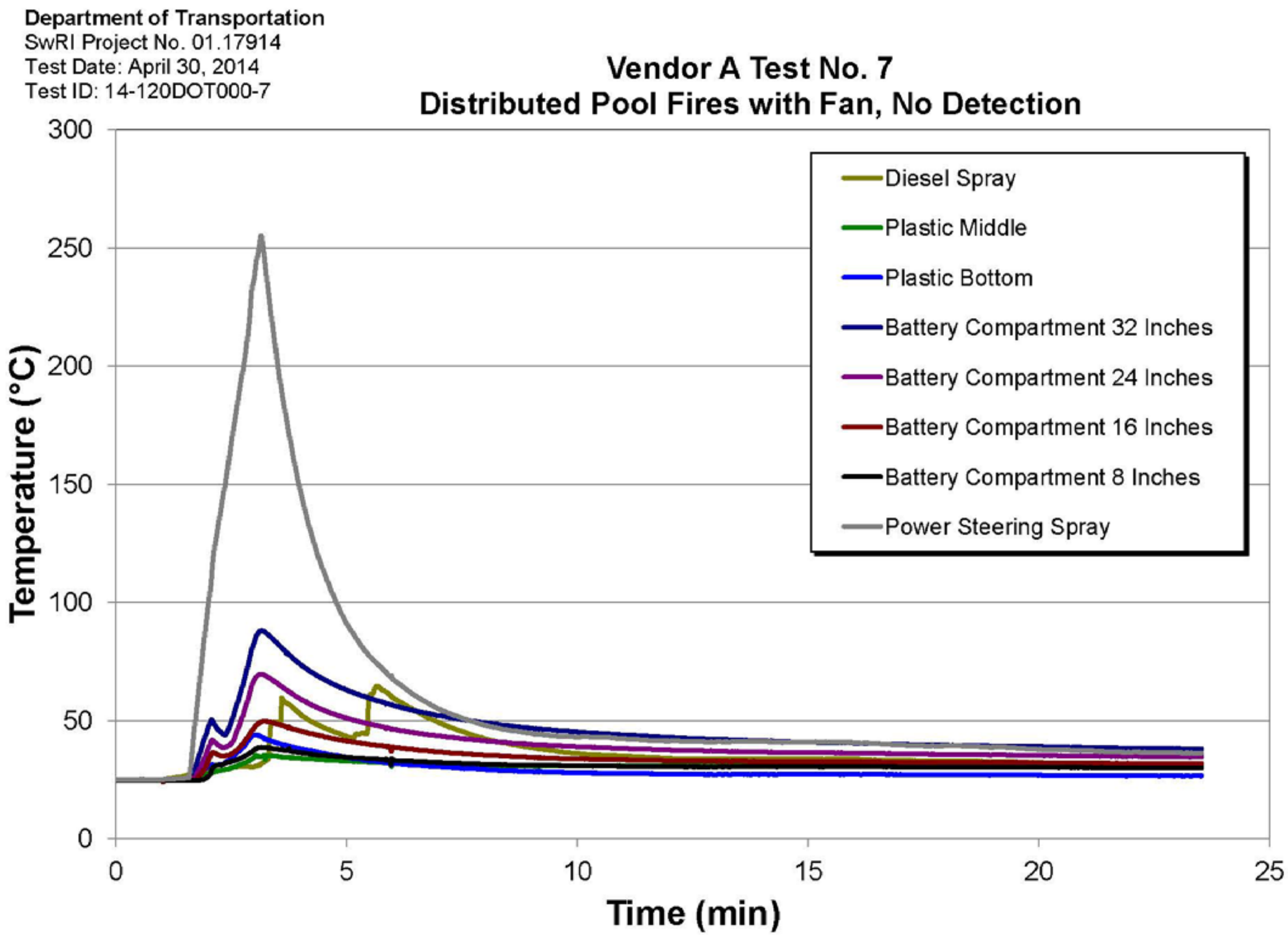
Department of Transportation
SwRI Project No. 01.17914
Test Date: April 29, 2014
Test ID: 14-119DOT000-3
Vendor A Test No. 3
Hot Surface Re-Ignition Test, LTD Detection, Cooling Agent Only
Heater 1
Heater 2
Temperature (°C)
Time (min)
0
100
200
300
400
500
600
700
800
900
0
5
10
15
20
25
30


Department of Transportation
SwRI Project No. 01.17914
Test Date: April 29, 2014
Test ID: 14-119DOT000-4
Vendor A Test No. 4
Diesel Spray Fire with Fan, LTD and Optical Detection
Temperature (°C)
0
100
200
300
400
500
600
700
Time (min)
0
5
10
15
20
25
30

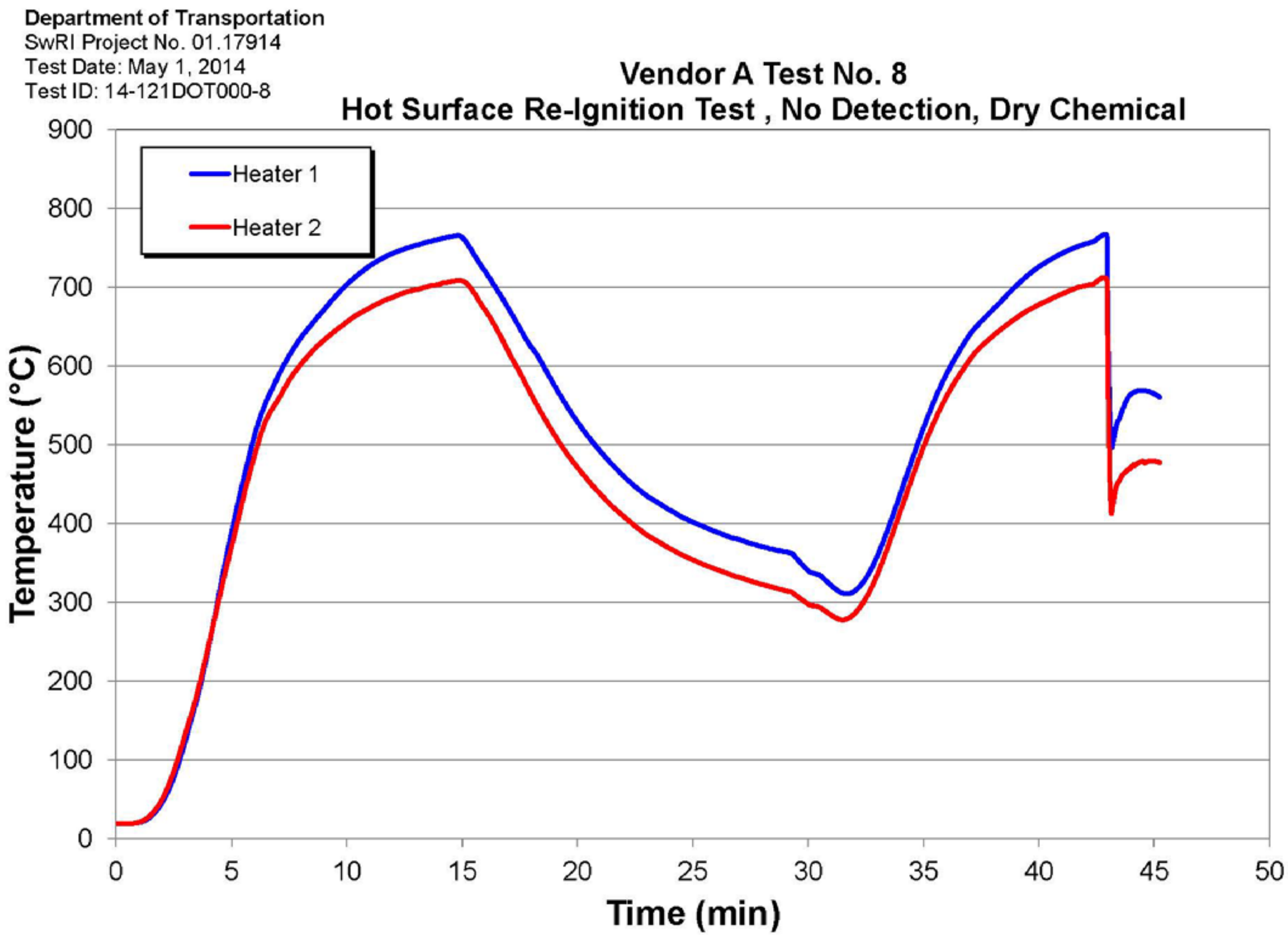

Department of Transportation
SwRI Project No. 01.17914
Test Date: April 30, 2014
Test ID: 14-120DOT000-5
Vendor A Test No. 5
Battery Compartment Fire with Fan, LTD Detection
Battery Compartment 32 Inches
Battery Compartment 24 Inches
Battery Compartment 16 Inches
Battery Compartment 8 Inches
Temperature (°C)
Time (min)
0
20
40
60
80
100
120
0
1
2
3
4
5
6

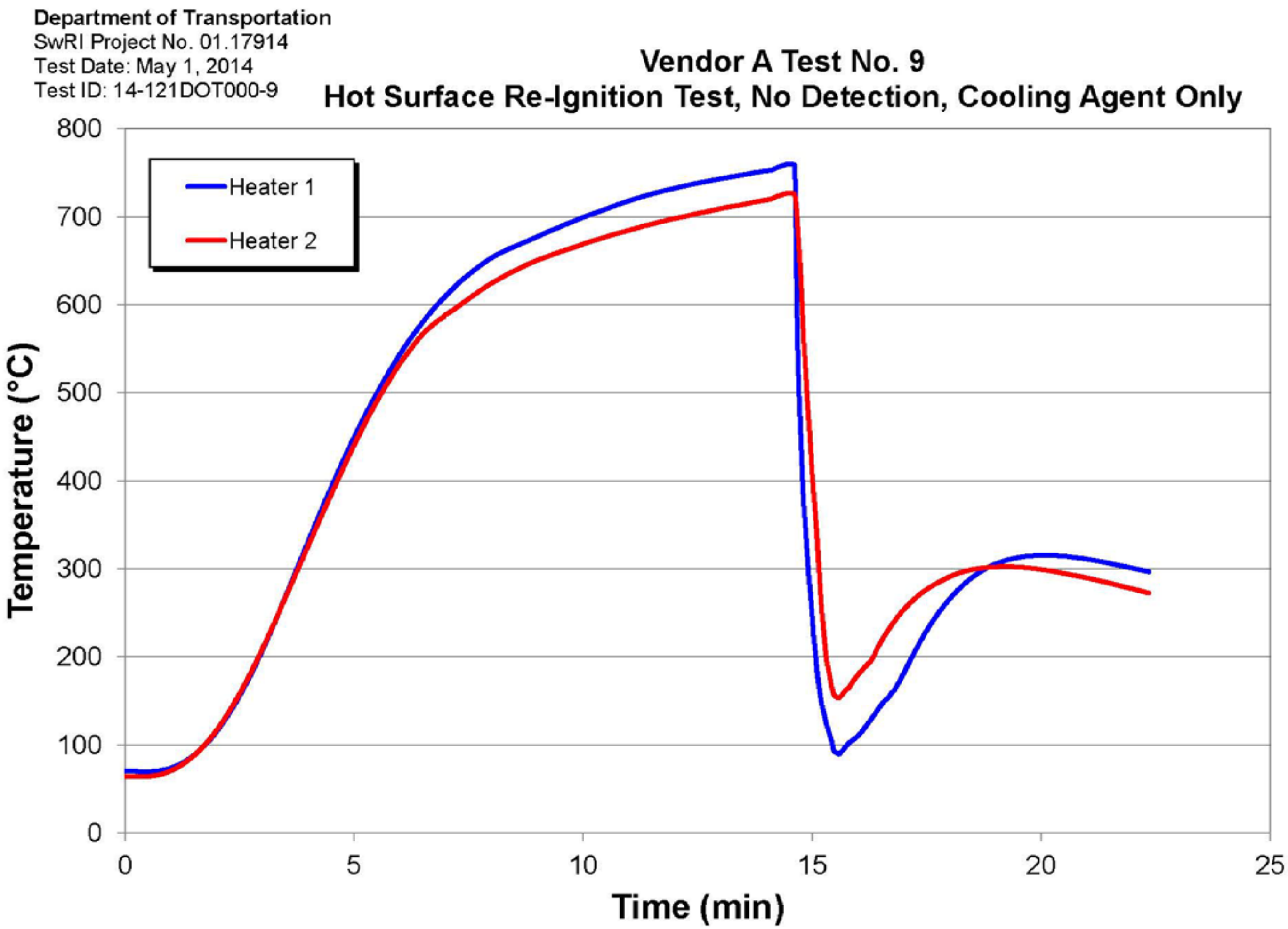


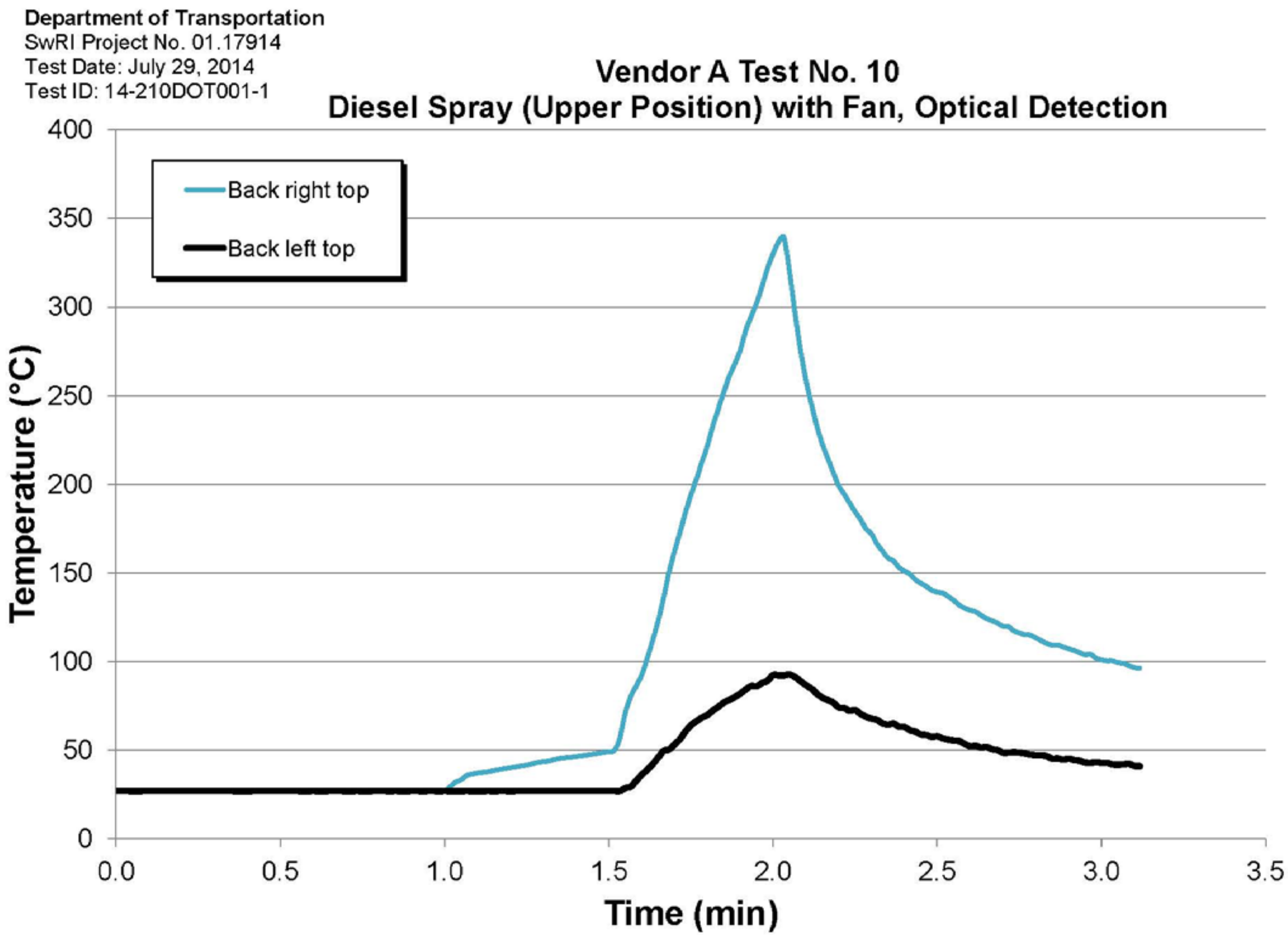
Department of Transportation
SwRI Project No. 01.17914
Test Date: April 30, 2014
Test ID: 14-120DOT000-6
Vendor A Test No. 6
Plastics Fire with Fan, LTD Detection
Plastic Middle
Plastic Bottom
Temperature (°C)
Time (min)
50
45
40
35
30
25
20
15
10
5
0
0
1
2
3
4
5
6
7
8

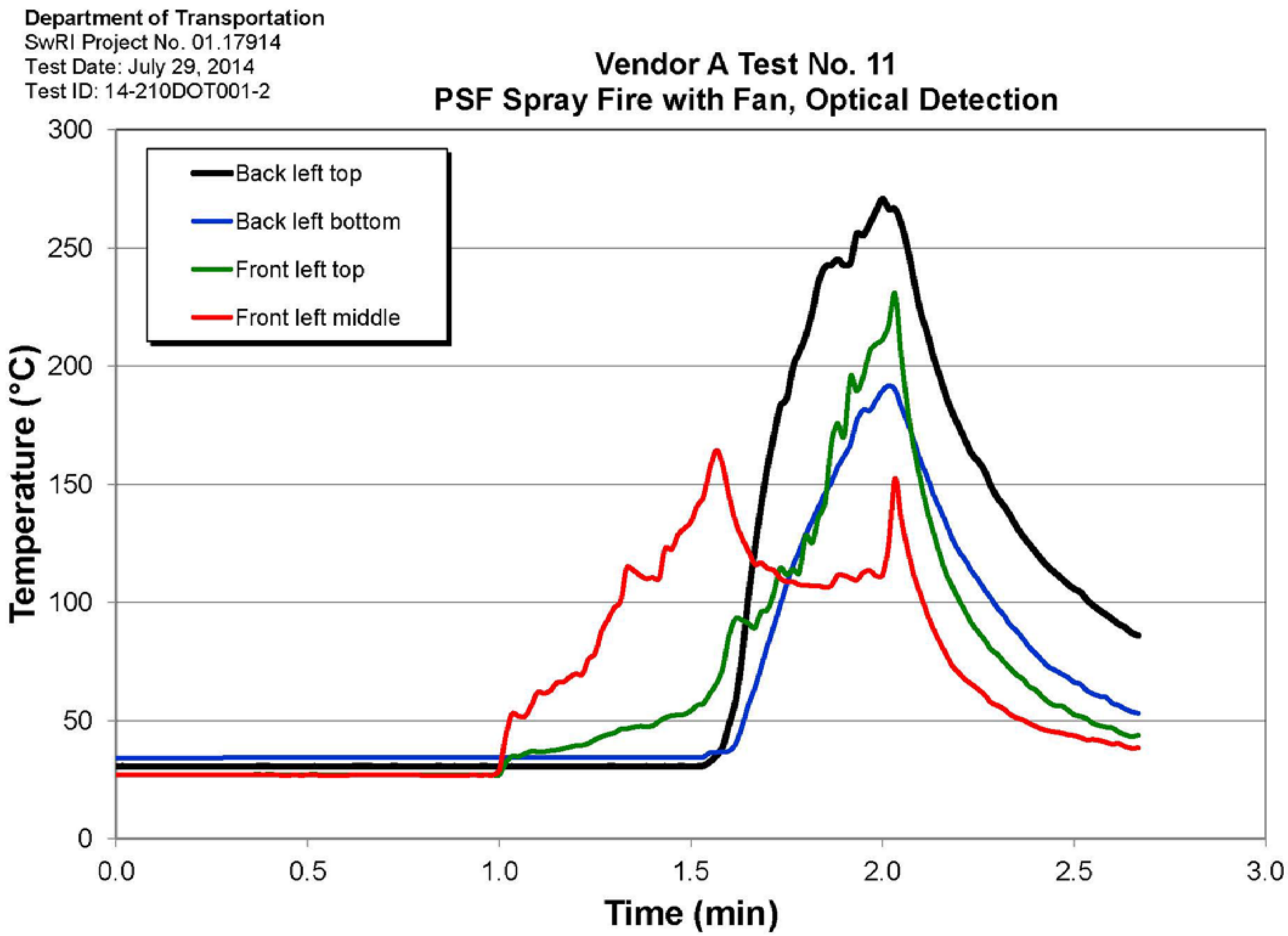


Department of Transportation
SwRI Project No. 01.17914
Test Date: April 30, 2014
Test ID: 14-120DOT000-7
Vendor A Test No. 7
Distributed Pool Fires with Fan, No Detection
Temperature (°C)
Time (min)
Diesel Spray
Plastic Middle
Plastic Bottom
Battery Compartment 32 Inches
Battery Compartment 24 Inches
Battery Compartment 16 Inches
Battery Compartment 8 Inches
Power Steering Spray

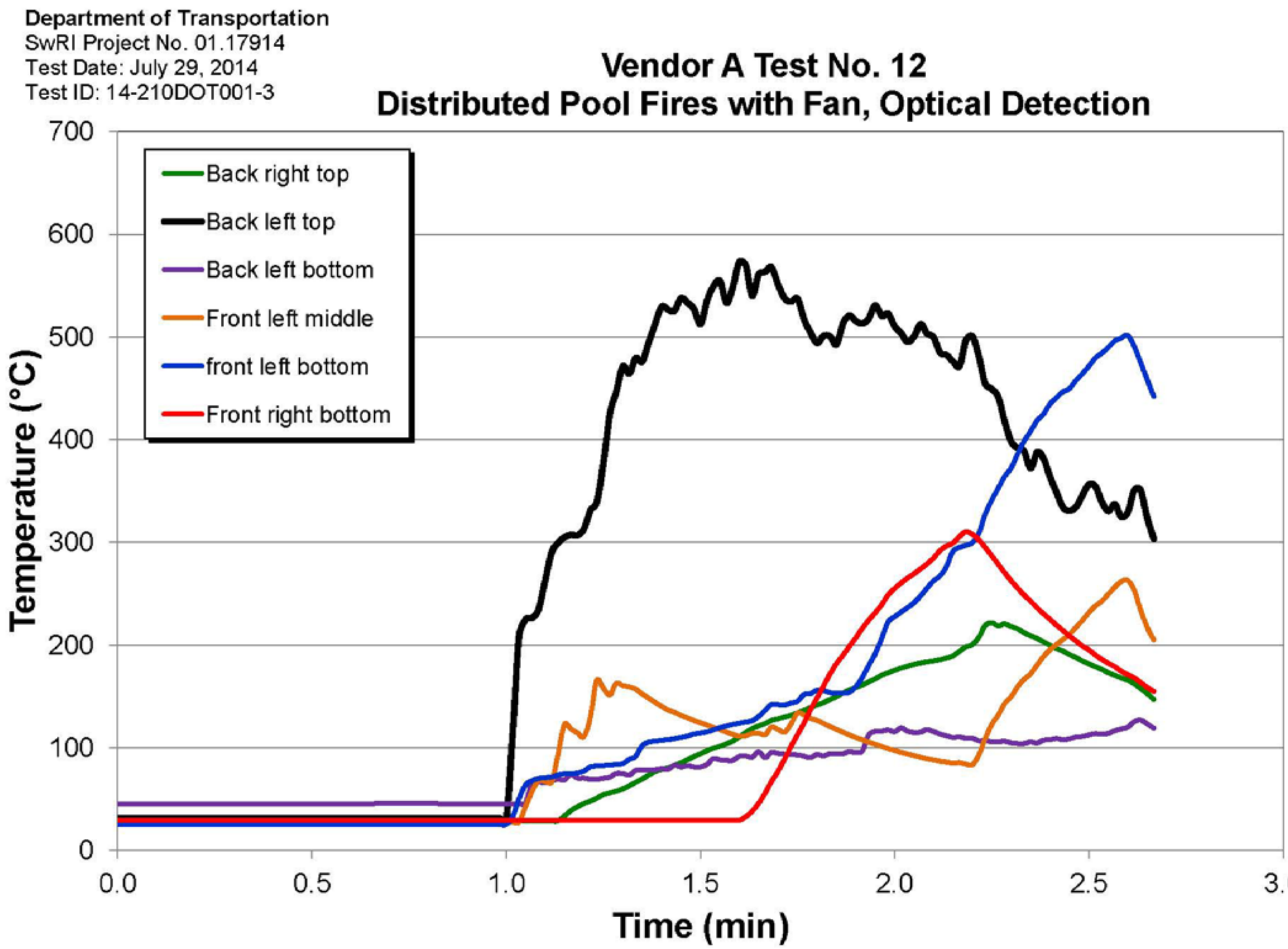

Department of Transportation
SwRI Project No. 01.17914
Test Date: May 1, 2014
Test ID: 14-121DOT000-8
Vendor A Test No. 8
Hot Surface Re-Ignition Test , No Detection, Dry Chemical
Heater 1
Heater 2
Temperature (°C)
Time (min)
0
100
200
300
400
500
600
700
800
900
0
5
10
15
20
25
30
35
40
45
50

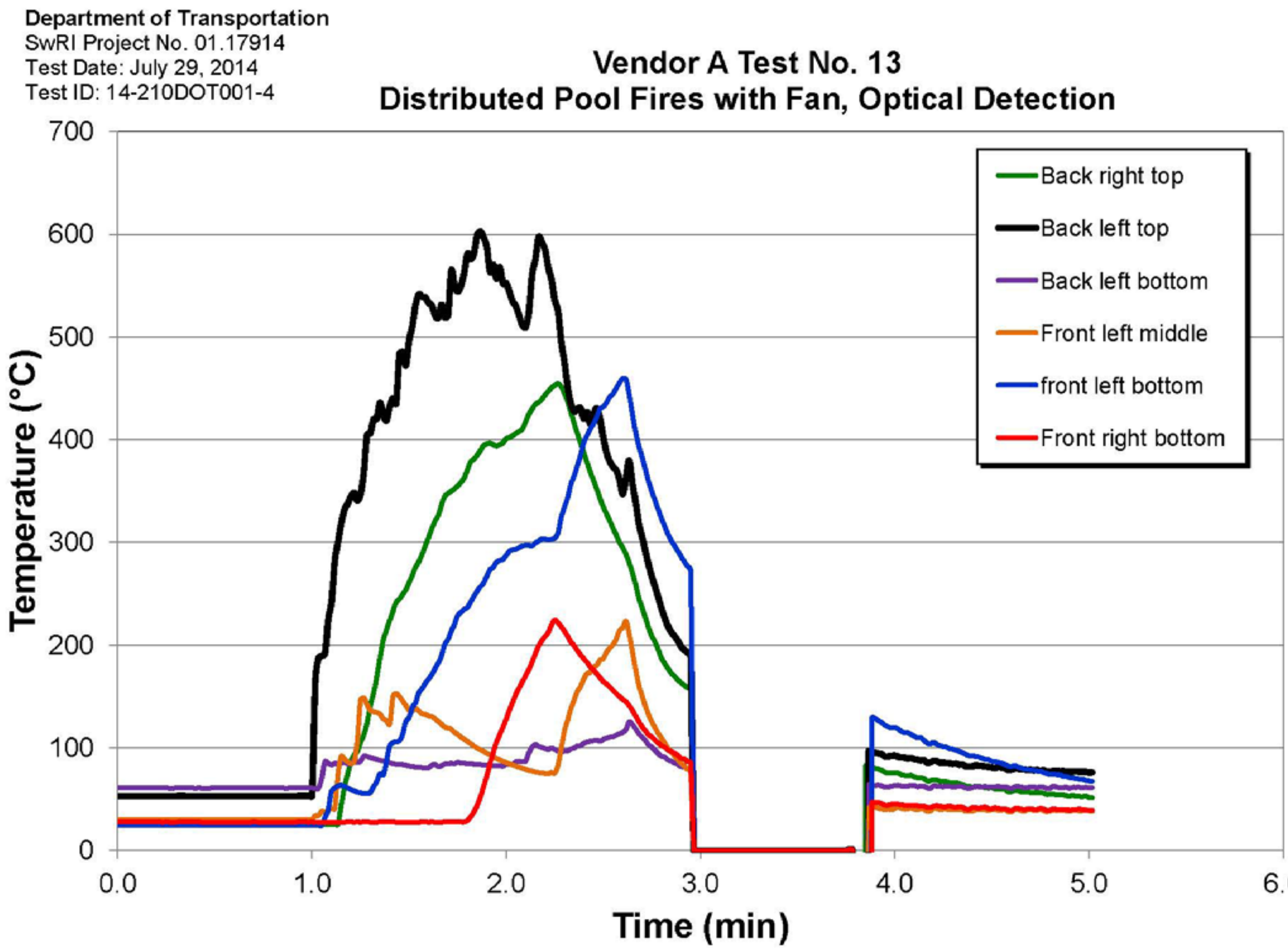

Department of Transportation
SwRI Project No. 01.17914
Test Date: May 1, 2014
Test ID: 14-121DOT000-9
Vendor A Test No. 9
Hot Surface Re-Ignition Test, No Detection, Cooling Agent Only
Heater 1
Heater 2
Temperature (°C)
Time (min)
0
100
200
300
400
500
600
700
800
0
5
10
15
20
25

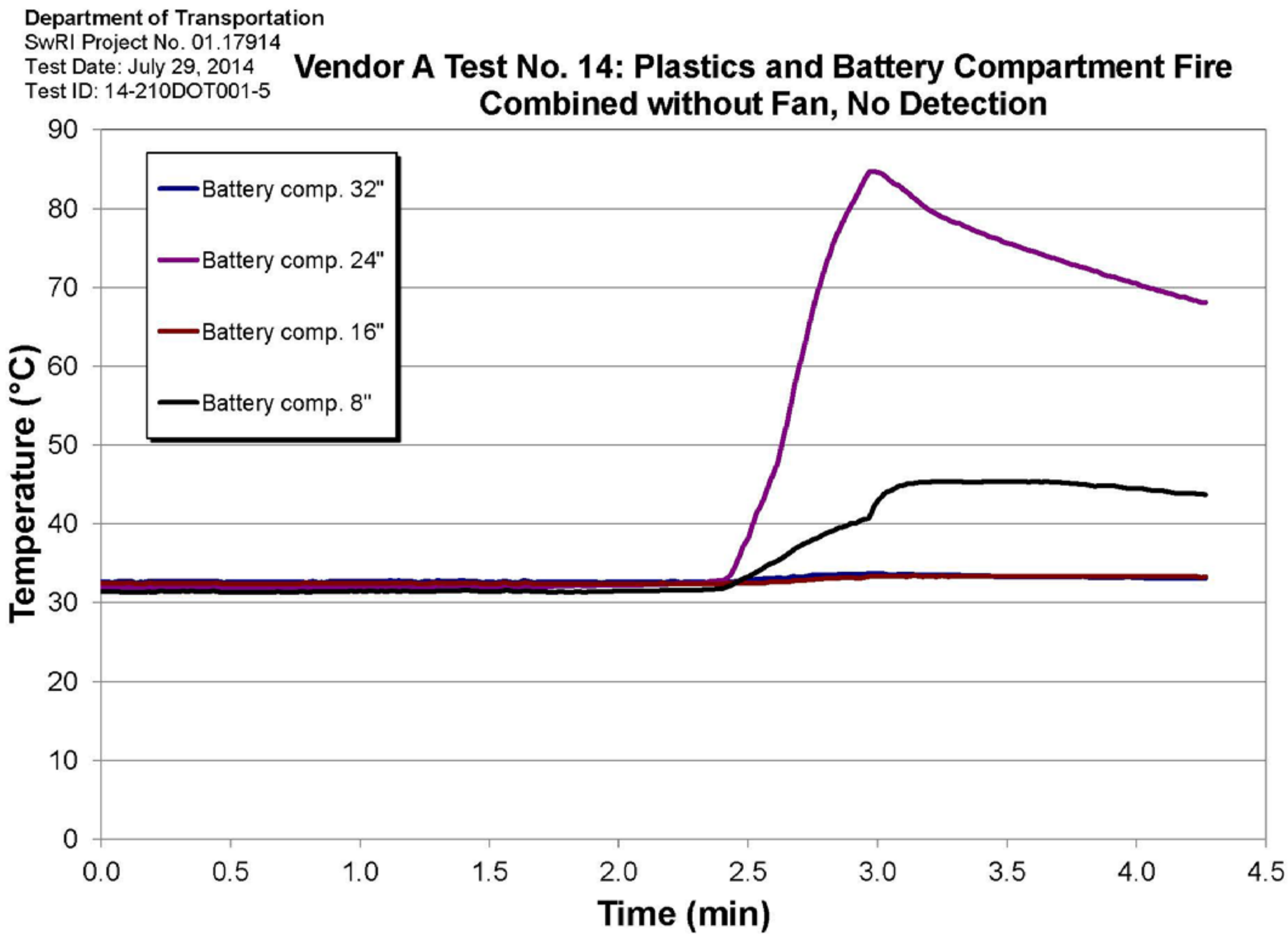

Department of Transportation
SwRI Project No. 01.17914
Test Date: July 29, 2014
Test ID: 14-210DOT001-1
Vendor A Test No. 10
Diesel Spray (Upper Position) with Fan, Optical Detection
Back right top
Back left top
Temperature (°C)
Time (min)
0
50
100
150
200
250
300
350
400
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5



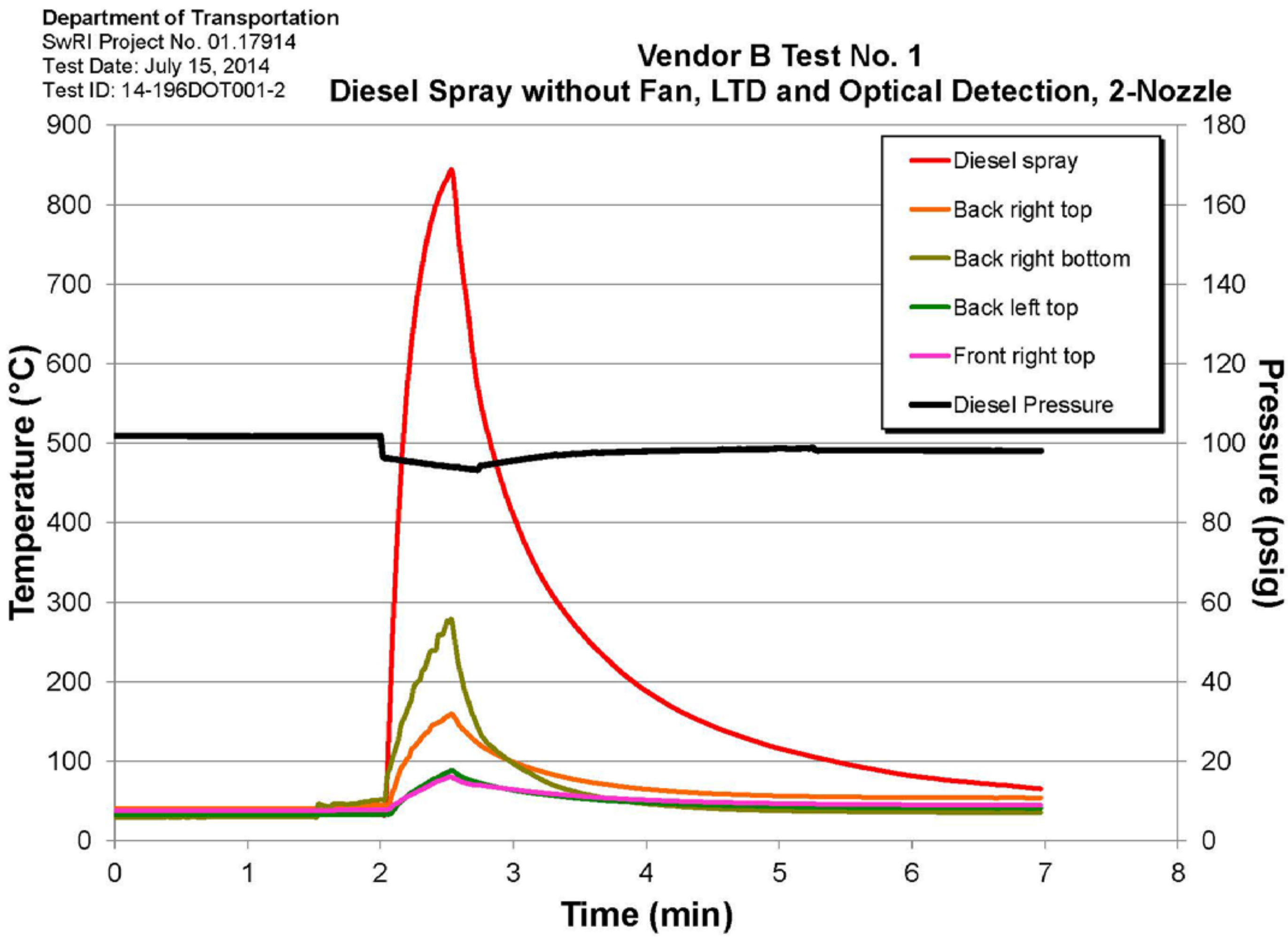
Department of Transportation
SwRI Project No. 01.17914
Test Date: July 29, 2014
Test ID: 14-210DOT001-2
Vendor A Test No. 11
PSF Spray Fire with Fan, Optical Detection
Temperature (°C)
Time (min)
Back left top
Back left bottom
Front left top
Front left middle
0
50
100
150
200
250
300
0.0
0.5
1.0
1.5
2.0
2.5
3.0

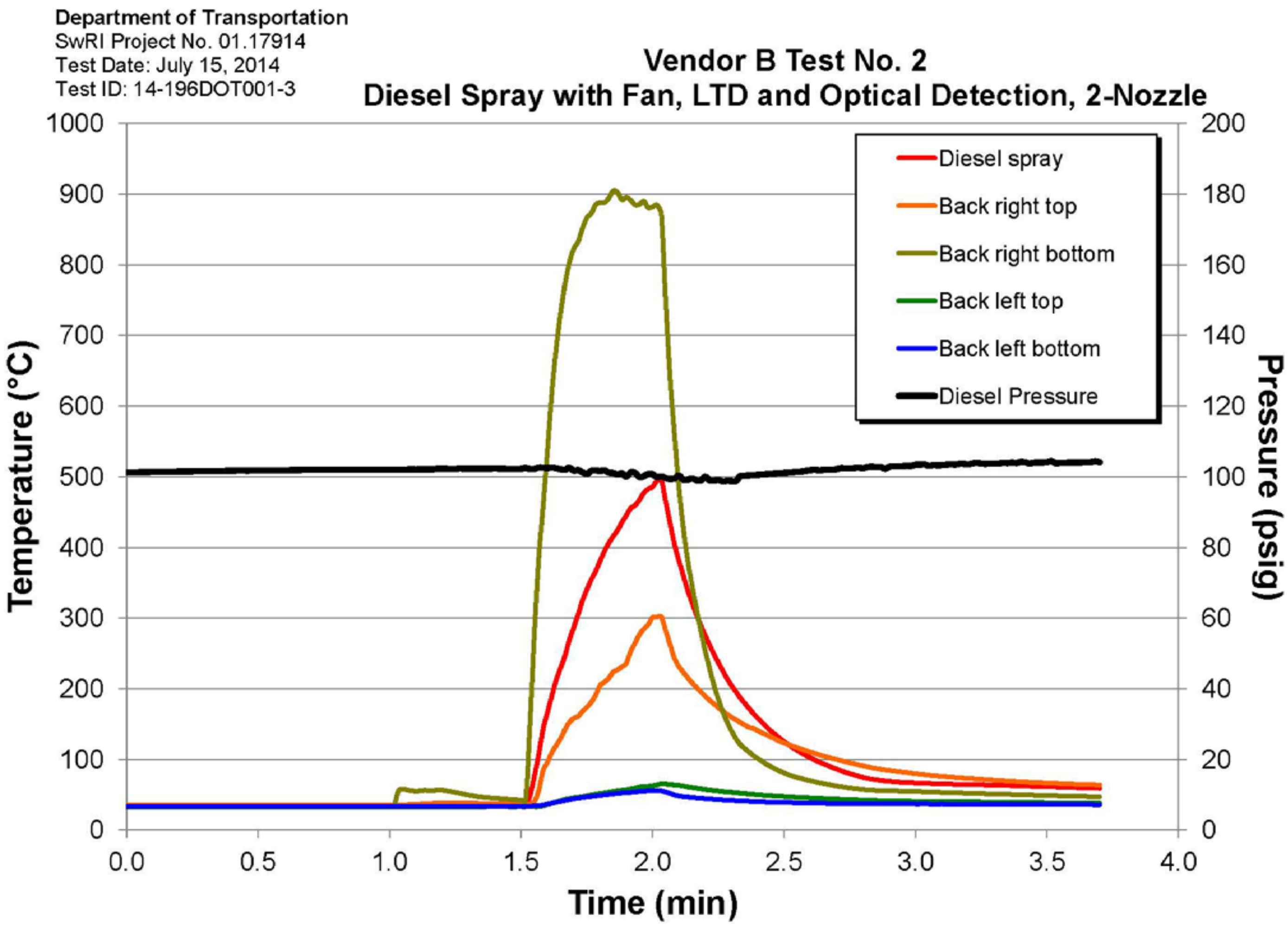

Department of Transportation
SwRI Project No. 01.17914
Test Date: July 29, 2014
Test ID: 14-210DOT001-3
Vendor A Test No. 12
Distributed Pool Fires with Fan, Optical Detection
Back right top
Back left top
Back left bottom
Front left middle
front left bottom
Front right bottom
Temperature (°C)
Time (min)
0
100
200
300
400
500
600
700
0.0
0.5
1.0
1.5
2.0
2.5
3.0


Department of Transportation
SwRI Project No. 01.17914
Test Date: July 29, 2014
Test ID: 14-210DOT001-4
Vendor A Test No. 13
Distributed Pool Fires with Fan, Optical Detection
Temperature (°C)
Time (min)
Back right top
Back left top
Back left bottom
Front left middle
front left bottom
Front right bottom
0
100
200
300
400
500
600
700
0.0
1.0
2.0
3.0
4.0
5.0
6.0

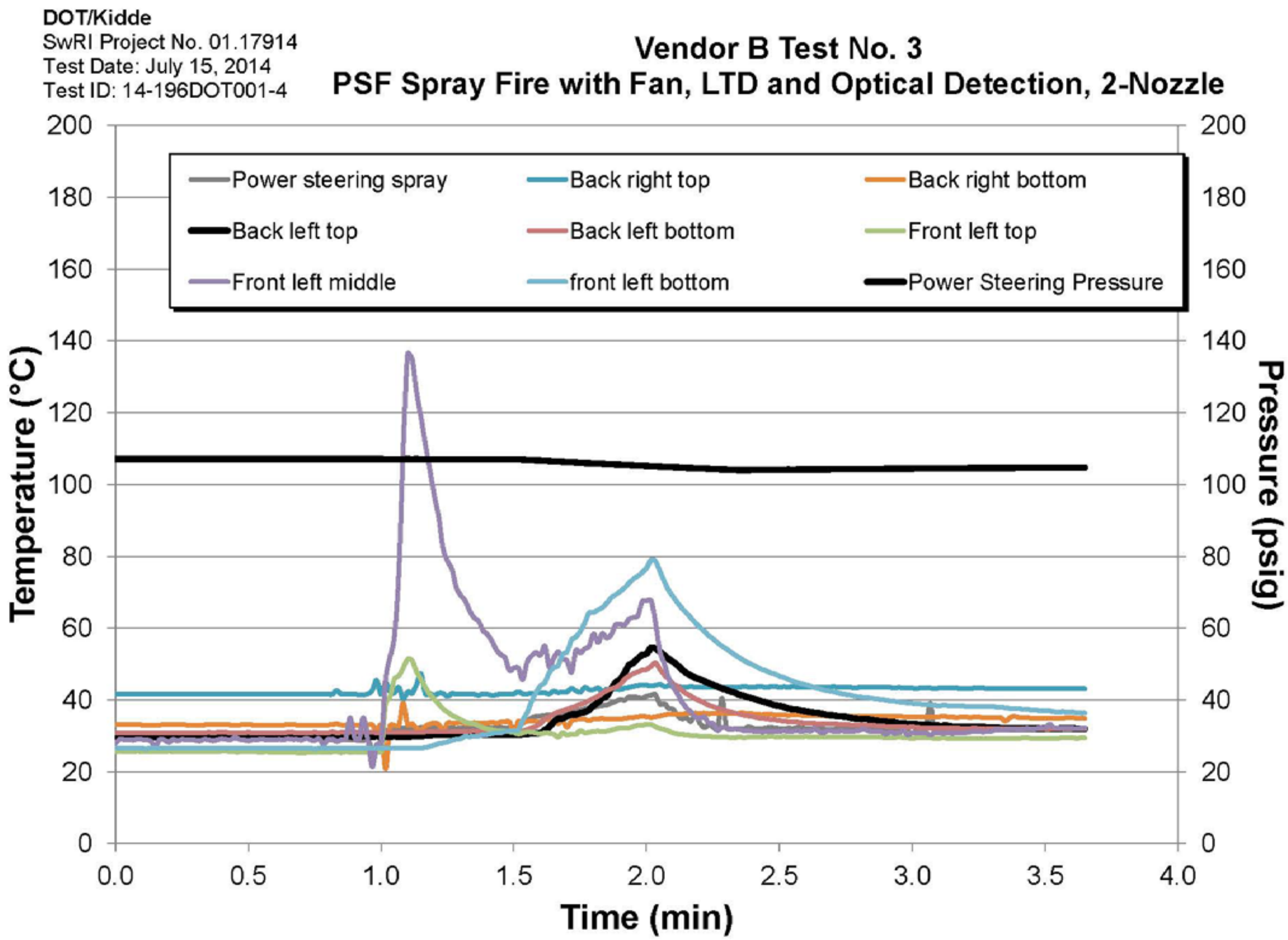

Department of Transportation
SwRI Project No. 01.17914
Test Date: July 29, 2014
Test ID: 14-210DOT001-5
Vendor A Test No. 14: Plastics and Battery Compartment Fire
Combined without Fan, No Detection
Battery comp. 32"
Battery comp. 24"
Battery comp. 16"
Battery comp. 8"
Temperature (°C)
Time (min)
0
10
20
30
40
50
60
70
80
90
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5

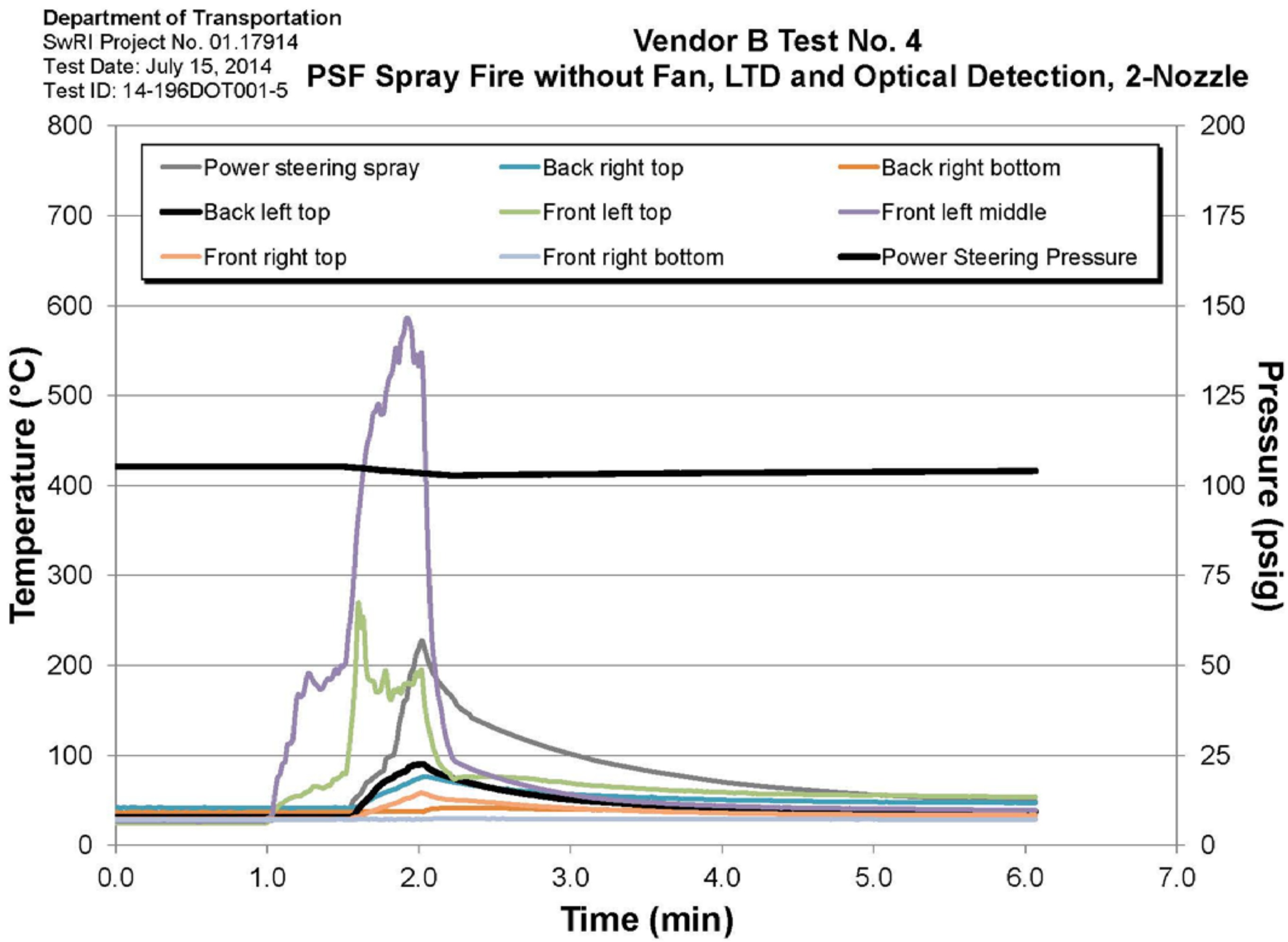
APPENDIX F
ENGINE COMPARTMENT VENDOR B TEST DATA
(CONSISTING OF 15 PAGES)


Department of Transportation
SwRI Project No. 01.17914
Test Date: July 15, 2014
Test ID: 14-196DOT001-2
Vendor B Test No. 1
Diesel Spray without Fan, LTD and Optical Detection, 2-Nozzle
Temperature (°C)
Pressure (psig)
Time (min)
Diesel spray
Back right top
Back right bottom
Back left top
Front right top
Diesel Pressure
0
100
200
300
400
500
600
700
800
900
0
20
40
60
80
100
120
140
160
180
0
1
2
3
4
5
6
7
8

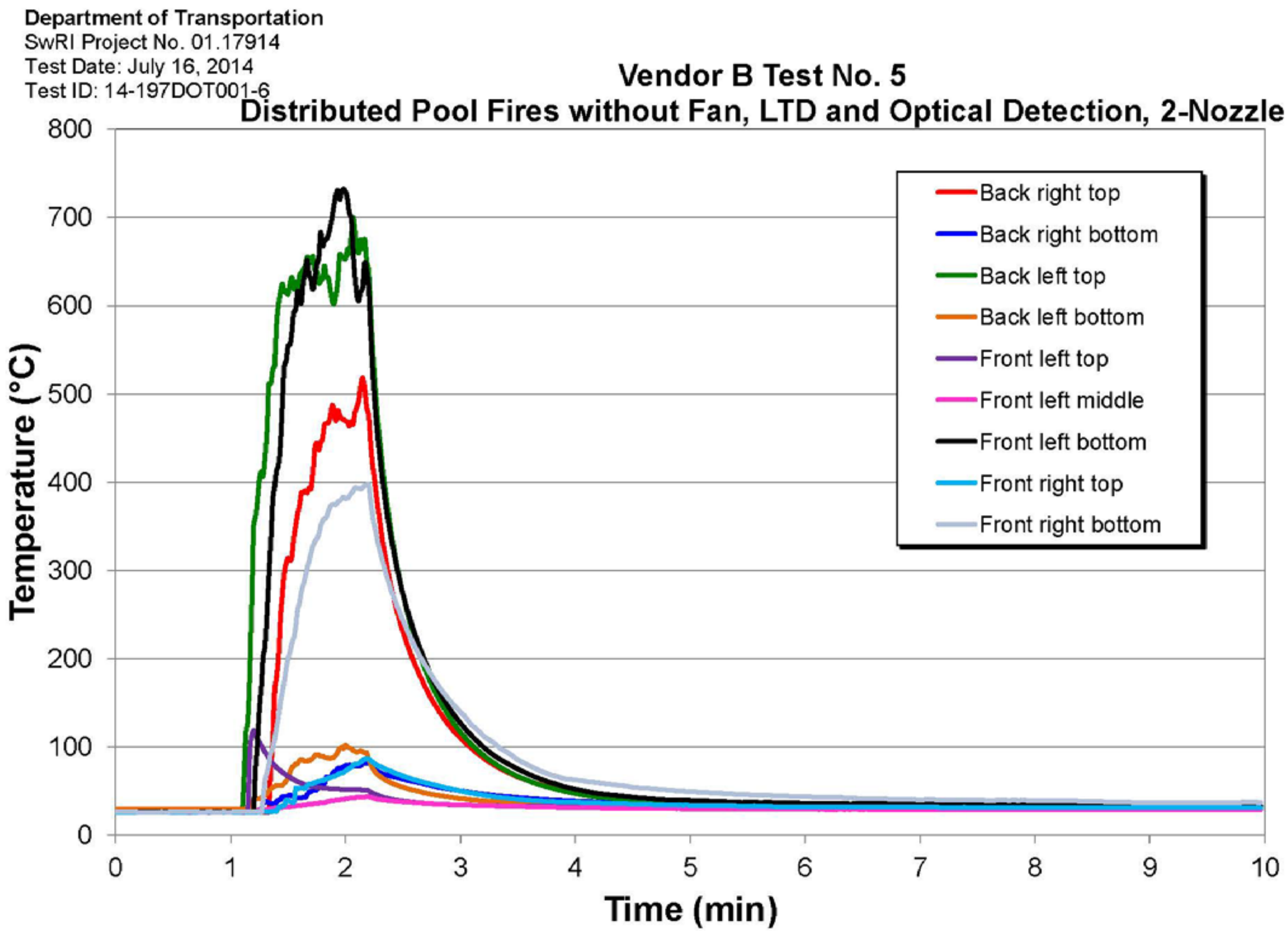


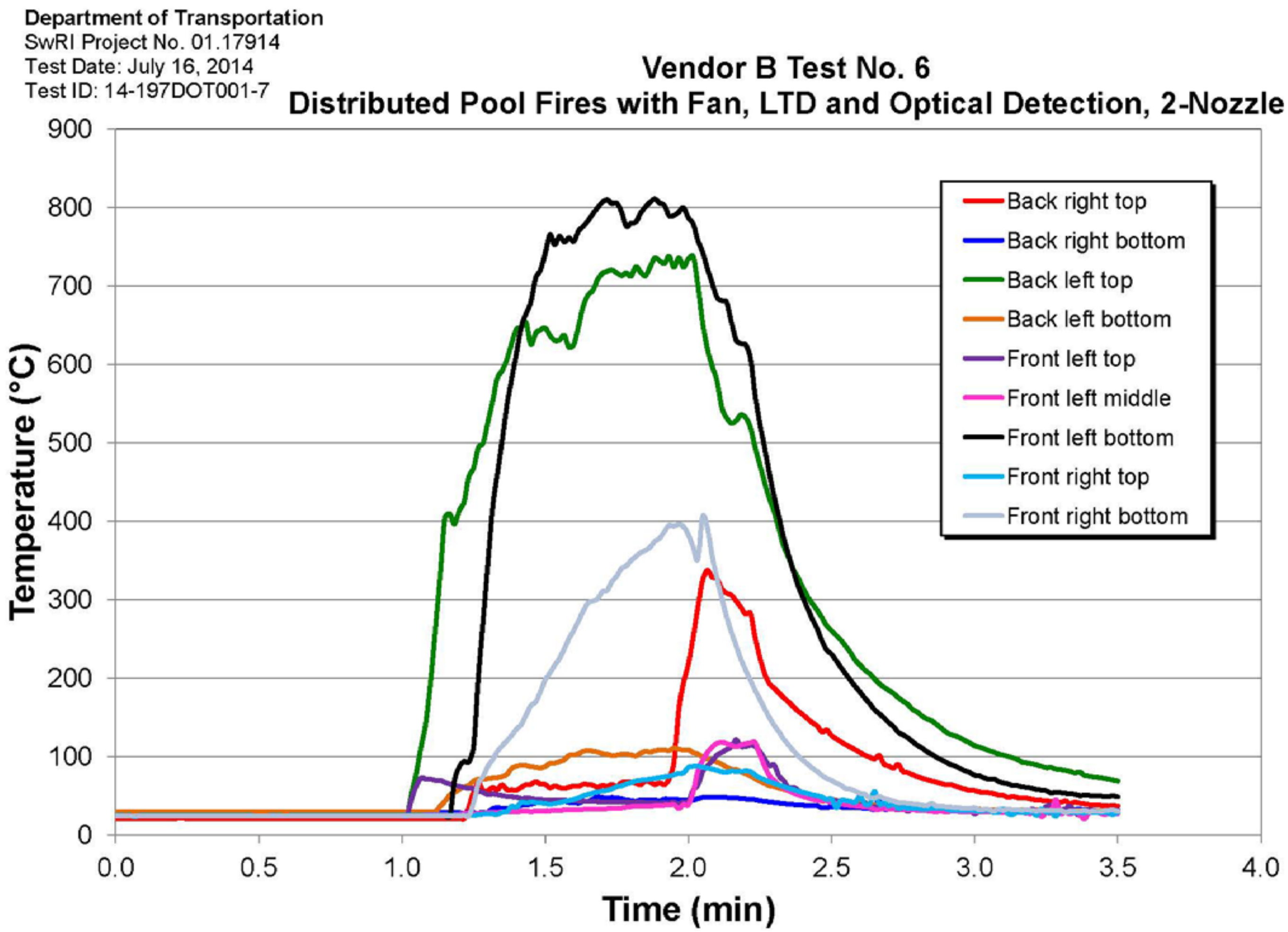
Department of Transportation
SwRI Project No. 01.17914
Test Date: July 15, 2014
Test ID: 14-196DOT001-3
Vendor B Test No. 2
Diesel Spray with Fan, LTD and Optical Detection, 2-Nozzle
Diesel spray
Back right top
Back right bottom
Back left top
Back left bottom
Diesel Pressure
Temperature (°C)
Pressure (psig)
Time (min)
1000
900
800
700
600
500
400
300
200
100
0
200
180
160
140
120
100
80
60
40
20
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

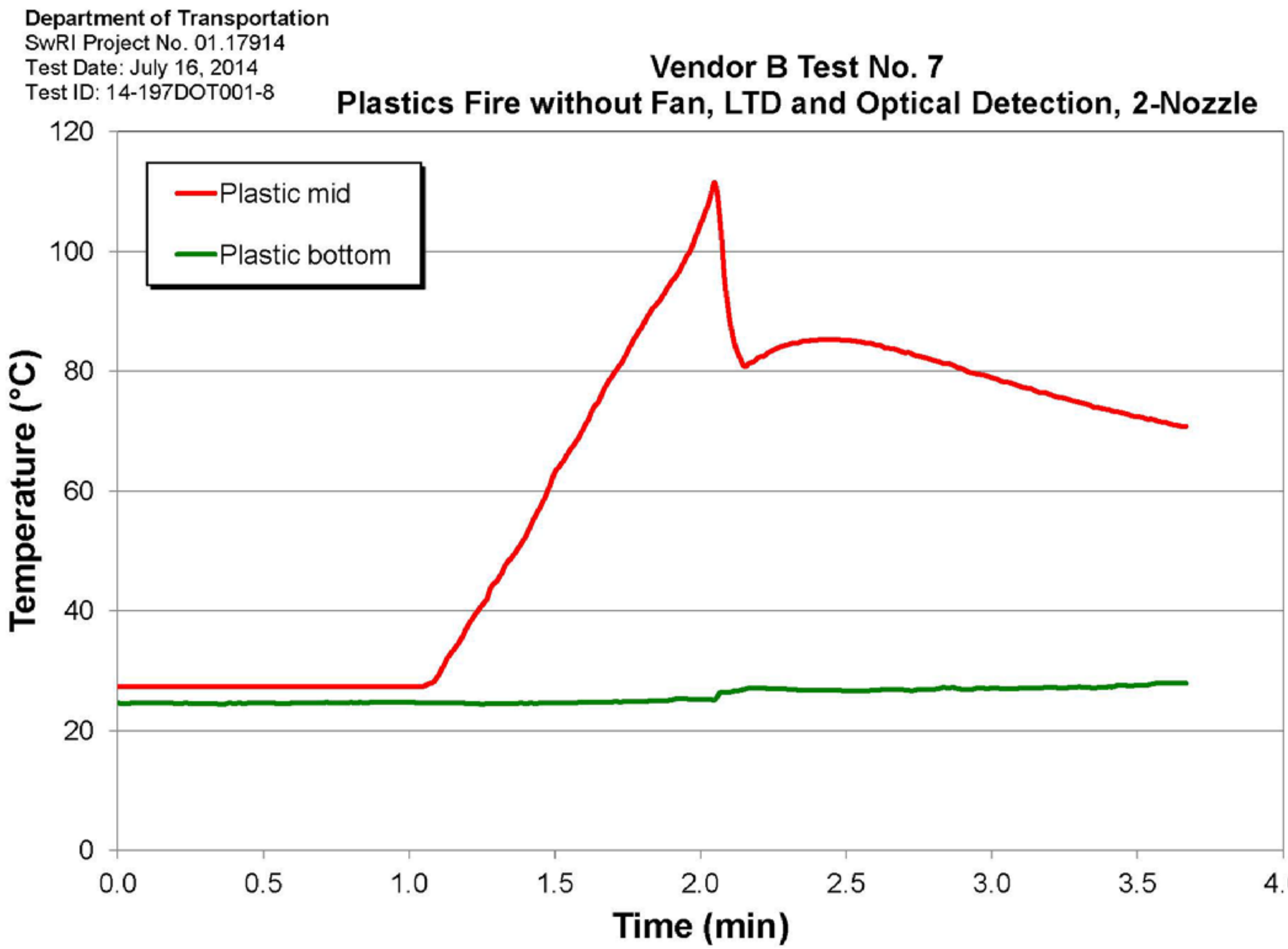

DOT/Kidde
SwRI Project No. 01.17914
Test Date: July 15, 2014
Test ID: 14-196DOT001-4
Vendor B Test No. 3
PSF Spray Fire with Fan, LTD and Optical Detection, 2-Nozzle
Power steering spray
Back right top
Back right bottom
Back left top
Back left bottom
Front left top
Front left middle
front left bottom
Power Steering Pressure
Temperature (°C)
Pressure (psig)
Time (min)
200
180
160
140
120
100
80
60
40
20
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0



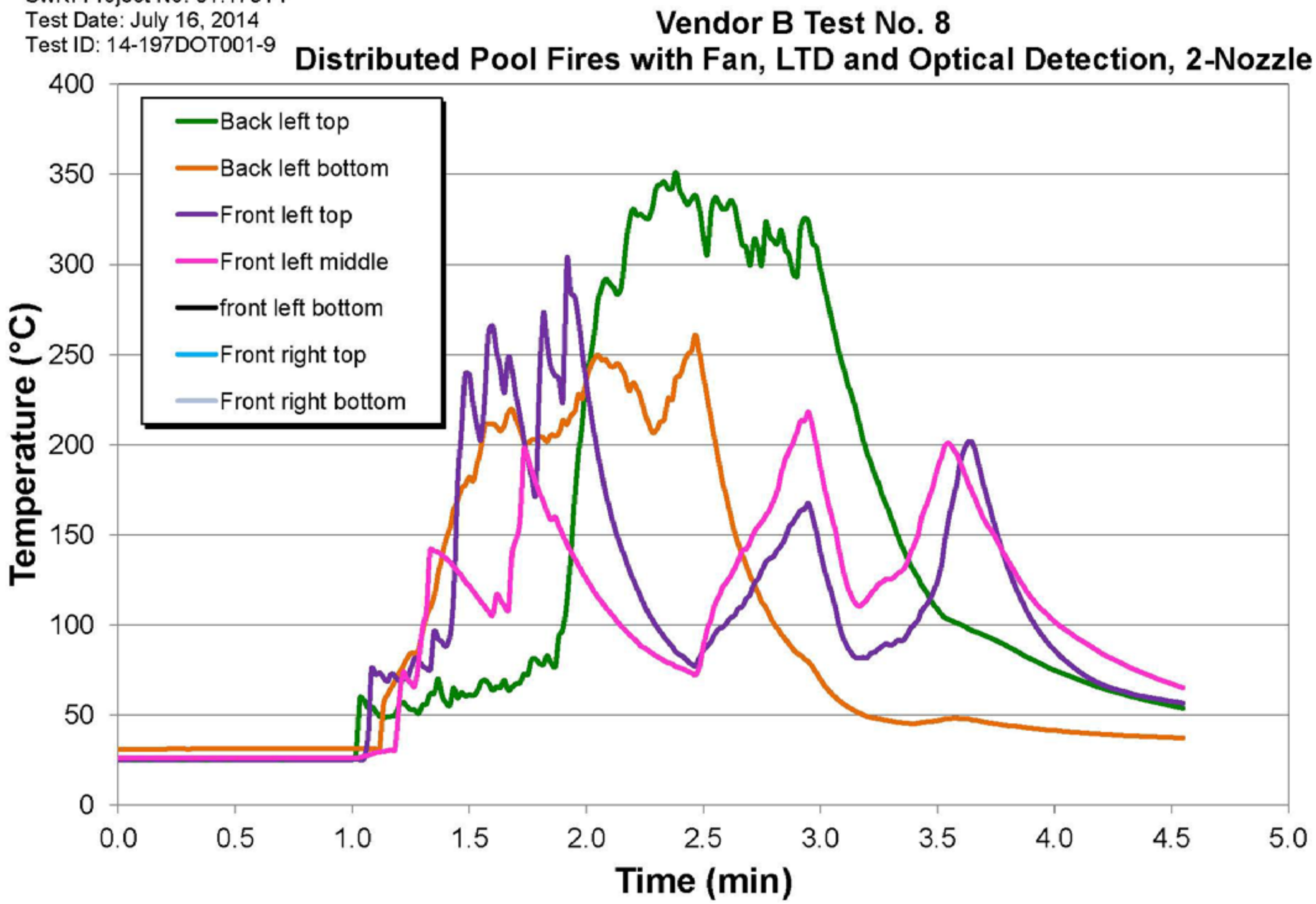
Department of Transportation
SwRI Project No. 01.17914
Test Date: July 15, 2014
Test ID: 14-196DOT001-5
Vendor B Test No. 4
PSF Spray Fire without Fan, LTD and Optical Detection, 2-Nozzle
Power steering spray
Back right top
Back right bottom
Back left top
Front left top
Front left middle
Front right top
Front right bottom
Power Steering Pressure
Temperature (°C)
Pressure (psig)
Time (min)
0
100
200
300
400
500
600
700
800
0
25
50
75
100
125
150
175
200
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0

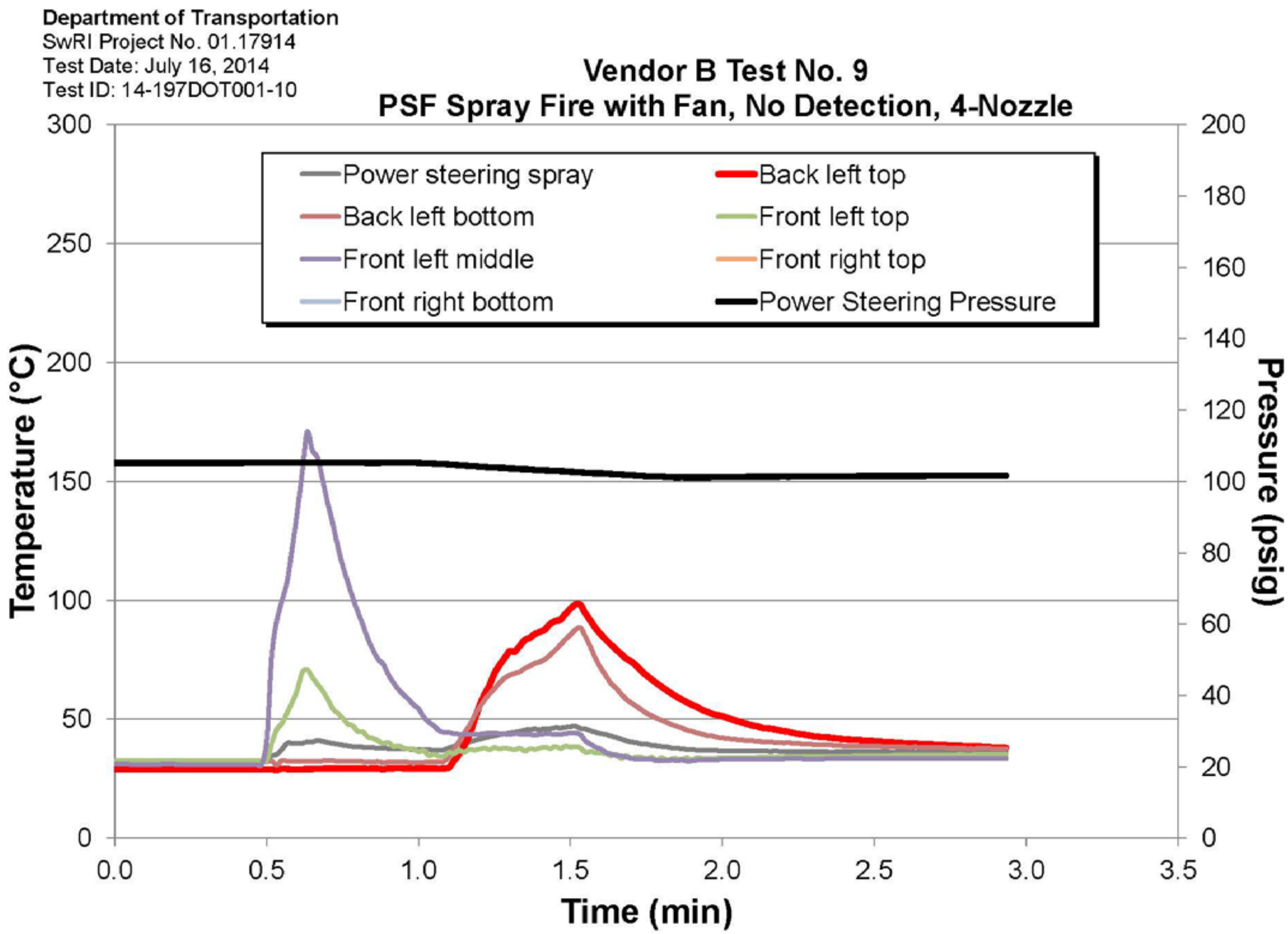

Department of Transportation
SwRI Project No. 01.17914
Test Date: July 16, 2014
Test ID: 14-197DOT001-6
Vendor B Test No. 5
Distributed Pool Fires without Fan, LTD and Optical Detection, 2-Nozzle
Temperature (°C)
Time (min)
0
100
200
300
400
500
600
700
800
0
1
2
3
4
5
6
7
8
9
10
Back right top
Back right bottom
Back left top
Back left bottom
Front left top
Front left middle
Front left bottom
Front right top
Front right bottom


Department of Transportation
SwRI Project No. 01.17914
Test Date: July 16, 2014
Test ID: 14-197DOT001-7
Vendor B Test No. 6
Distributed Pool Fires with Fan, LTD and Optical Detection, 2-Nozzle
Temperature (°C)
Time (min)
0
100
200
300
400
500
600
700
800
900
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Back right top
Back right bottom
Back left top
Back left bottom
Front left top
Front left middle
Front left bottom
Front right top
Front right bottom

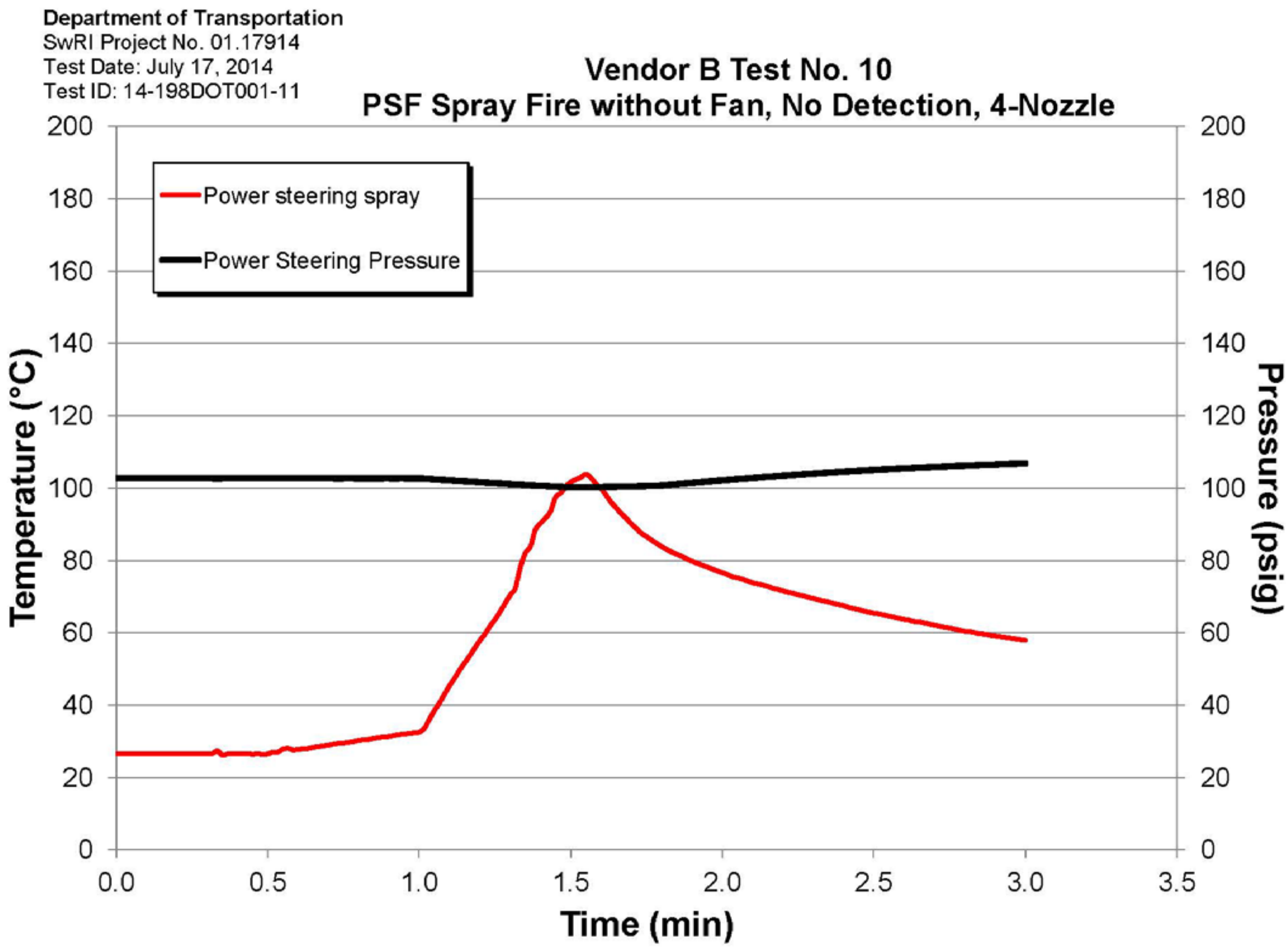

Department of Transportation
SwRI Project No. 01.17914
Test Date: July 16, 2014
Test ID: 14-197DOT001-8
Vendor B Test No. 7
Plastics Fire without Fan, LTD and Optical Detection, 2-Nozzle
Plastic mid
Plastic bottom
Temperature (°C)
Time (min)
0
20
40
60
80
100
120
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

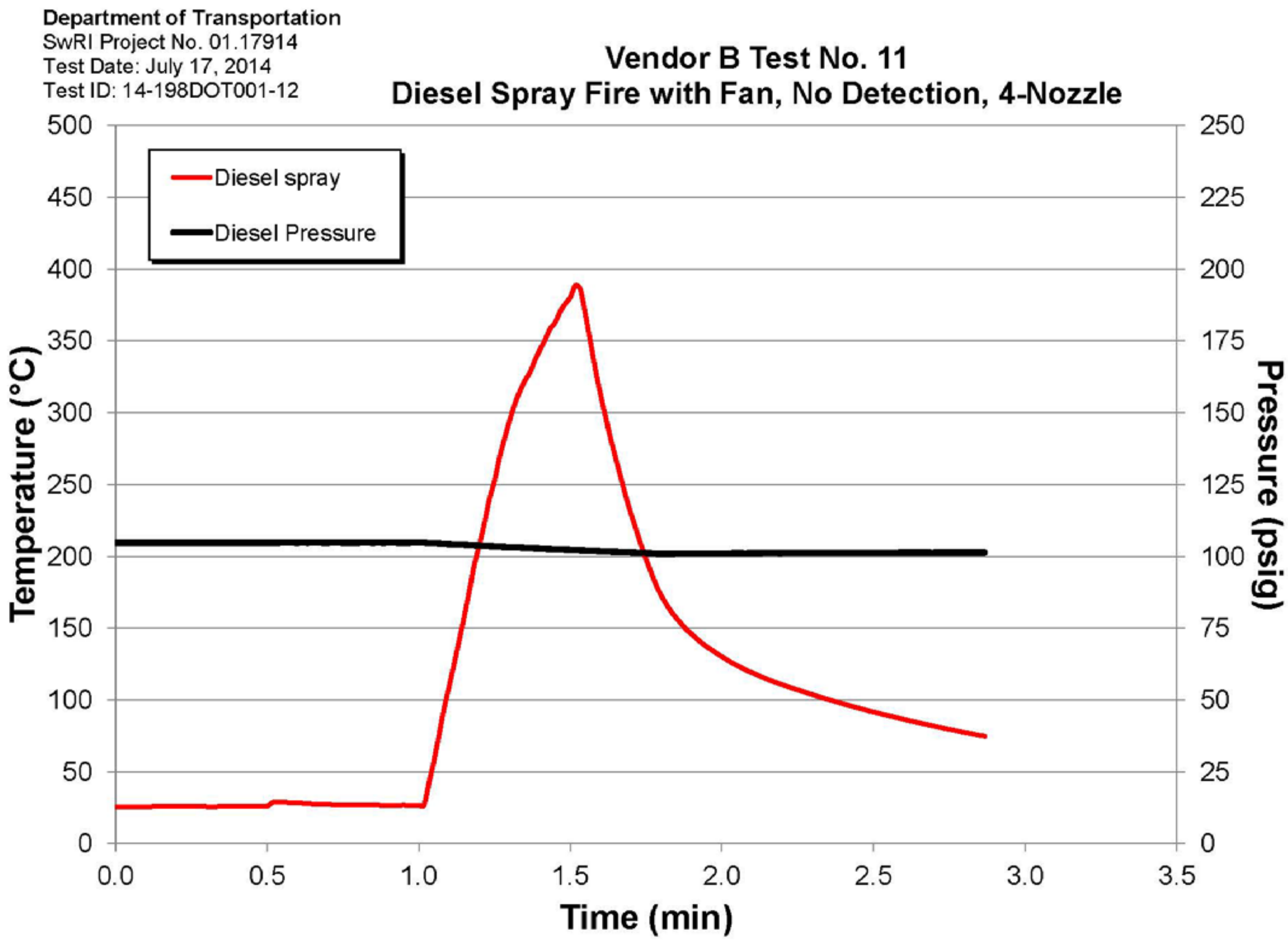
Department of Transportation
SwRI Project No. 01.17914
Test Date: July 16, 2014
Test ID: 14-197DOT001-9



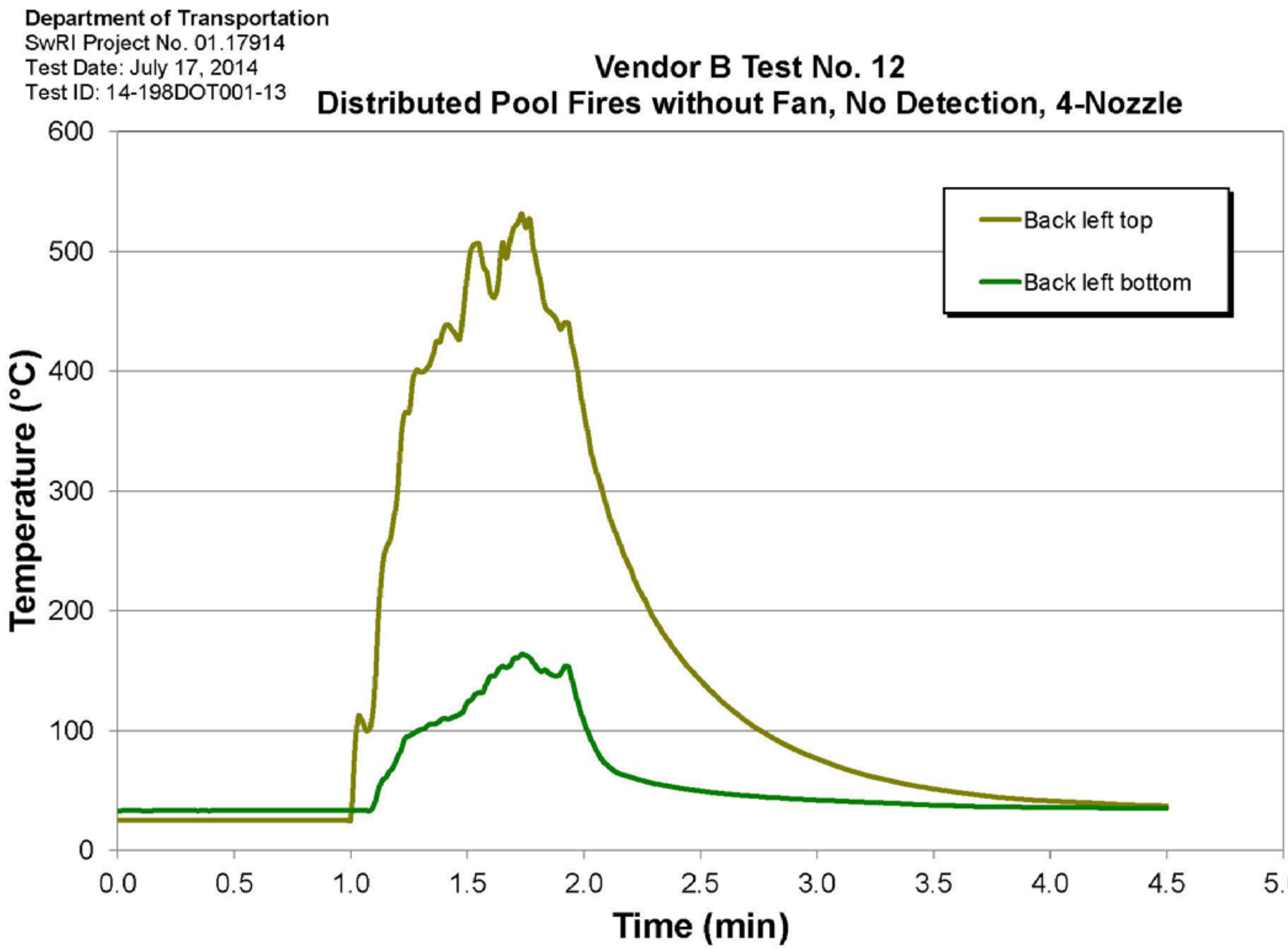


Department of Transportation
SwRI Project No. 01.17914
Test Date: July 16, 2014
Test ID: 14-197DOT001-10
Vendor B Test No. 9
PSF Spray Fire with Fan, No Detection, 4-Nozzle
Power steering spray
Back left top
Back left bottom
Front left top
Front left middle
Front right top
Front right bottom
Power Steering Pressure
Temperature (°C)
Pressure (psig)
Time (min)
0
50
100
150
200
250
300
0
20
40
60
80
100
120
140
160
180
200
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5

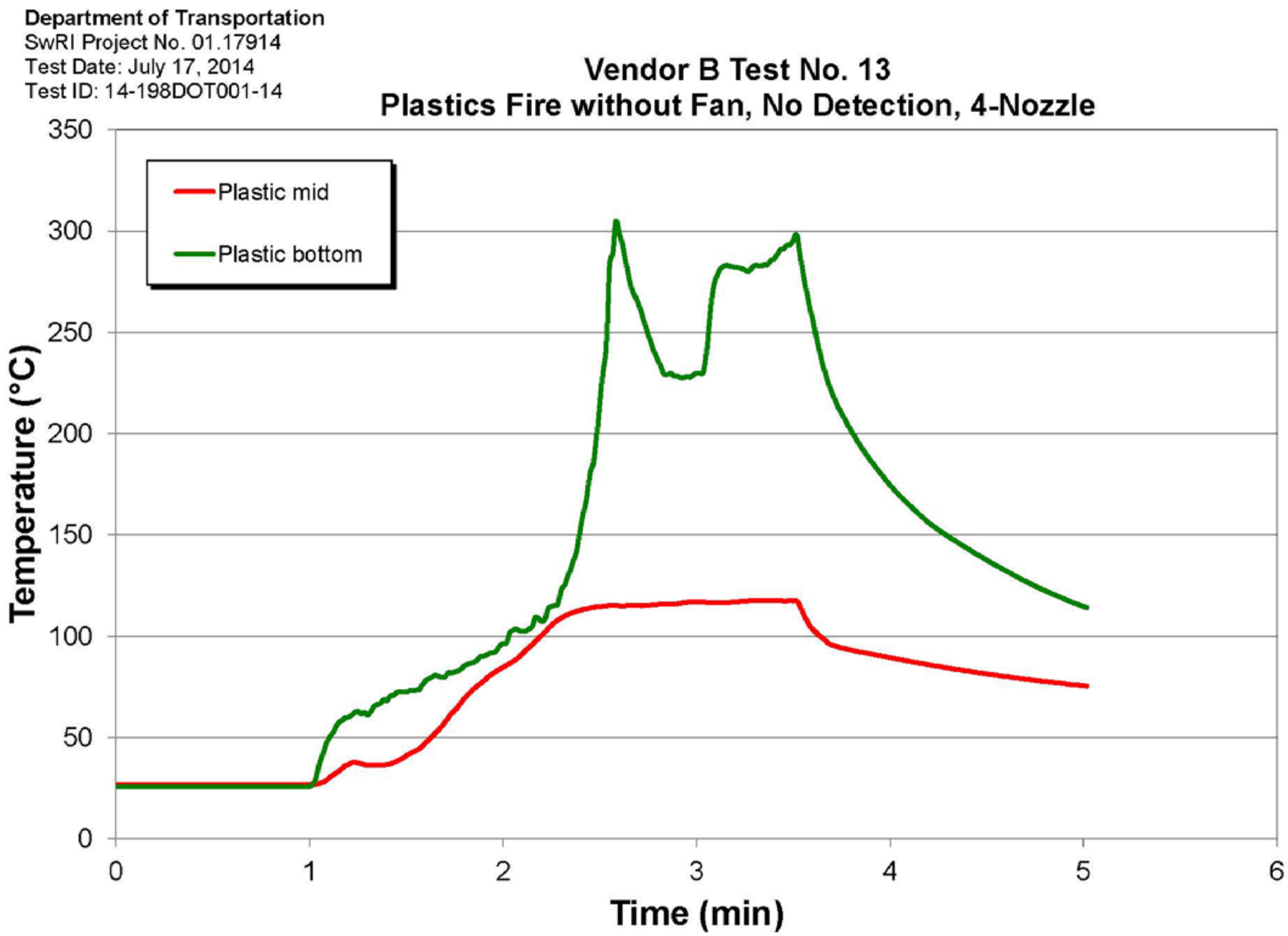

Department of Transportation
SwRI Project No. 01.17914
Test Date: July 17, 2014
Test ID: 14-198DOT001-11
Vendor B Test No. 10
PSF Spray Fire without Fan, No Detection, 4-Nozzle
Power steering spray
Power Steering Pressure
Temperature (°C)
Pressure (psig)
Time (min)
0
20
40
60
80
100
120
140
160
180
200
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5

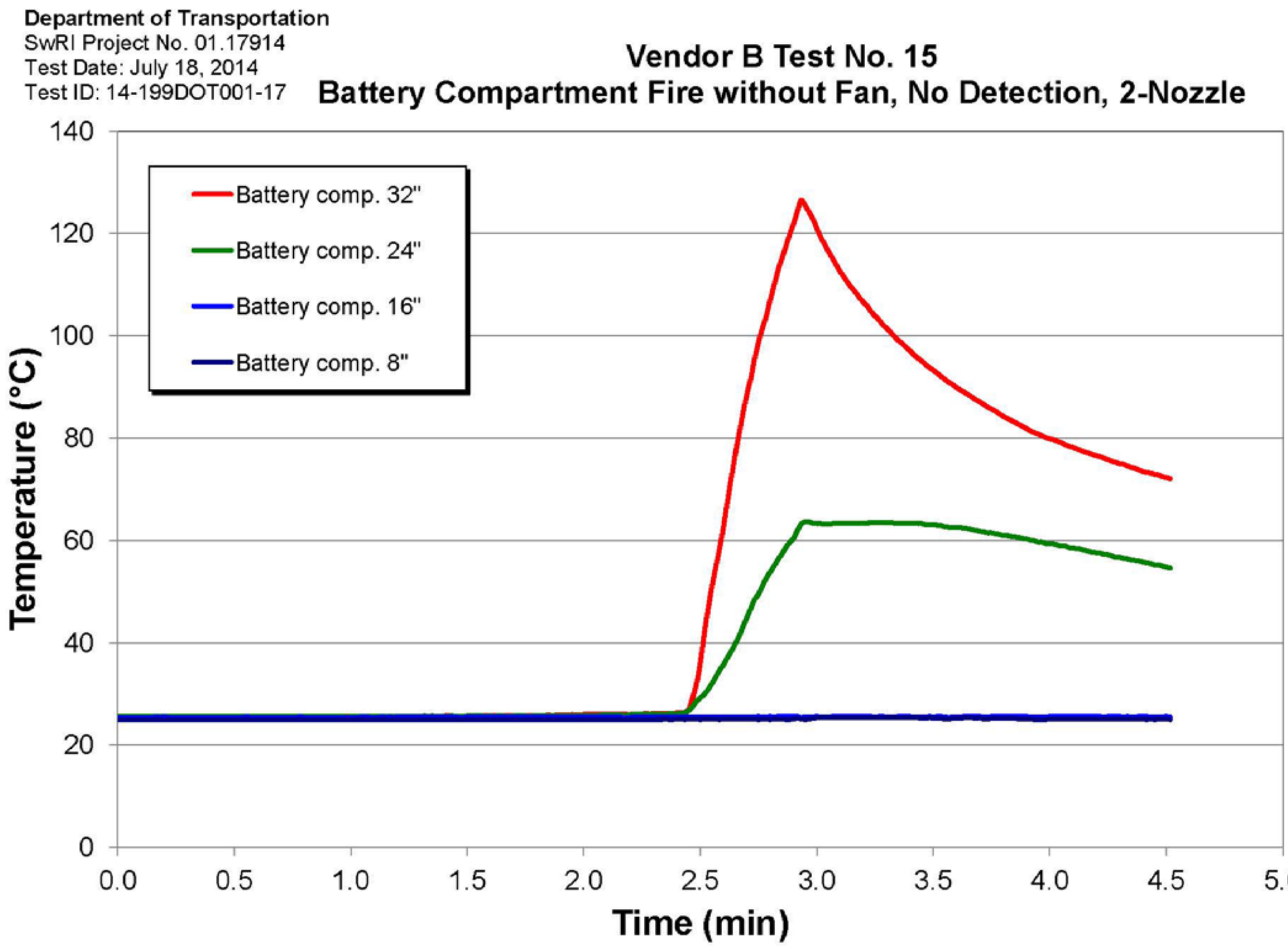


Department of Transportation
SwRI Project No. 01.17914
Test Date: July 17, 2014
Test ID: 14-198DOT001-12
Vendor B Test No. 11
Diesel Spray Fire with Fan, No Detection, 4-Nozzle
Diesel spray
Diesel Pressure
Temperature (°C)
Pressure (psig)
Time (min)
0
50
100
150
200
250
300
350
400
450
500
0
25
50
75
100
125
150
175
200
225
250
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5

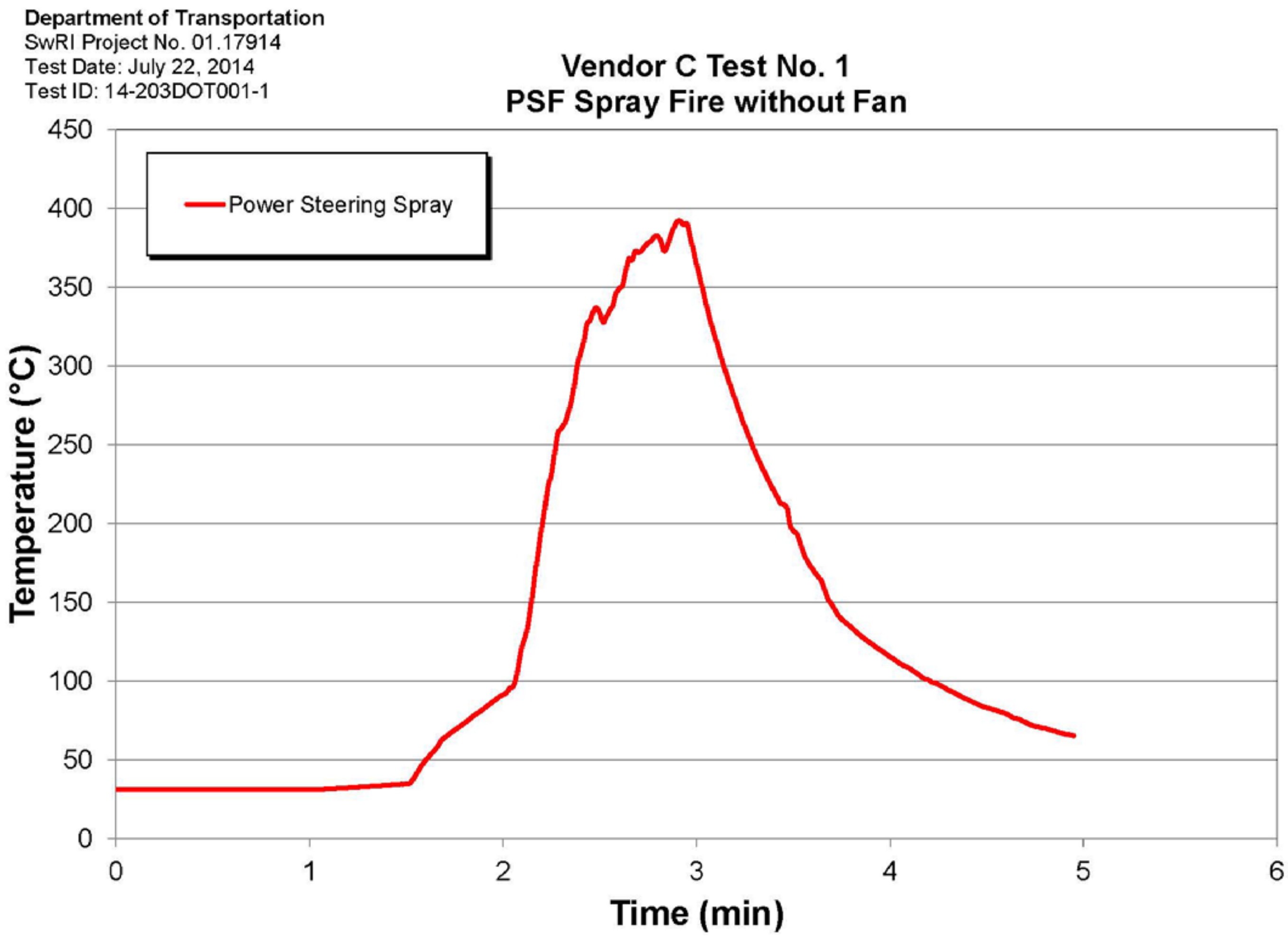


Department of Transportation
SwRI Project No. 01.17914
Test Date: July 17, 2014
Test ID: 14-198DOT001-13
Vendor B Test No. 12
Distributed Pool Fires without Fan, No Detection, 4-Nozzle
Temperature (°C)
Time (min)
Back left top
Back left bottom
0
100
200
300
400
500
600
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0

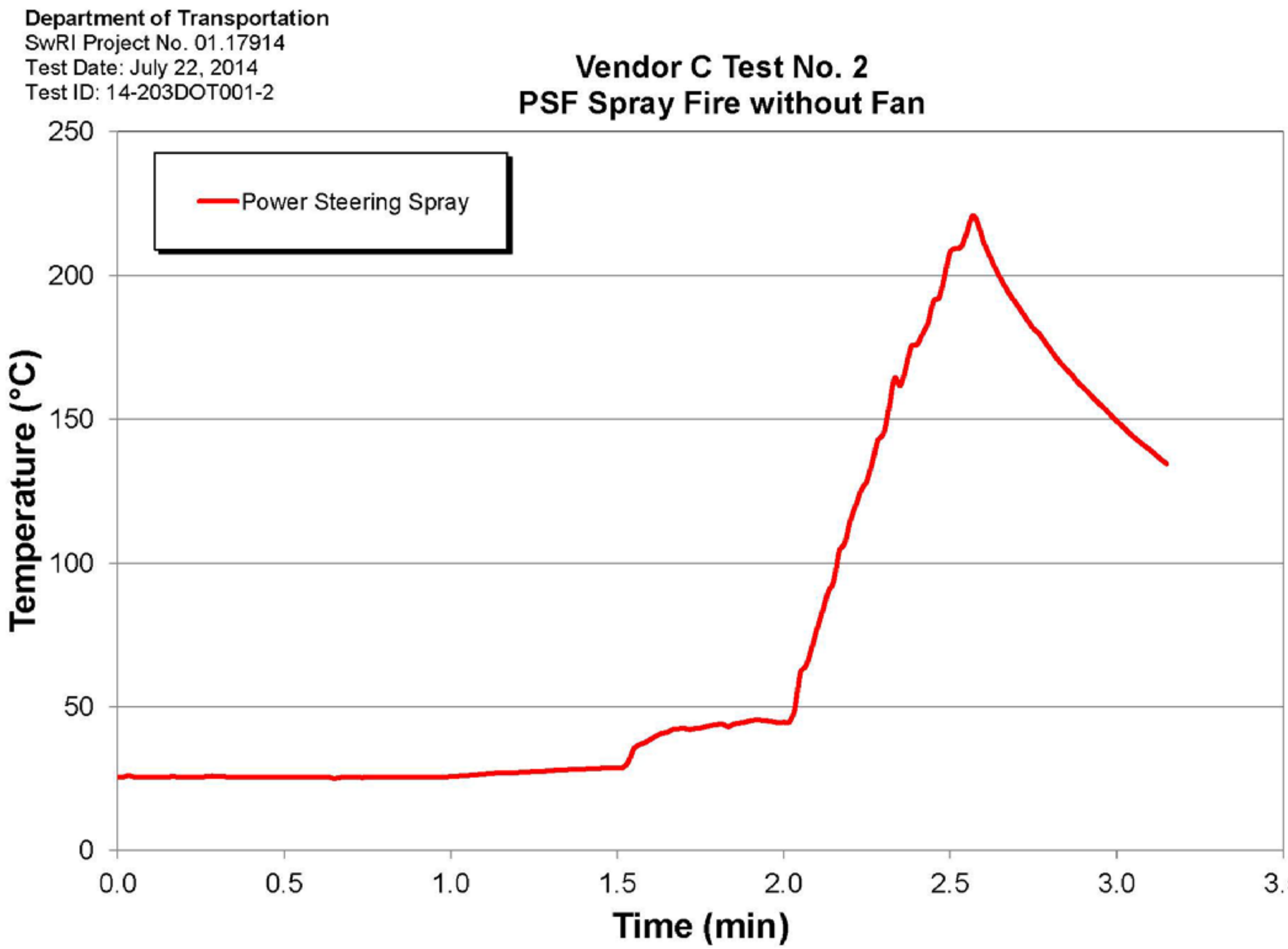

Department of Transportation
SwRI Project No. 01.17914
Test Date: July 17, 2014
Test ID: 14-198DOT001-14
Vendor B Test No. 13
Plastics Fire without Fan, No Detection, 4-Nozzle
Plastic mid
Plastic bottom
Temperature (°C)
Time (min)
0
50
100
150
200
250
300
350
0
1
2
3
4
5
6

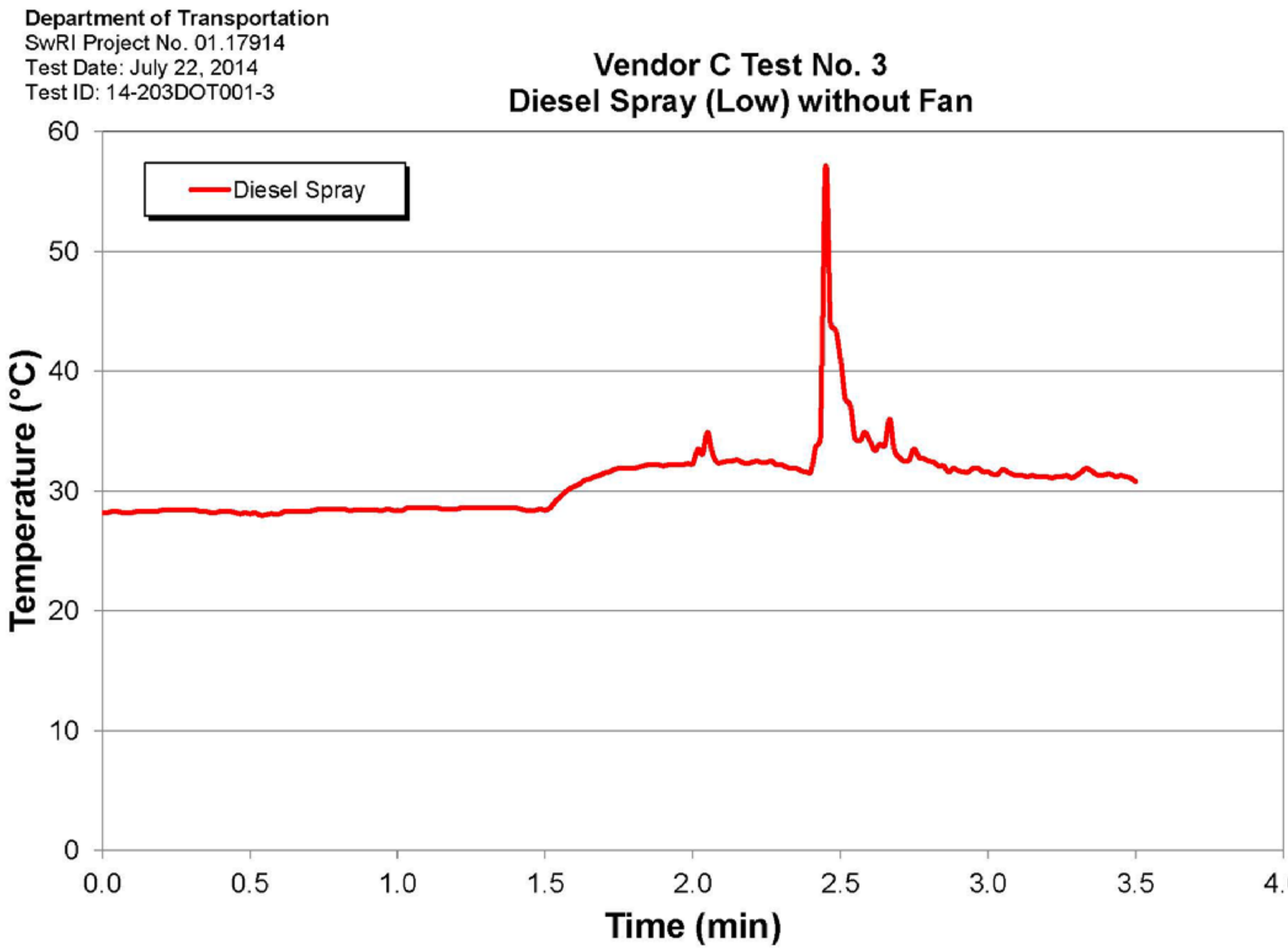

Department of Transportation
SwRI Project No. 01.17914
Test Date: July 18, 2014
Test ID: 14-199DOT001-17
Vendor B Test No. 15
Battery Compartment Fire without Fan, No Detection, 2-Nozzle
Battery comp. 32"
Battery comp. 24"
Battery comp. 16"
Battery comp. 8"
Temperature (°C)
Time (min)
0
20
40
60
80
100
120
140
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0

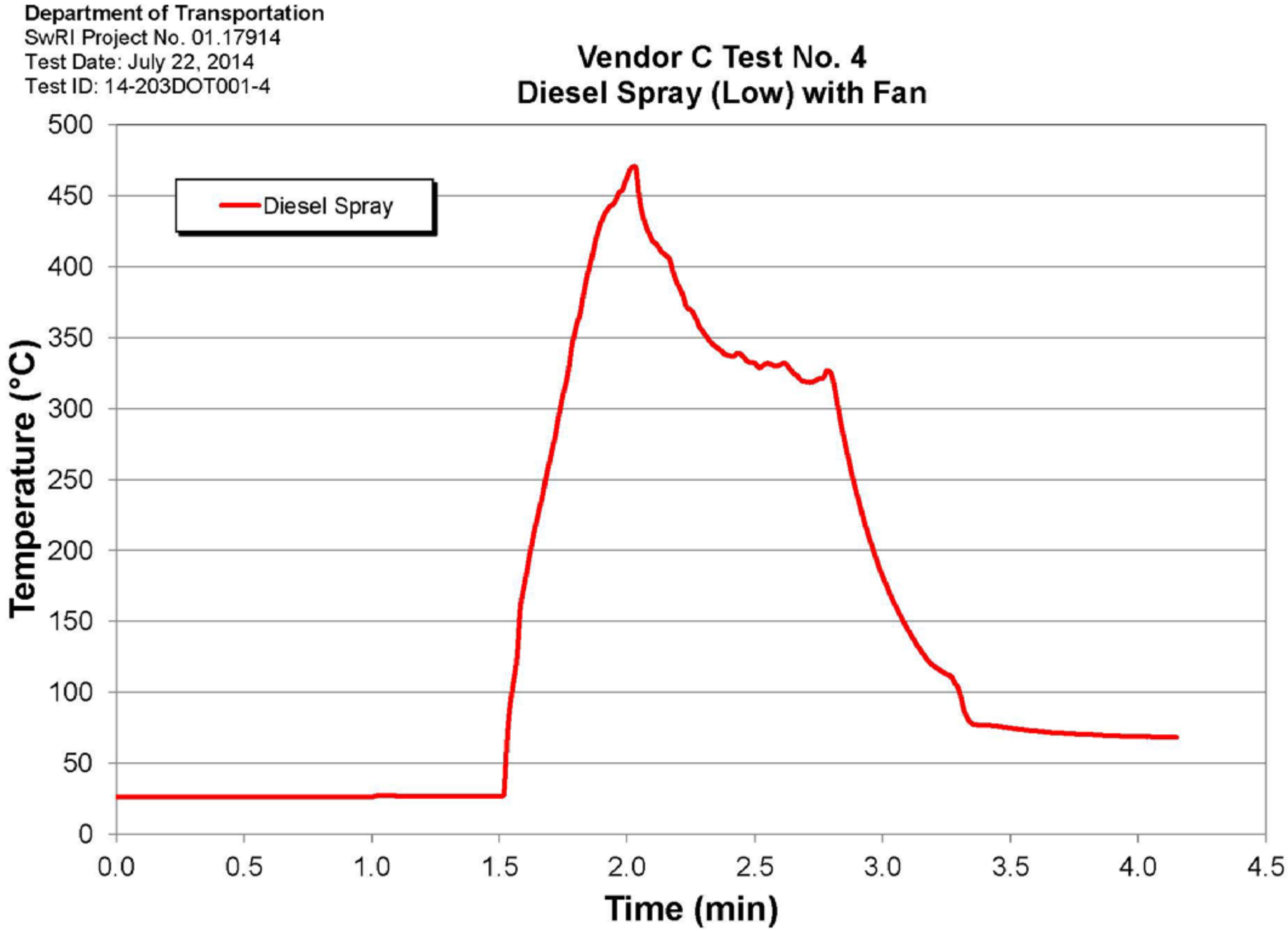
APPENDIX G
ENGINE COMPARTMENT VENDOR C TEST DATA
(CONSISTING OF 26 PAGES)

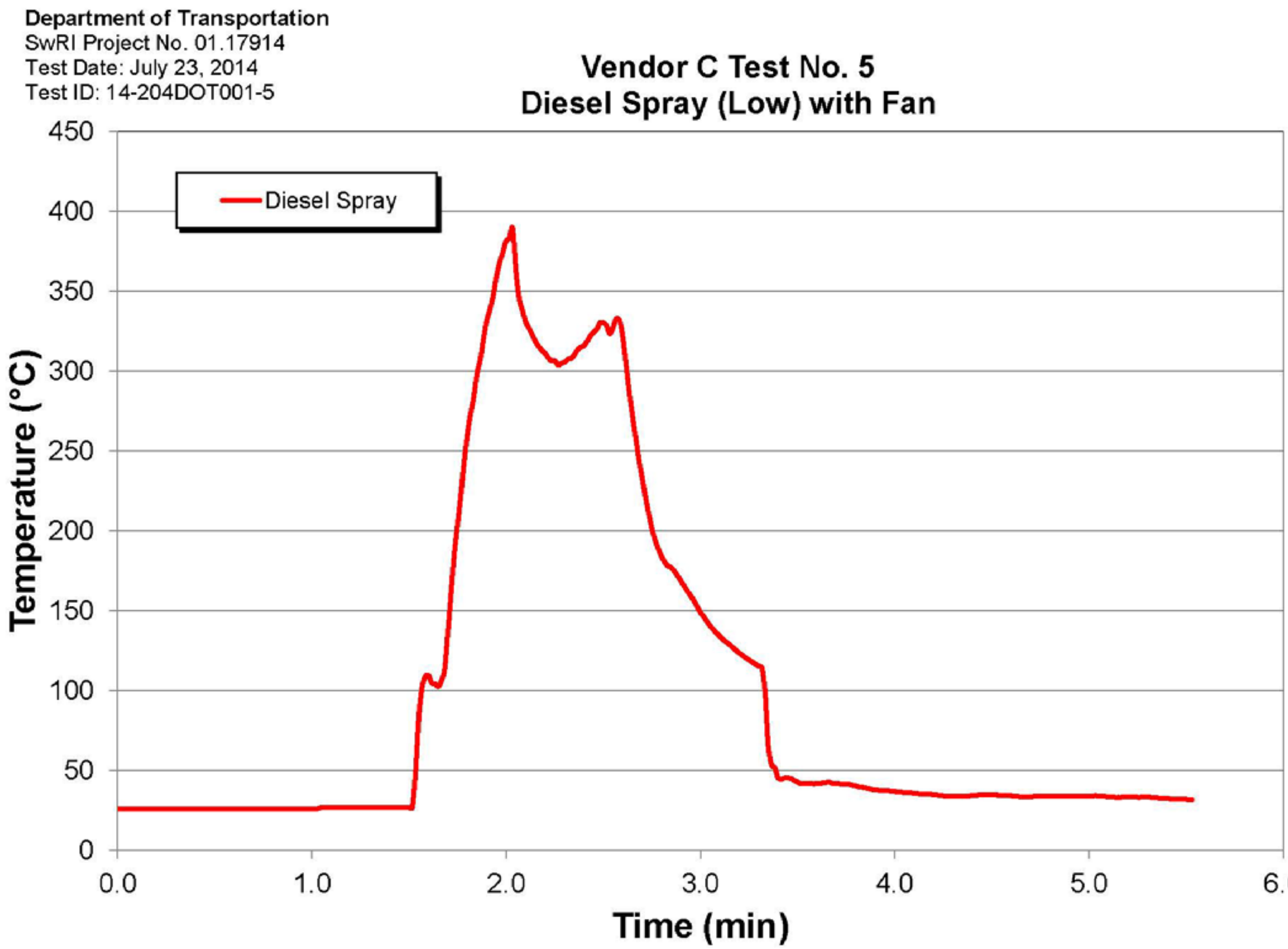


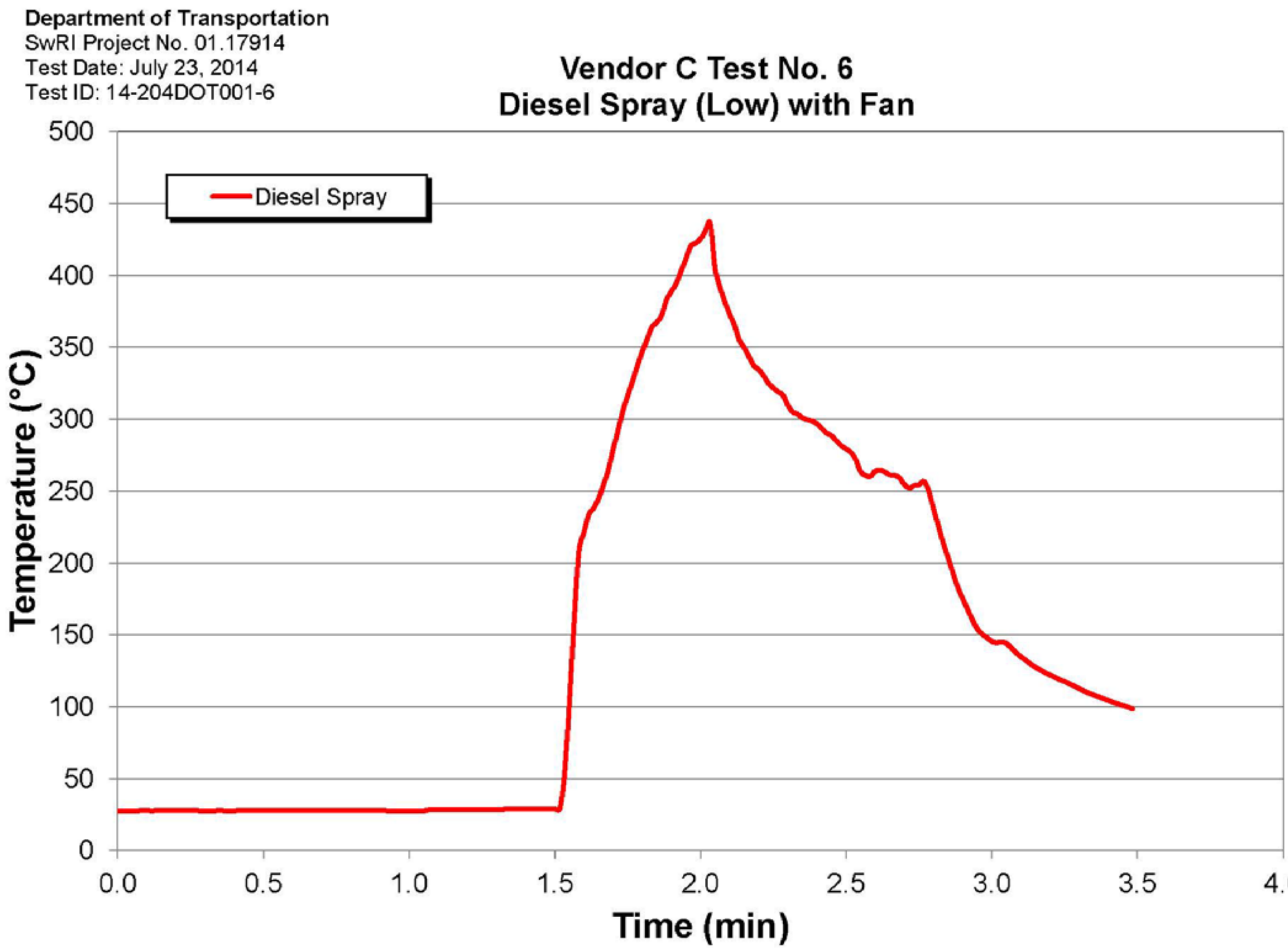
Department of Transportation
SwRI Project No. 01.17914
Test Date: July 22, 2014
Test ID: 14-203DOT001-1
Vendor C Test No. 1
PSF Spray Fire without Fan
Power Steering Spray
Temperature (°C)
Time (min)
0
50
100
150
200
250
300
350
400
450
0
1
2
3
4
5
6

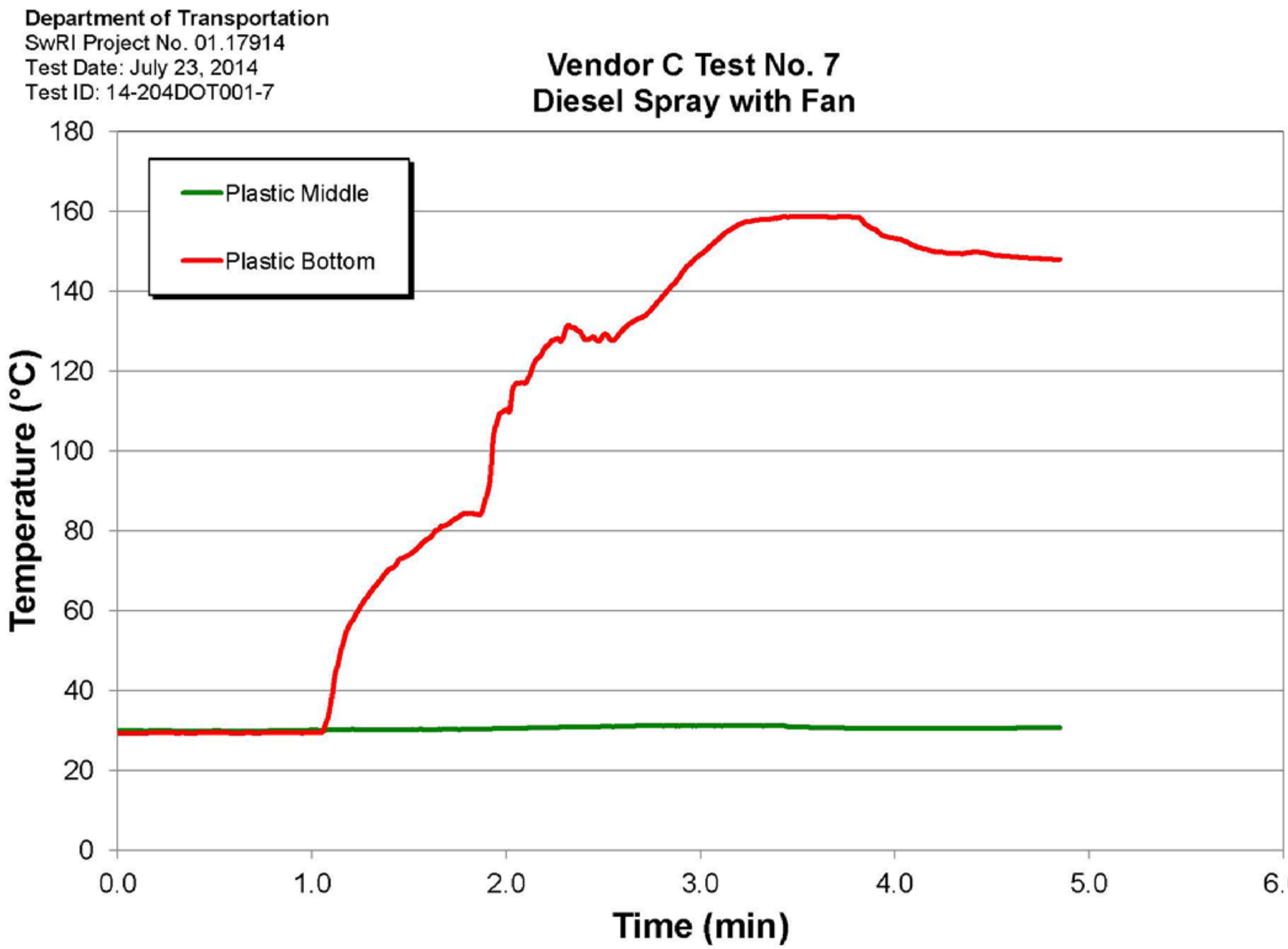

Department of Transportation
SwRI Project No. 01.17914
Test Date: July 22, 2014
Test ID: 14-203DOT001-2
Vendor C Test No. 2
PSF Spray Fire without Fan
Power Steering Spray
Temperature (°C)
250
200
150
100
50
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Time (min)

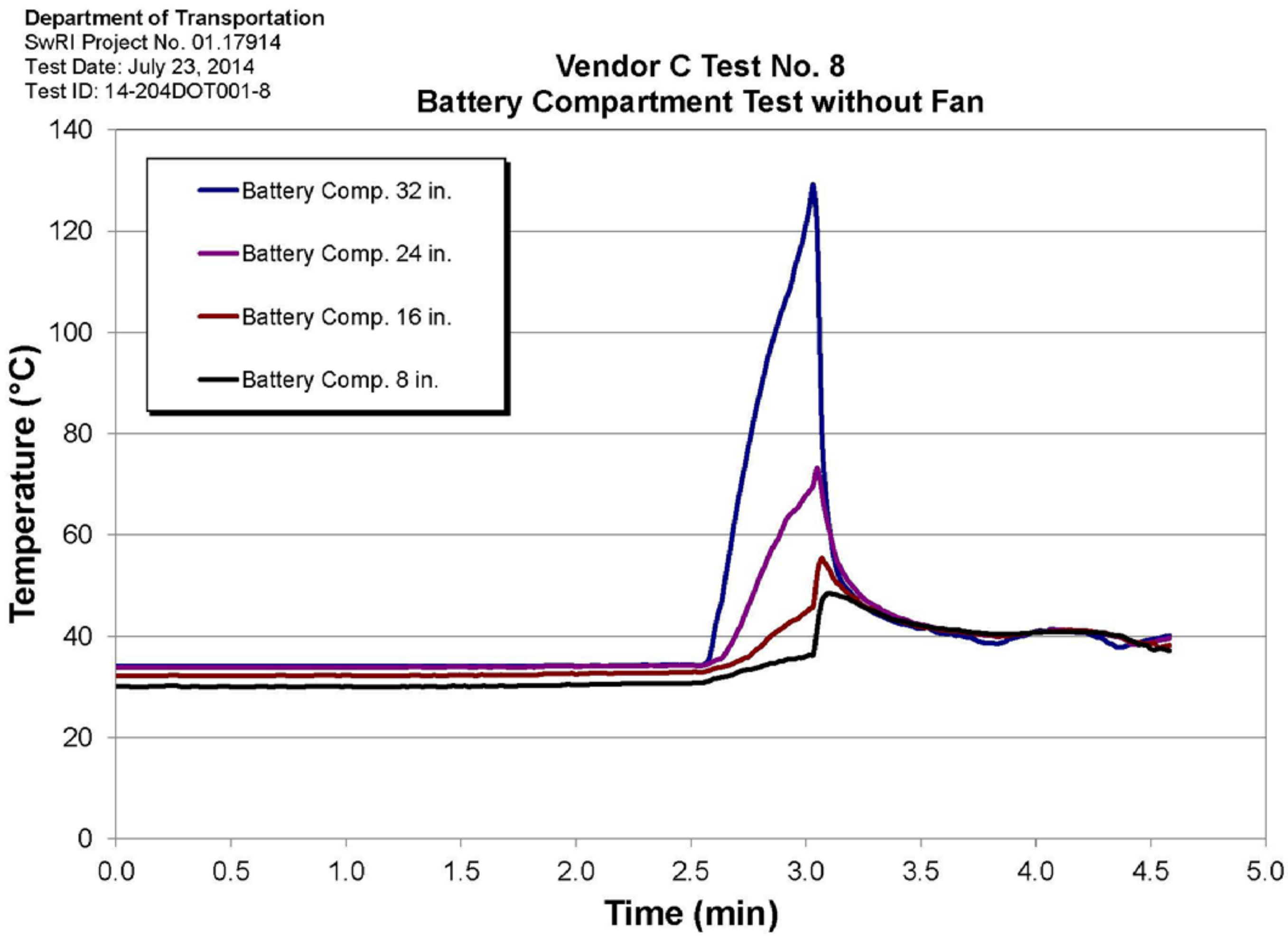

Department of Transportation
SwRI Project No. 01.17914
Test Date: July 22, 2014
Test ID: 14-203DOT001-3
Vendor C Test No. 3
Diesel Spray (Low) without Fan
Diesel Spray
Temperature (°C)
Time (min)
0
10
20
30
40
50
60
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

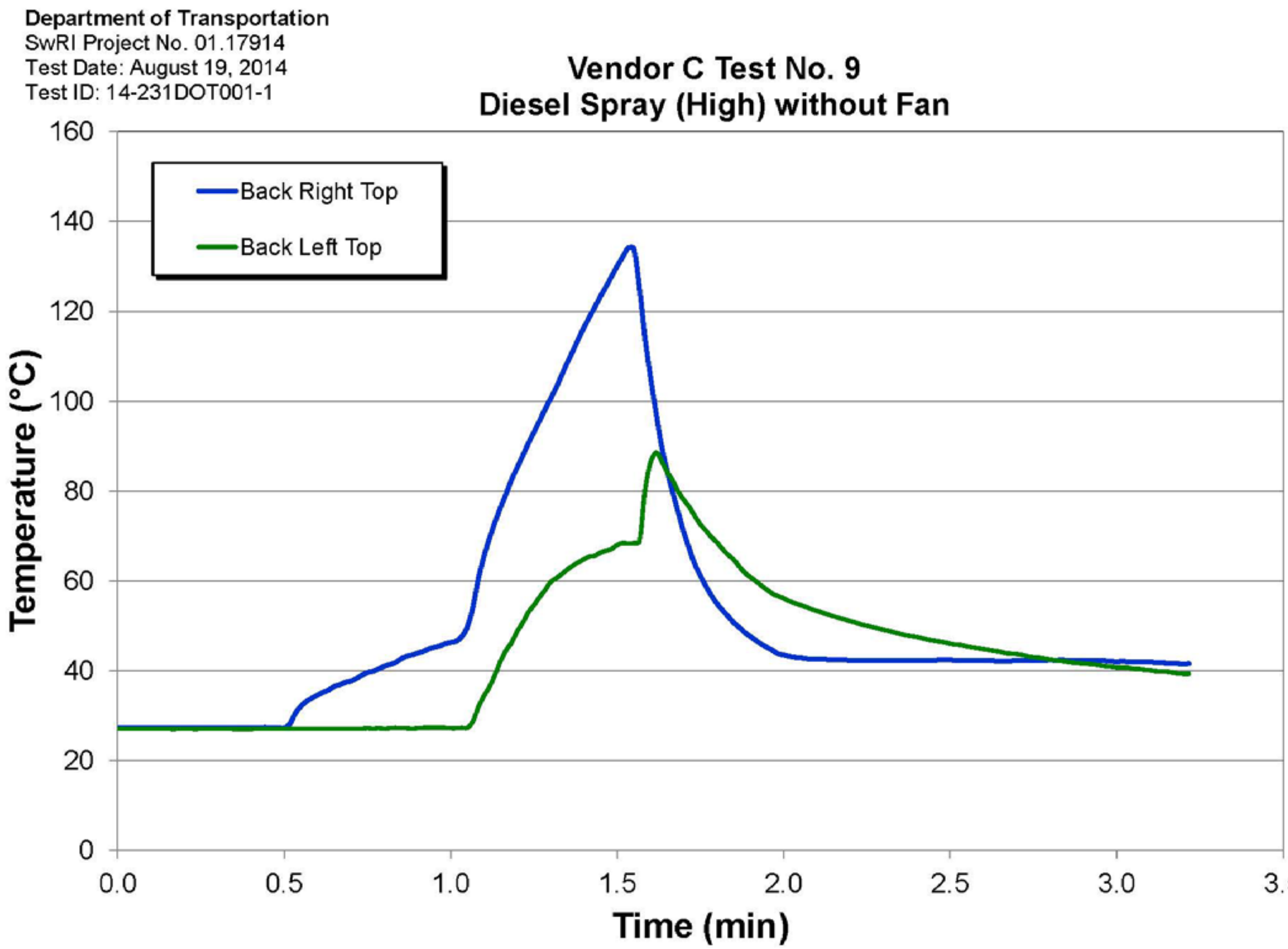

Department of Transportation
SwRI Project No. 01.17914
Test Date: July 22, 2014
Test ID: 14-203DOT001-4
Vendor C Test No. 4
Diesel Spray (Low) with Fan
Diesel Spray
Temperature (°C)
Time (min)
0
50
100
150
200
250
300
350
400
450
500
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5


Department of Transportation
SwRI Project No. 01.17914
Test Date: July 23, 2014
Test ID: 14-204DOT001-5
Vendor C Test No. 5
Diesel Spray (Low) with Fan
Diesel Spray
Temperature (°C)
Time (min)
0
50
100
150
200
250
300
350
400
450
0.0
1.0
2.0
3.0
4.0
5.0
6.0

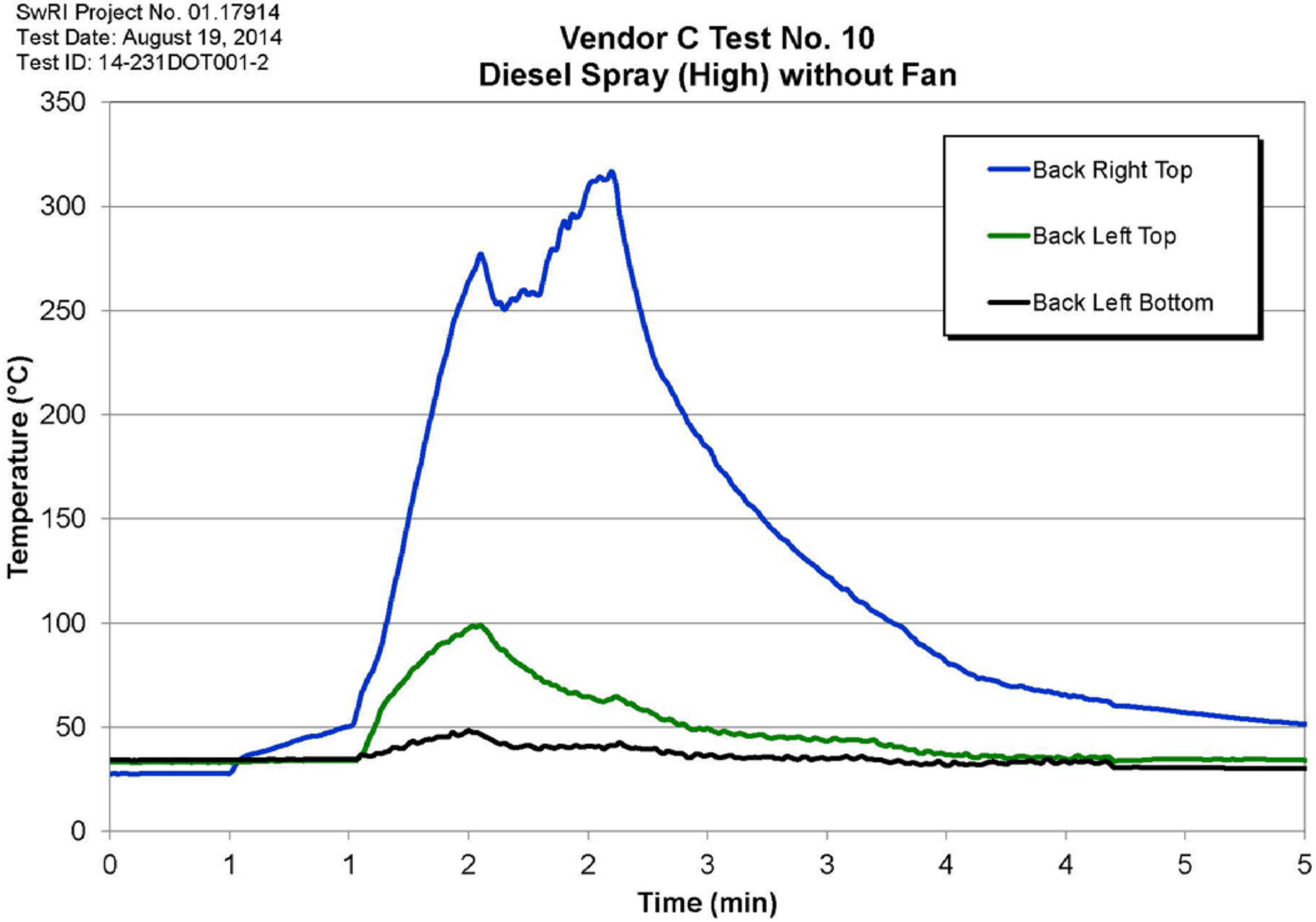

Department of Transportation
SwRI Project No. 01.17914
Test Date: July 23, 2014
Test ID: 14-204DOT001-6
Vendor C Test No. 6
Diesel Spray (Low) with Fan
Diesel Spray
Temperature (°C)
Time (min)
0
50
100
150
200
250
300
350
400
450
500
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

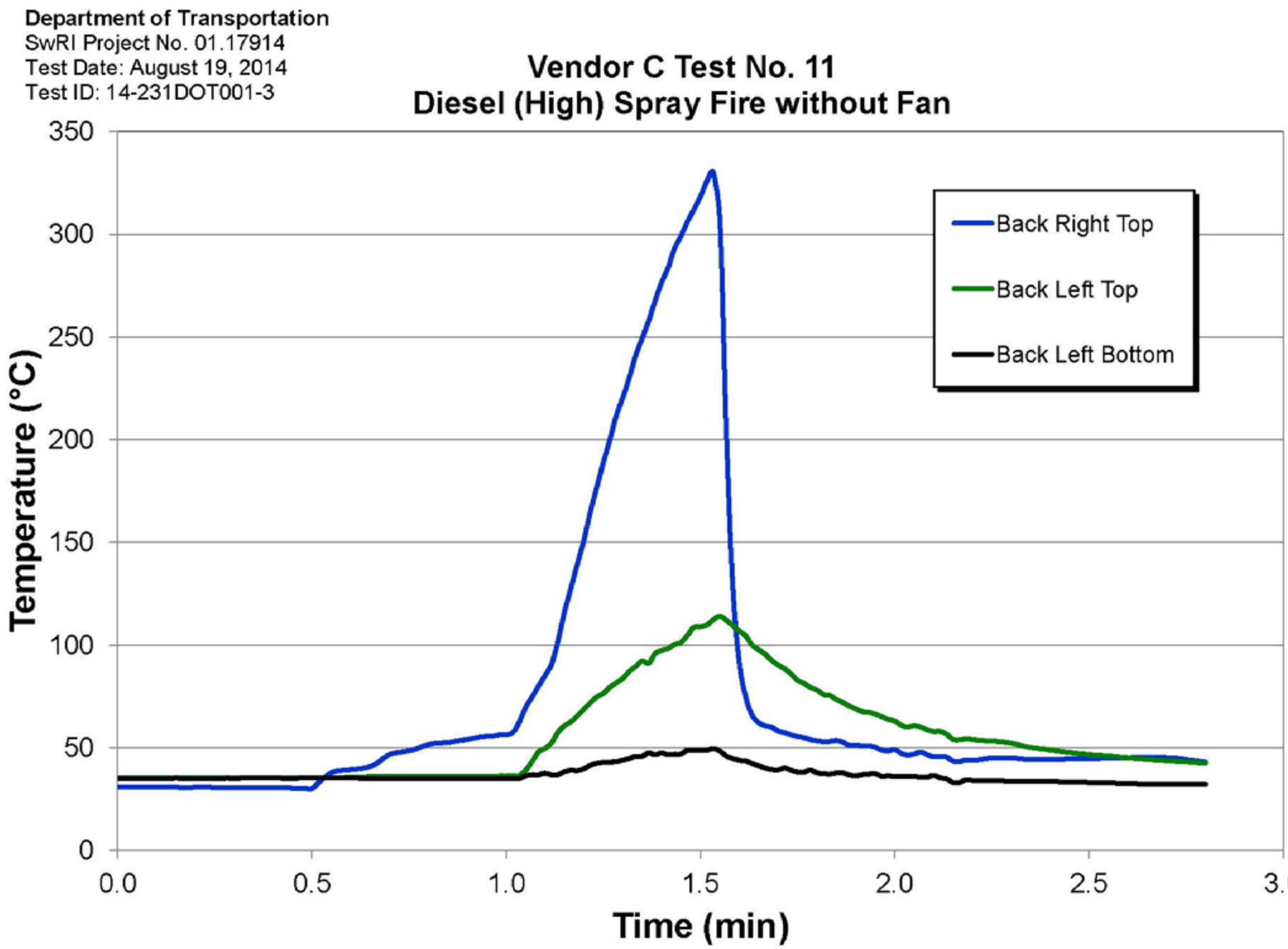

Department of Transportation
SwRI Project No. 01.17914
Test Date: July 23, 2014
Test ID: 14-204DOT001-7
Vendor C Test No. 7
Diesel Spray with Fan
Plastic Middle
Plastic Bottom
Temperature (°C)
Time (min)
0
20
40
60
80
100
120
140
160
180
0.0
1.0
2.0
3.0
4.0
5.0
6.0


Department of Transportation
SwRI Project No. 01.17914
Test Date: July 23, 2014
Test ID: 14-204DOT001-8
Vendor C Test No. 8
Battery Compartment Test without Fan
Battery Comp. 32 in.
Battery Comp. 24 in.
Battery Comp. 16 in.
Battery Comp. 8 in.
Temperature (°C)
140
120
100
80
60
40
20
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Time (min)

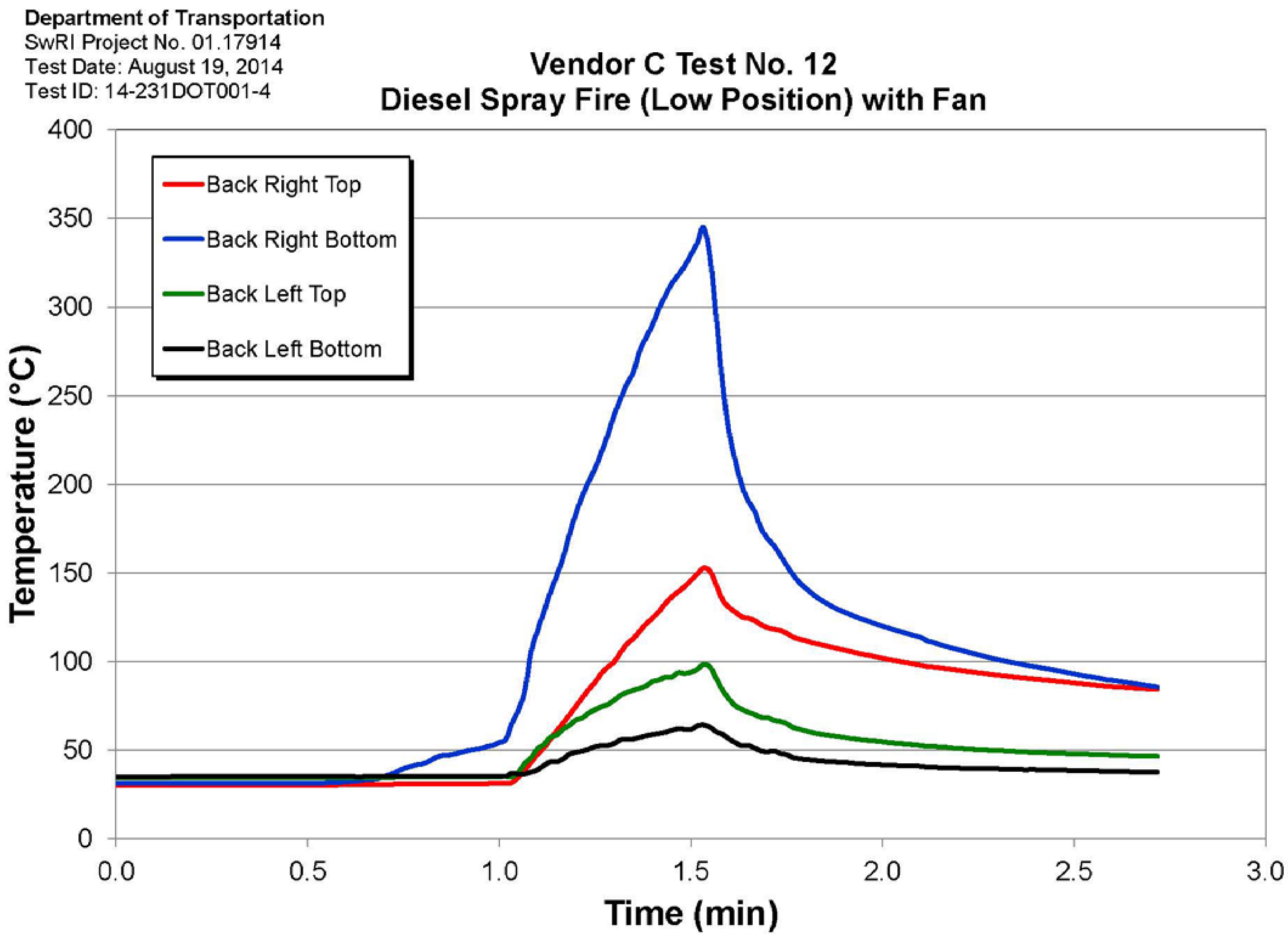

Department of Transportation
SwRI Project No. 01.17914
Test Date: August 19, 2014
Test ID: 14-231DOT001-1
Vendor C Test No. 9
Diesel Spray (High) without Fan
Back Right Top
Back Left Top
Temperature (°C)
Time (min)
0
20
40
60
80
100
120
140
160
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5

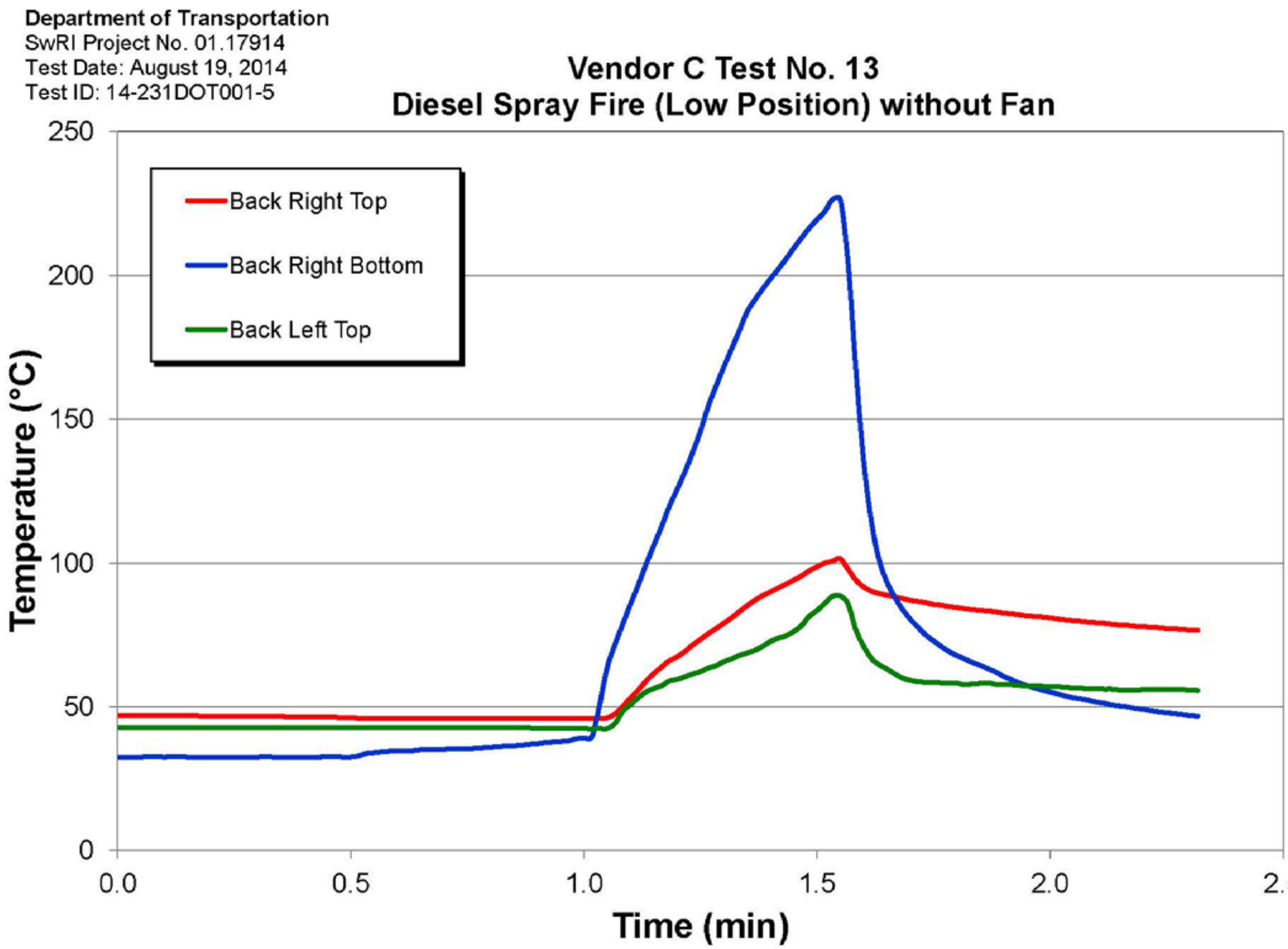
Department of Transportation
SwRI Project No. 01.17914
Test Date: August 19, 2014
Test ID: 14-231DOT001-2



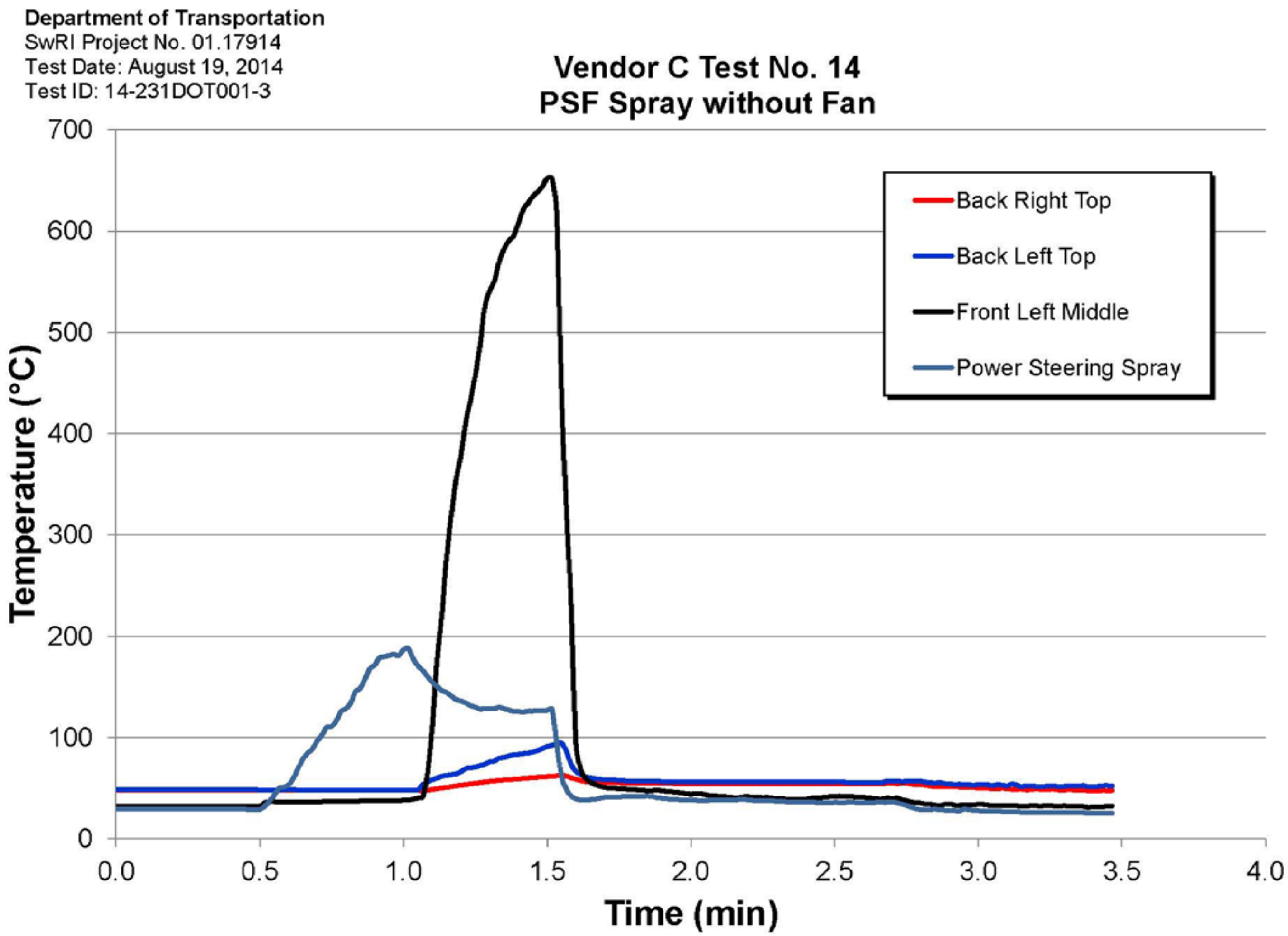


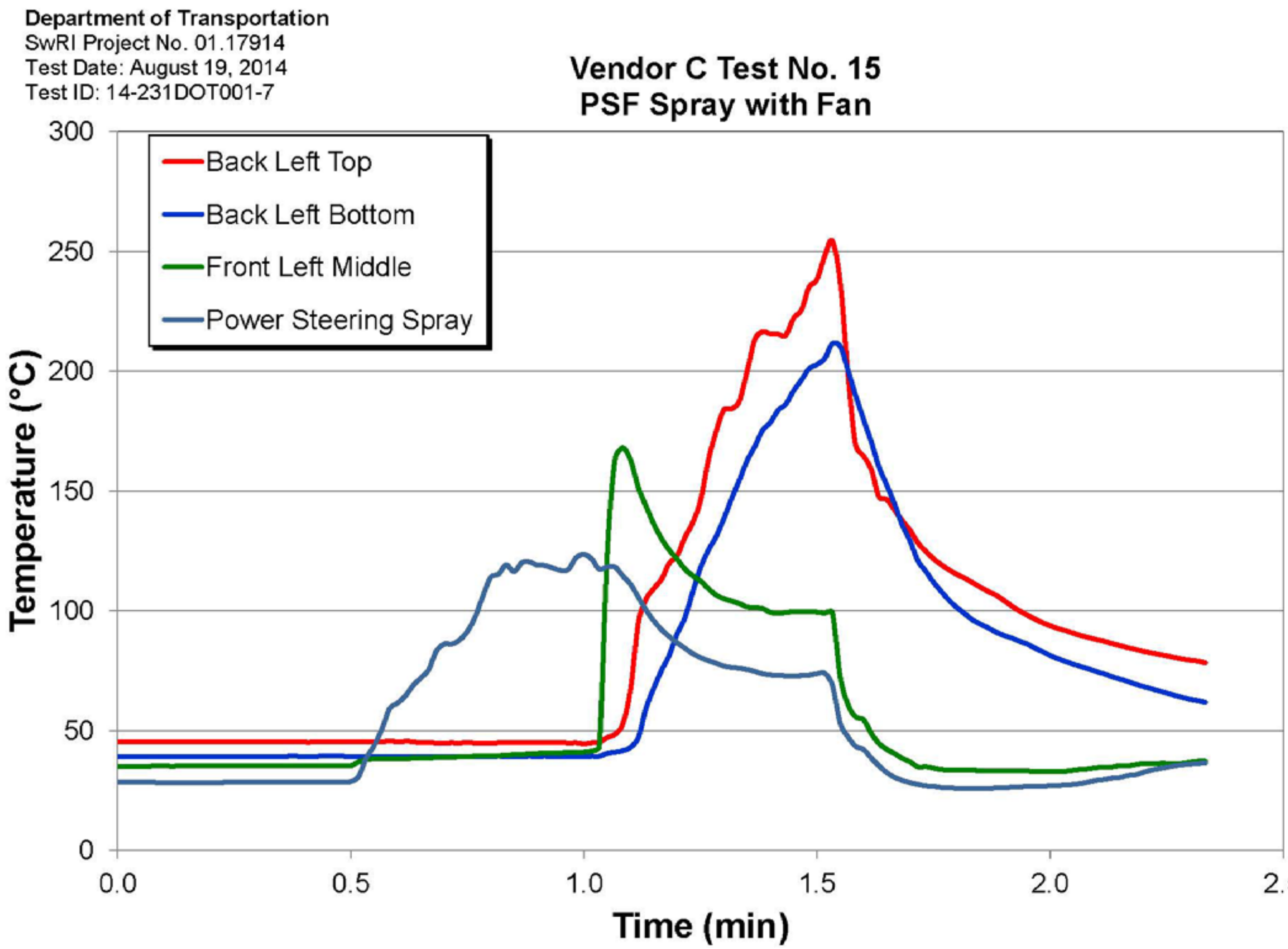
Department of Transportation
SwRI Project No. 01.17914
Test Date: August 19, 2014
Test ID: 14-231DOT001-3
Vendor C Test No. 11
Diesel (High) Spray Fire without Fan
Temperature (°C)
Time (min)
Back Right Top
Back Left Top
Back Left Bottom
0
50
100
150
200
250
300
350
0.0
0.5
1.0
1.5
2.0
2.5
3.0

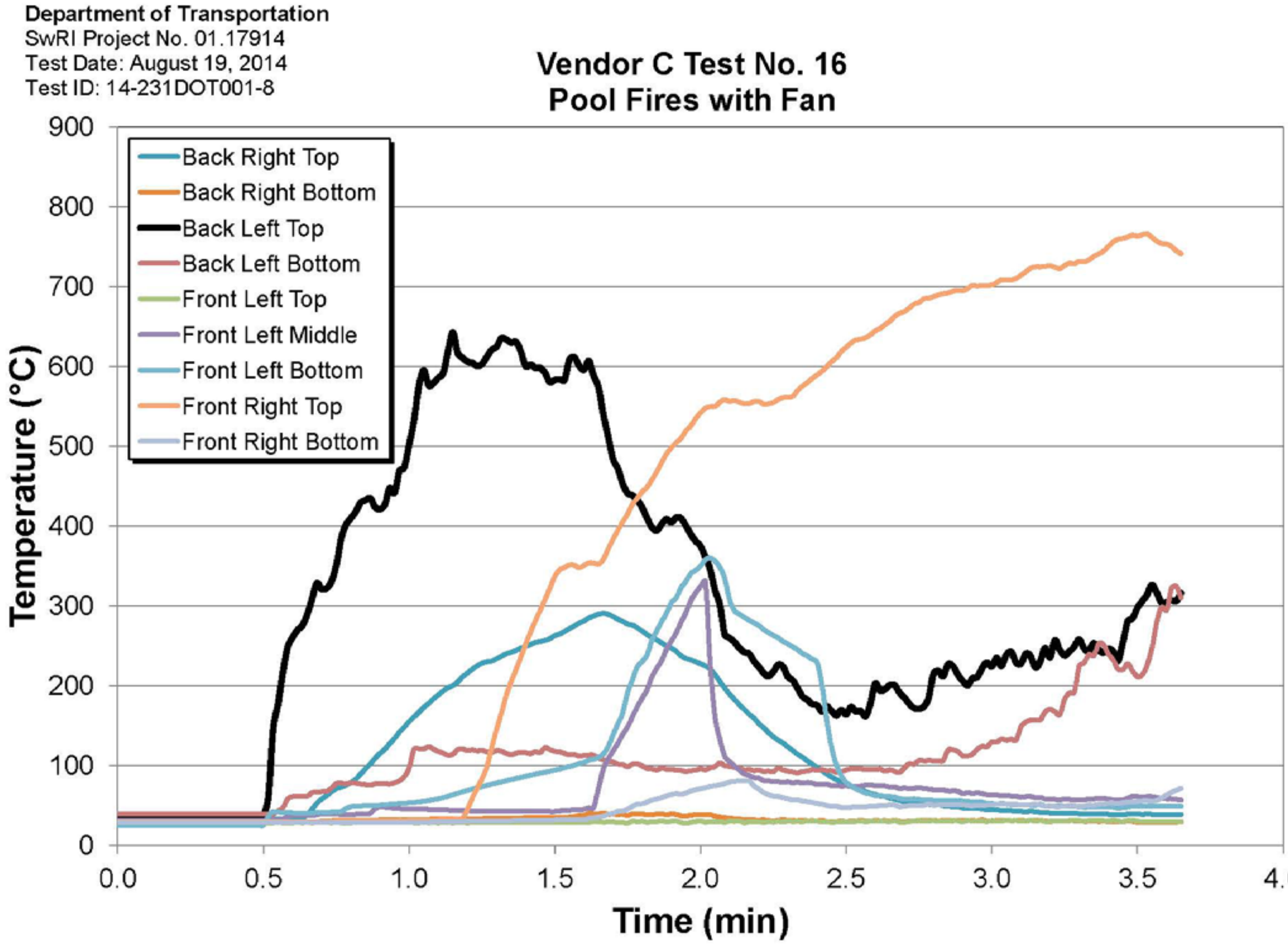

Department of Transportation
SwRI Project No. 01.17914
Test Date: August 19, 2014
Test ID: 14-231DOT001-4
Vendor C Test No. 12
Diesel Spray Fire (Low Position) with Fan
Back Right Top
Back Right Bottom
Back Left Top
Back Left Bottom
Temperature (°C)
Time (min)
0
50
100
150
200
250
300
350
400
0.0
0.5
1.0
1.5
2.0
2.5
3.0

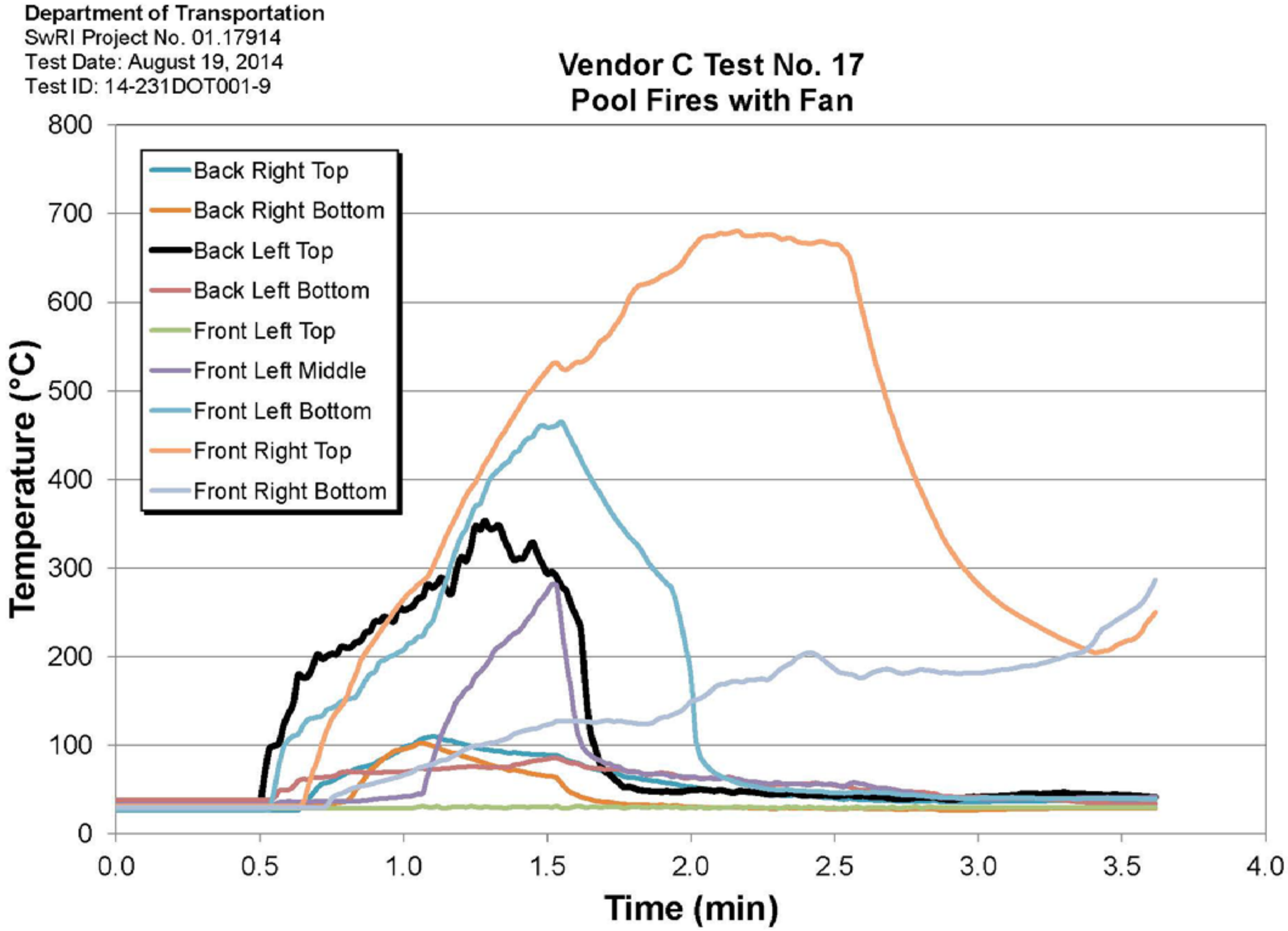


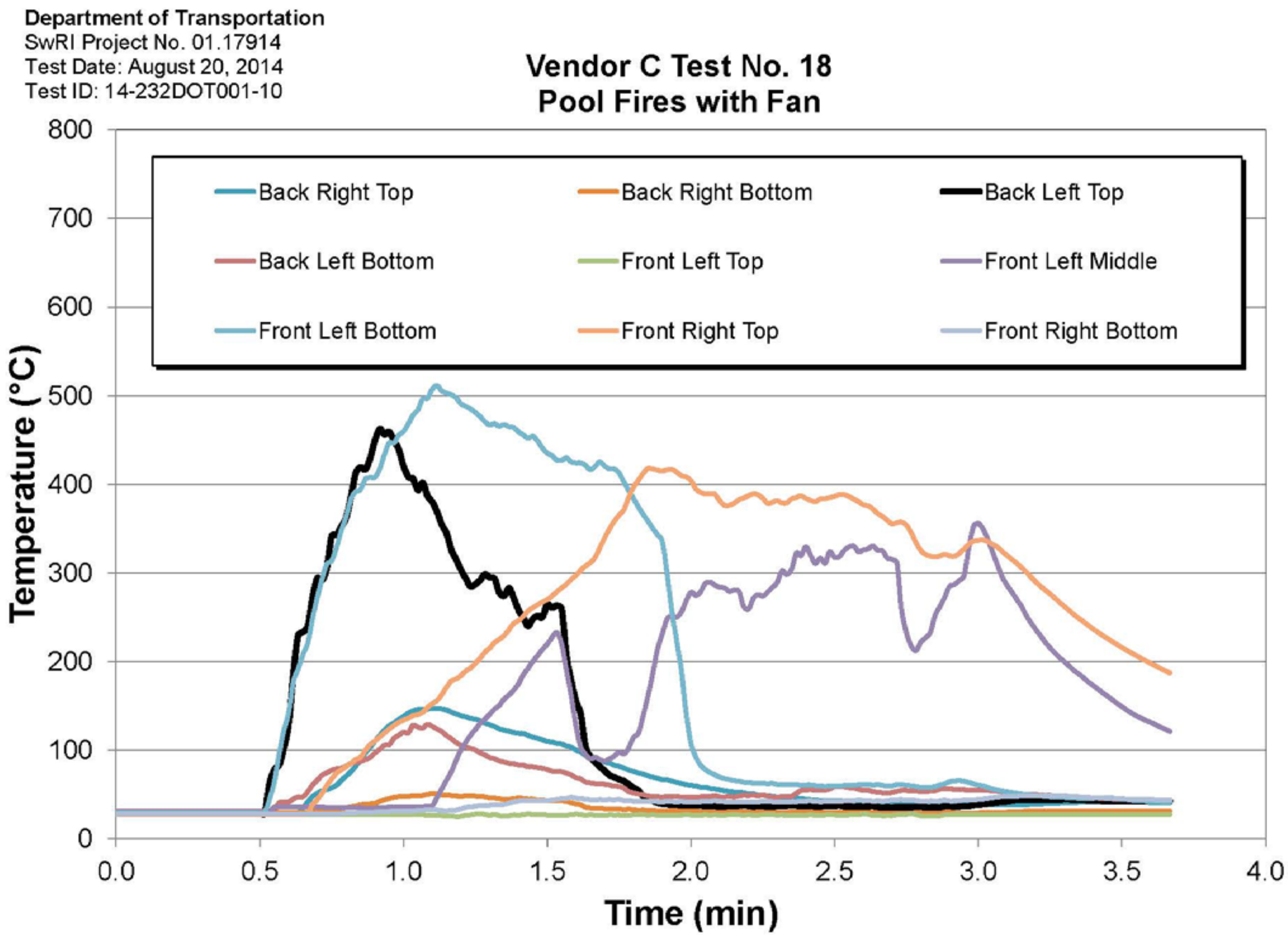
Department of Transportation
SwRI Project No. 01.17914
Test Date: August 19, 2014
Test ID: 14-231DOT001-5
Vendor C Test No. 13
Diesel Spray Fire (Low Position) without Fan
Back Right Top
Back Right Bottom
Back Left Top
Temperature (°C)
Time (min)
250
200
150
100
50
0
0.0
0.5
1.0
1.5
2.0
2.5


Department of Transportation
SwRI Project No. 01.17914
Test Date: August 19, 2014
Test ID: 14-231DOT001-3
Vendor C Test No. 14
PSF Spray without Fan
Temperature (°C)
Time (min)
Back Right Top
Back Left Top
Front Left Middle
Power Steering Spray
0
100
200
300
400
500
600
700
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

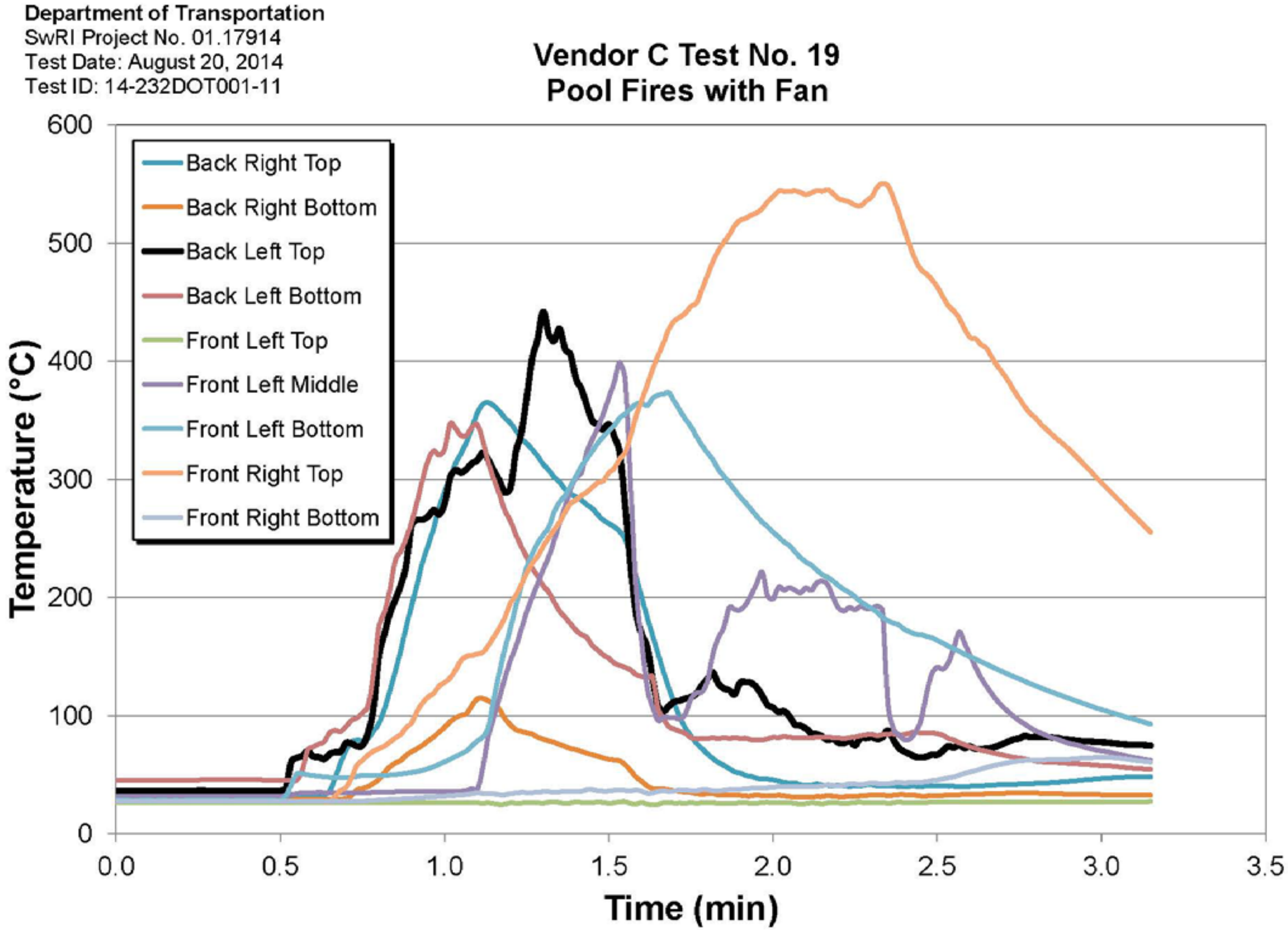

Department of Transportation
SwRI Project No. 01.17914
Test Date: August 19, 2014
Test ID: 14-231DOT001-7
Vendor C Test No. 15
PSF Spray with Fan
Back Left Top
Back Left Bottom
Front Left Middle
Power Steering Spray
Temperature (°C)
300
250
200
150
100
50
0
0.0
0.5
1.0
1.5
2.0
2.5
Time (min)

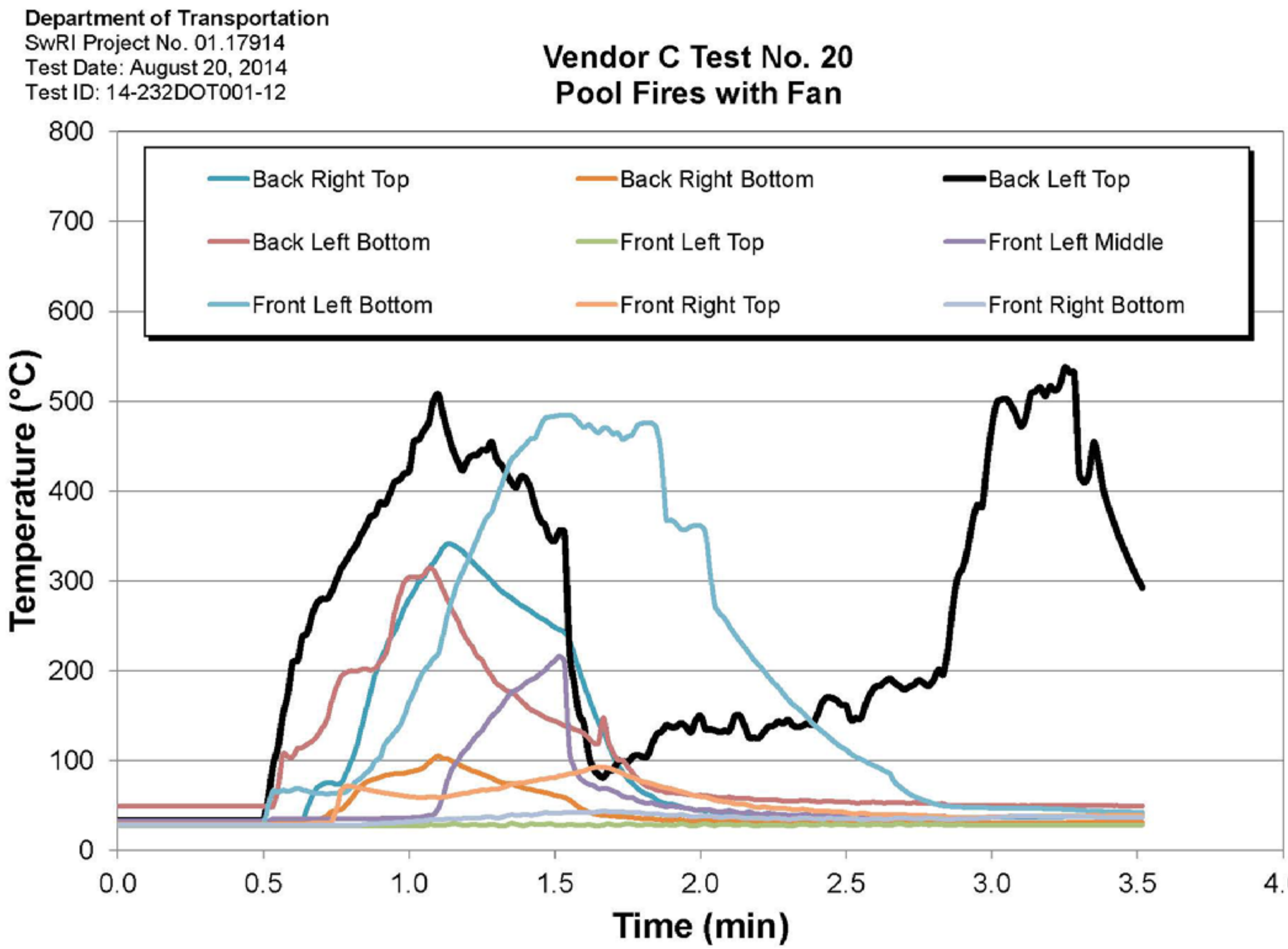

Department of Transportation
SwRI Project No. 01.17914
Test Date: August 19, 2014
Test ID: 14-231DOT001-8
Vendor C Test No. 16
Pool Fires with Fan
Temperature (°C)
Time (min)
Back Right Top
Back Right Bottom
Back Left Top
Back Left Bottom
Front Left Top
Front Left Middle
Front Left Bottom
Front Right Top
Front Right Bottom
900
800
700
600
500
400
300
200
100
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

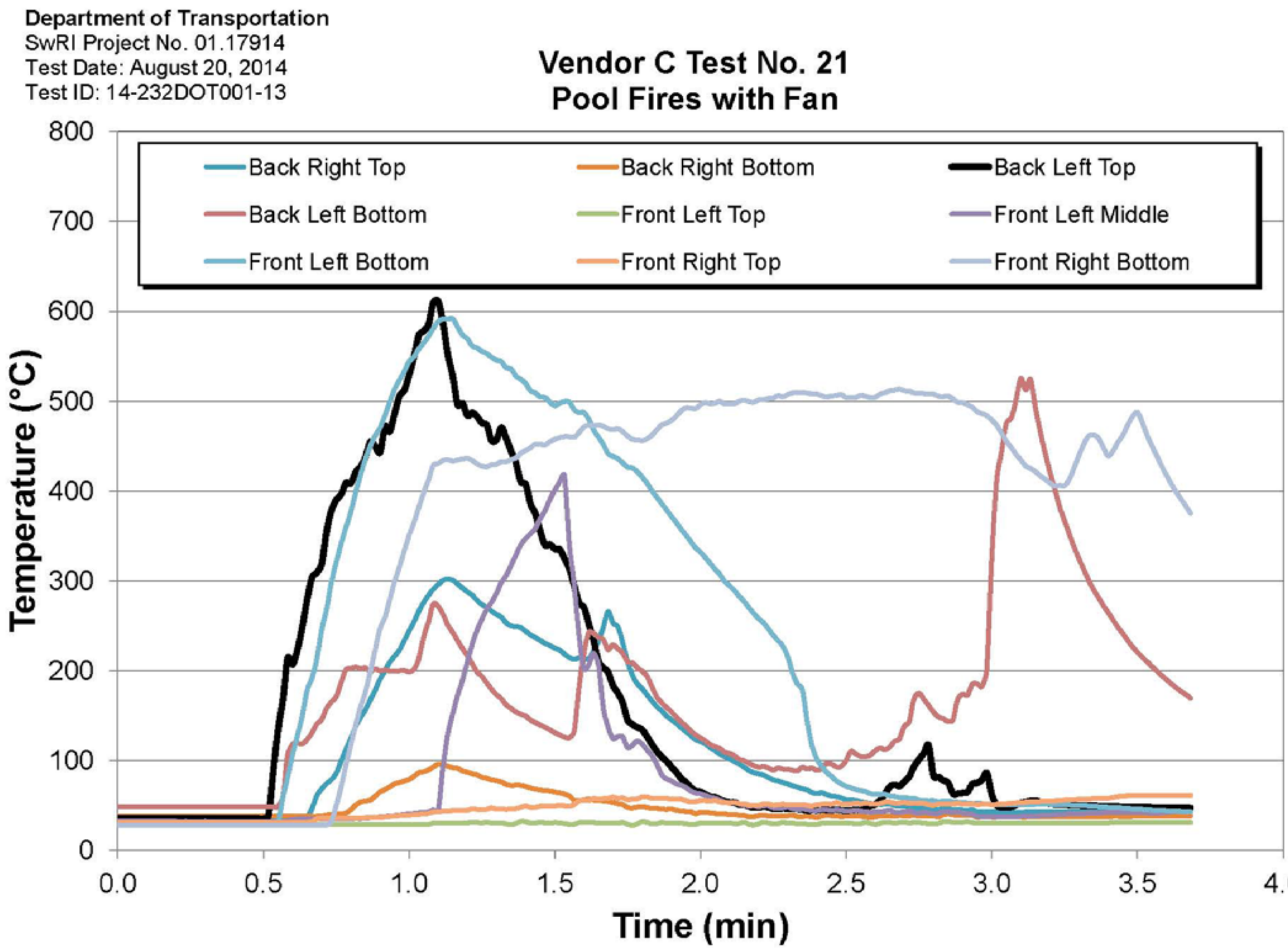

Department of Transportation
SwRI Project No. 01.17914
Test Date: August 19, 2014
Test ID: 14-231DOT001-9
Vendor C Test No. 17
Pool Fires with Fan
Temperature (°C)
800
700
600
500
400
300
200
100
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Time (min)
Back Right Top
Back Right Bottom
Back Left Top
Back Left Bottom
Front Left Top
Front Left Middle
Front Left Bottom
Front Right Top
Front Right Bottom

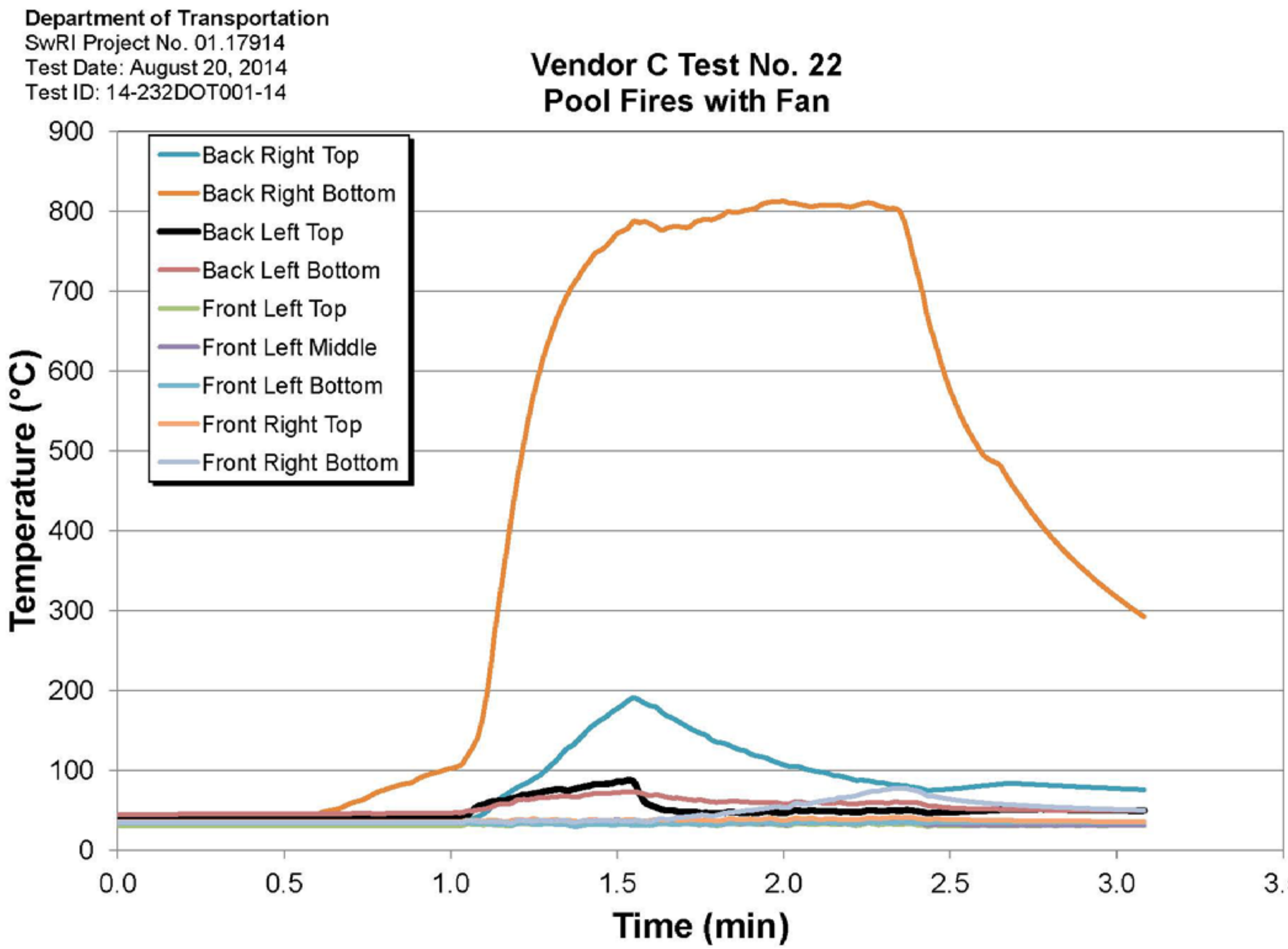


Department of Transportation
SwRI Project No. 01.17914
Test Date: August 20, 2014
Test ID: 14-232DOT001-10
Vendor C Test No. 18
Pool Fires with Fan
Back Right Top
Back Right Bottom
Back Left Top
Back Left Bottom
Front Left Top
Front Left Middle
Front Left Bottom
Front Right Top
Front Right Bottom
Temperature (°C)
Time (min)
0
100
200
300
400
500
600
700
800
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

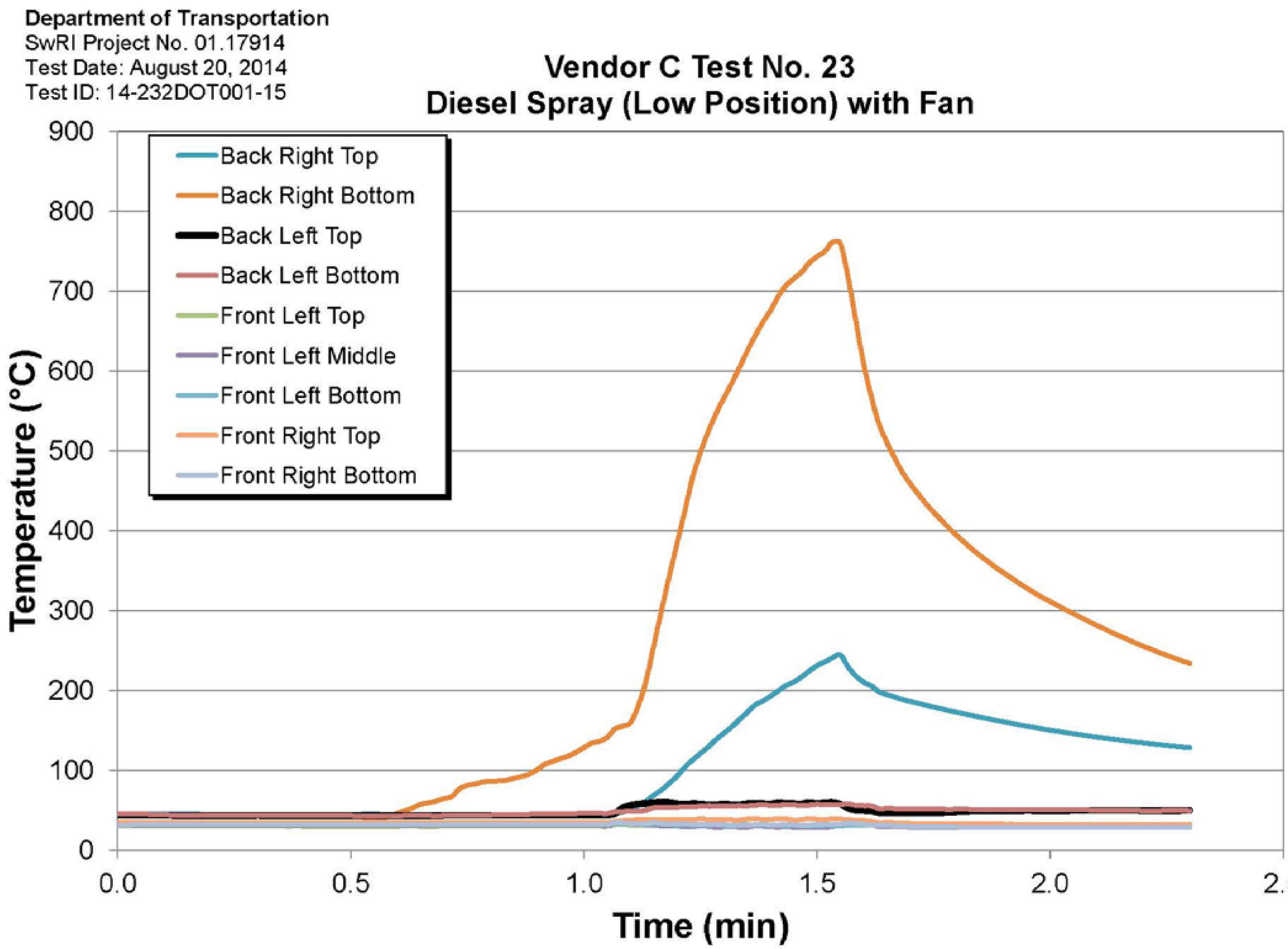

Department of Transportation
SwRI Project No. 01.17914
Test Date: August 20, 2014
Test ID: 14-232DOT001-11
Vendor C Test No. 19
Pool Fires with Fan
Temperature (°C)
Time (min)
Back Right Top
Back Right Bottom
Back Left Top
Back Left Bottom
Front Left Top
Front Left Middle
Front Left Bottom
Front Right Top
Front Right Bottom
0
100
200
300
400
500
600
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5

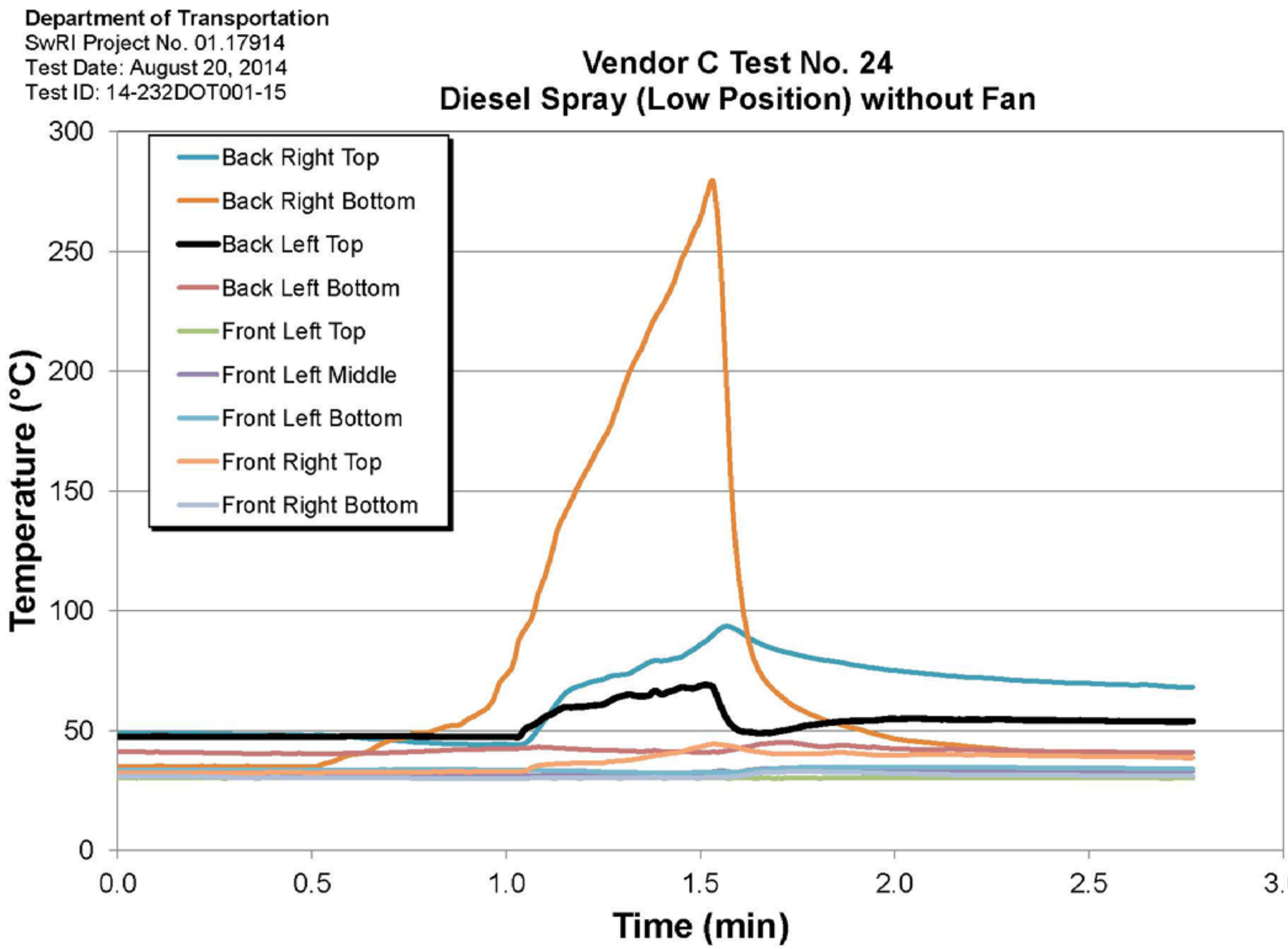

Department of Transportation
SwRI Project No. 01.17914
Test Date: August 20, 2014
Test ID: 14-232DOT001-12
Vendor C Test No. 20
Pool Fires with Fan
Back Right Top
Back Right Bottom
Back Left Top
Back Left Bottom
Front Left Top
Front Left Middle
Front Left Bottom
Front Right Top
Front Right Bottom
Temperature (°C)
0
100
200
300
400
500
600
700
800
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Time (min)


Department of Transportation
SwRI Project No. 01.17914
Test Date: August 20, 2014
Test ID: 14-232DOT001-13
Vendor C Test No. 21
Pool Fires with Fan
Back Right Top
Back Right Bottom
Back Left Top
Back Left Bottom
Front Left Top
Front Left Middle
Front Left Bottom
Front Right Top
Front Right Bottom
Temperature (°C)
Time (min)
0
100
200
300
400
500
600
700
800
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

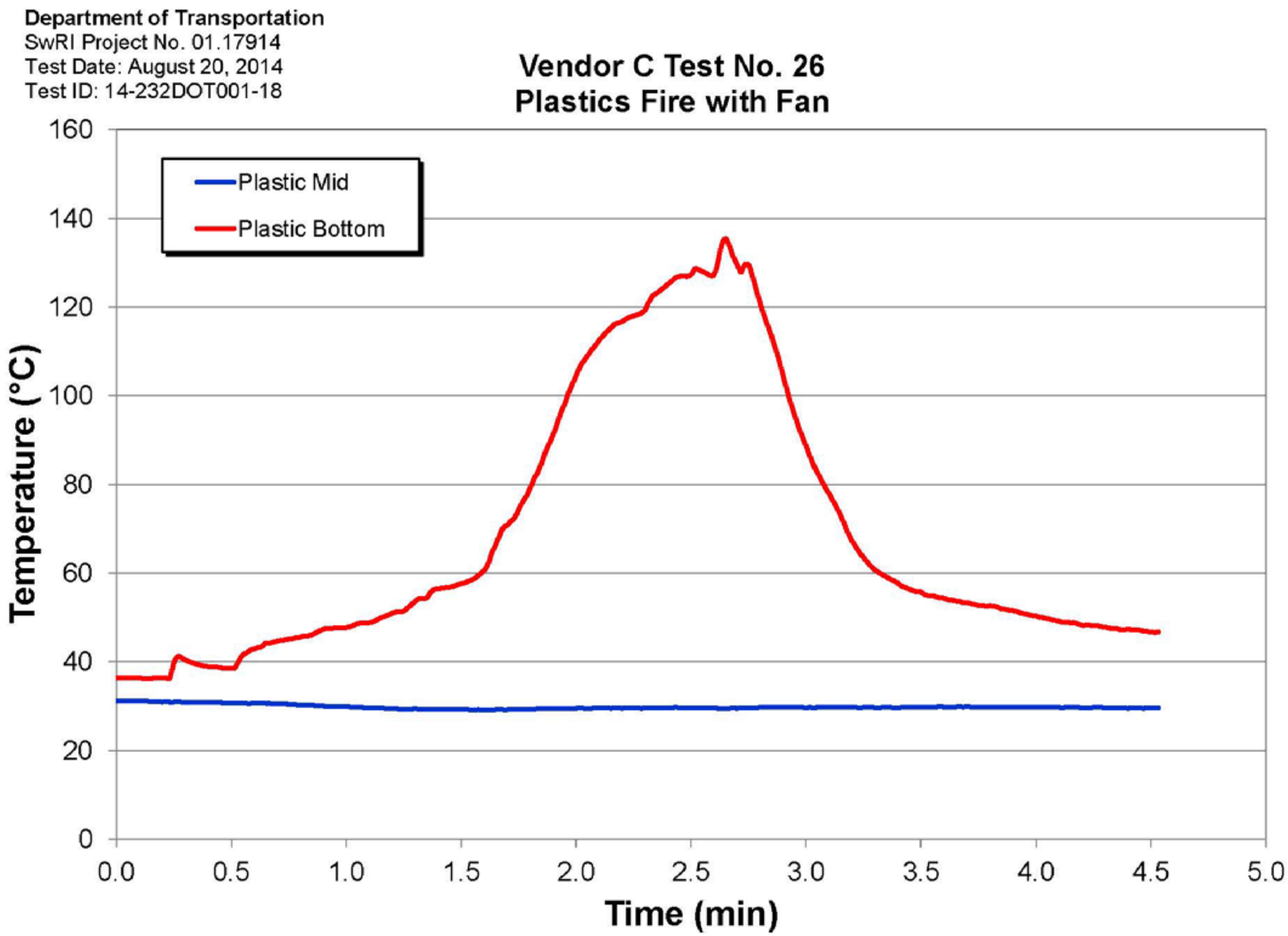


Department of Transportation
SwRI Project No. 01.17914
Test Date: August 20, 2014
Test ID: 14-232DOT001-14
Vendor C Test No. 22
Pool Fires with Fan
Temperature (°C)
Time (min)
Back Right Top
Back Right Bottom
Back Left Top
Back Left Bottom
Front Left Top
Front Left Middle
Front Left Bottom
Front Right Top
Front Right Bottom
0
100
200
300
400
500
600
700
800
900
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5


Department of Transportation
SwRI Project No. 01.17914
Test Date: August 20, 2014
Test ID: 14-232DOT001-15
Vendor C Test No. 23
Diesel Spray (Low Position) with Fan
Back Right Top
Back Right Bottom
Back Left Top
Back Left Bottom
Front Left Top
Front Left Middle
Front Left Bottom
Front Right Top
Front Right Bottom
Temperature (°C)
Time (min)
0
100
200
300
400
500
600
700
800
900
0.0
0.5
1.0
1.5
2.0
2.5



Department of Transportation
SwRI Project No. 01.17914
Test Date: August 20, 2014
Test ID: 14-232DOT001-15
Vendor C Test No. 24
Diesel Spray (Low Position) without Fan
Back Right Top
Back Right Bottom
Back Left Top
Back Left Bottom
Front Left Top
Front Left Middle
Front Left Bottom
Front Right Top
Front Right Bottom
Temperature (°C)
Time (min)
0
50
100
150
200
250
300
0.0
0.5
1.0
1.5
2.0
2.5
3.0


Department of Transportation
SwRI Project No. 01.17914
Test Date: August 20, 2014
Test ID: 14-232DOT001-18
Vendor C Test No. 26
Plastics Fire with Fan
Plastic Mid
Plastic Bottom
Temperature (°C)
Time (min)
0
20
40
60
80
100
120
140
160
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0

APPENDIX H
ENGINE COMPARTMENT DETECTION/SUPPRESSION SYSTEM DRAFT TEST PROCEDURE
(CONSISTING OF 15 PAGES)

Engine Compartment Detection/Suppression System Draft Test Procedure

Purpose:

The purpose of this test procedure is to qualify detection and suppression systems for use in motorcoach engine compartments.

Basis of the Test:

This test procedure is based on a single tag axle that is supported at one end with a bearing structure and driven by an electric motor connected to the wheel lug nut assembly. The wheel is heated by partially engaging the disk brakes on the tag axle, causing heat to be transferred through the rotor and wheel assembly and into the tire.

Test Specimens:

Detection and suppression systems are to be provided by the manufacturer and installed per manufacturer's instructions. Suppression nozzles are not permitted to be aimed directly at a known fire source location. The goal of the installation is to provide active fire protection to the entire engine compartment without knowledge of where the fire will originate. Additional details about nozzle placement for selected fire scenarios are provided below.

Test Fixture:

Figure 1 provides a representation of the test fixture and Figure 2 provides a photograph of the actual assembly. Full drawings can be referenced in Appendix B.

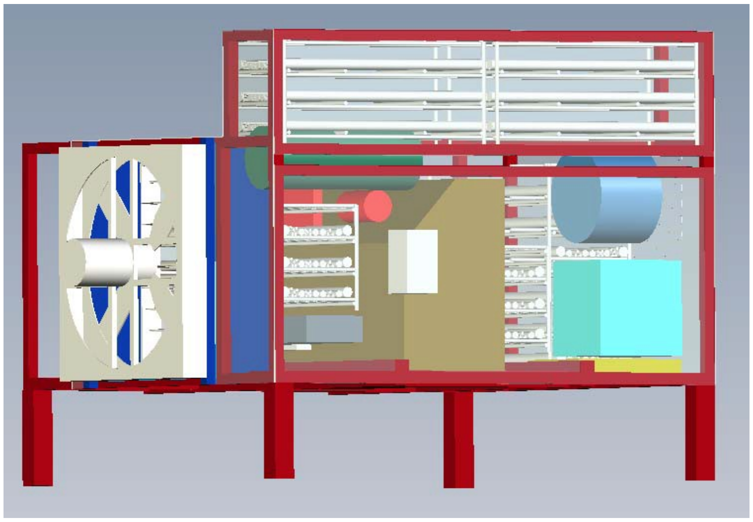


Figure 1. Engine Compartment Mockup Test Fixture Design.

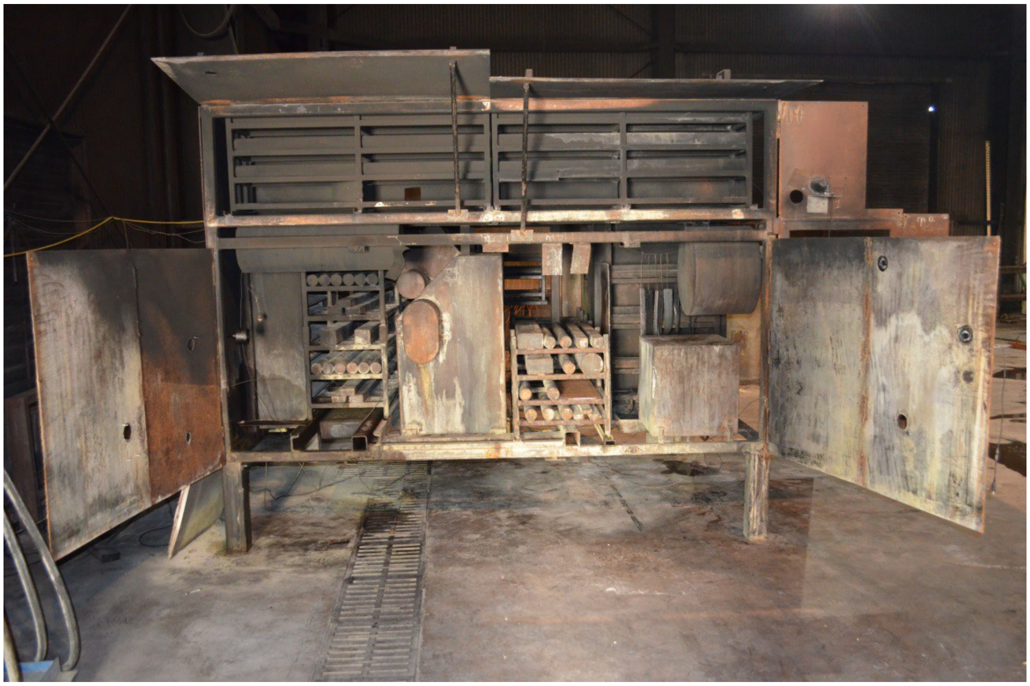


Figure 2. Engine Compartment Test Fixture (Rear View).

Figure 3. Engine Compartment Test Fixture (Forward View).

Test Fixture Instrumentation:

Several measurements are required to be verified during each test. It is not required to record this data with a data acquisition system, but the measurements should be verified for each fire scenario. They are summarized as follows.

- Test Pressures
    - Oil pressure for hot surface re-ignition test. The oil is dripped at nominally 10 psig through the specified nozzle to achieve the required flow rate.
    - Diesel pressure and Power Steering Fluid (PSF) pressure for spray fire scenarios. Both spray fires require a nominal 100 psig discharge pressure to achieve the required flow rate.
    - Note that the flow rate specified in the fire scenario section is the requirement and alternative means of verifying the flow rate is acceptable. For example, the mass loss of supply fuel could be used as a way to verify the flow rate, or an inline flow meter could be used.

- Temperatures
    - A minimum of two thermocouples should be used on the hot surface to verify the nominal 750 ºC re-ignition temperature start time.
    - During the development of the procedure, additional thermocouples were utilized throughout the test fixture for additional data and to help confirm extinguishment. However, this is an optional requirement. The requirement is that the extinguishment time can be verified.
- Amp Reader
    - The current passed through the overheated wire ignition source in the battery compartment fire scenario should be verified to be at least 200 amps at initial discharge of the power source (e.g., bus batteries).

Fire Scenarios and Test Procedure:

The following fire scenarios (12 total tests) are required to be evaluated with the engine compartment detection and suppression system under test:

1. Hot Surface Re-Ignition Test (One Test)
    a. Real Bus Hazard: hot surface in engine compartment such as turbo and exhaust manifold.
    b. Ignition Material: continuous feed of lube oil through Hago Model 1.50/80ºH nozzle to drip oil at nominally 7 ml/min.
    c. Ignition Source: steel plate representing hot surface of turbo/exhaust manifold. Heated from behind by quartz IR panel heater.
    d. Location: upper left (hot) side of engine.
    e. Procedure: raise nominal temperature of hot plate to 750 ºC, open oil valve, observe dripping fire, after 15 s, turn off power to heaters for hot surface, after additional 15 s, discharge suppression system and record time to re-ignition, if any.
    f. Ventilation: conduct test without the fan running.
2. Diesel Spray Fires (Four tests)
    a. Real Bus Hazard: diesel spray fire as a result of a leak in the Diesel Particulate Filter (DPF) system. The diesel flow rate nominally equates to a 1.25-mm leak diameter with nominal operating conditions per motorcoach OEM for diesel line on DPF.

b. Ignition Material: continuous feed of diesel fuel through Monarch F-80 nozzle, 10.0 gal/hr flow rate, and 80º spray angle. The diesel spray nozzle is mounted in a small flame stabilizer (metal can nominally 3-in diameter and 3-in long).

c. Ignition Source: tell-tale cup (details below) positioned below the spray nozzle.

d. Locations: lower left (hot) side of engine and upper left (hot) side of engine.

e. Nozzle Placement: for the upper position diesel spray test, no suppression nozzles are permitted to be placed in the first bay of the clutter rack, while also being aimed toward the spray fire.

f. Procedure: ignite the tell-tale cup, after 30 s, discharge the diesel, after an additional 30 s discharge the suppression system and record observations.

g. Ventilation: perform tests with and without fan running.

   i. Nominal air speeds with fan running:

      1. Lower Diesel Spray: 1.75 m/s
      2. Lower Tell-Tale Cup: 0.60 m/s
      3. Upper Diesel Spray: 0.40 m/s
      4. Upper Tell-Tale Cup: 0.40 m/s

3. Power Steering Fluid (PSF) Fires (Two tests)

a. Real Bus Hazard: PSF spray fire as a result of a leak in the power steering system. The PSF flow rate will nominally equate to a 0.375-mm leak diameter with nominal operating conditions per motorcoach OEM for PSF line.

b. Ignition Material: continuous feed of PSF through Monarch F-80 nozzle, 15.5 gal/hr flow rate, and 80º spray angle. The PSF nozzle is mounted in a small flame stabilizer (metal can nominally 3-in diameter and 3-in long).

c. Ignition Source: tell-tale cup (details below) positioned below the spray nozzle.

d. Location: middle right (cold) side of engine.

e. Procedure: ignite the tell-tale cup, after 30 s, discharge the PSF, after an additional 30 s discharge the suppression system and record observations.

f. Ventilation: perform tests with and without fan running.

   i. Nominal air speeds with fan running:

      1. PSF Spray: 4.33 m/s
      2. PSF Tell-Tale Cup: 0.82 m/s

4. Distributed Pool Fires (Two tests)

   a. Real Bus Hazard: multiple fire locations after incipient fire has spread through compartment. This fire scenario also evaluates the ability of the system under test to adequately cover the full volume of the test fixture.

   b. Ignition Materials:

      i. 8 tell-tale cups, nominally 3-in diameter and 2-in high, each filled with 130 ml of heptane (approximate 1-in. depth)

      ii. 2 rectangular pans, each measuring 8 × 18 x 1-in. high, filled with 1750 ml of heptane (approximately 0.5-0.75-in. depth).

   c. Location: throughout the entire test fixture, eight tell-tale cups in nominal eight corners of primary compartment space (not including battery compartment), one rectangular pan in left (hot) side clutter and one rectangular pan in right (cold) side clutter.

   d. Procedure: The cups and rectangular pans are ignited within 30 s (pan is the last to be ignited) and 30 s after ignition of pan, the suppression system is manually discharged and observations are recorded.

   e. Ventilation: perform tests with and without fan running.

      i. Nominal air speeds with fan running:

         1. View from Front of Coach

            a. Tell-Tale Cup 4: 0.19 m/s
            b. Tell-Tale Cup 5: 0.92 m/s

c. Tell-Tale Cup 6: 0.62 m/s

d. Tell-Tale Cup 8: 5.46 m/s

e. Pan 1: 6.58 m/s

2. View from Rear of Coach

a. Tell-Tale Cup 1: 0.40 m/s

b. Tell-Tale Cup 2: 0.17 m/s

c. Tell-Tale Cup 3: 0.40 m/s

d. Tell-Tale Cup 7: 0.34 m/s

e. Pan 2: 0.35 m/s

5. Plastics Fire (Two Tests)

a. Real Bus Hazard: Class A material (plastics) fire close to the toilet holding tank and air filter housing components.

b. Ignition Materials:

i. 8 vertical strips of plastic, 4 ABS and 4 Polypropylene, each measuring 2-in × 28.75-in. long (nominally 1/8-in. thick)

ii. 4 horizontal strips of plastic, 1 of each type of plastic on lower two shelves of clutter rack adjacent to vertical strips and ignition pan.

iii. The material flammability of these materials has been characterized and can be referenced in Appendix C. The material flammability of test materials must be verified prior to each test session.

c. Ignition Source: 1 rectangular pan (same as pool fire test) with 120 ml of heptane used to ignite the plastic.

d. Location: lower right (cold) side of engine.

e. Procedure: Ignite the pan fire, after 105 s of pre-burn, discharge the suppression system and record observations.

f. Ventilation: conduct test with and without the fan running.

i. Nominal air speeds with fan running:

1. Ignition Pan: 0.43 m/s

2. Shelf 1 (Lowest): 0.33 m/s

3. Shelf 2: 0.27 m/s

4. Shelf 3: 0.25 m/s

5. Shelf 4 (Highest): 0.34 m/s

6. Battery Compartment Fire (One Test)

   a. Real Bus Hazard: overheated cable in battery compartment, which leads to a growing Class A fire.

   b. Ignition Materials:

      i. 1-in diameter pipe insulation – two horizontal sections 30 inches in length and one vertical section 25 inches in length. Prior to installation, each section is sprayed lightly with approximately 25 ml of diesel fuel. These sections are mounted just above the egg-crate foam and over the overheated cable.

      ii. Egg-crate foam plastic insulation – one 16 × 18-in panel applied to back wall of battery compartment directly over the overheated cable.

      iii. Plastic toolboxes – these are used to approximate battery boxes. Four of these boxes are placed in the compartment and 10 ml of grease is applied to the top surface of the back two boxes.

      iv. The material flammability of these materials has been characterized and can be referenced in Appendix C. The material flammability of test materials must be verified prior to each test session.

   c. Ignition Source: 23.5-in long thermoplastic cable overheated to ignition by discharging a nominal 200-amp load from two motorcoach batteries in series (24 volts). The cable also has approximately 5 ml of lubricating grease applied evenly over the surface of the cable insulation.

   d. Location: battery compartment.

   e. Nozzle Placement: suppression nozzles are not permitted to be installed in the space between the fuse box and the back wall of the battery compartment. If the nozzle installed for the purpose of extinguishing the battery compartment fire is outside the battery compartment, the access panel adjacent to the fuse box will remain open. If this nozzle is installed in the battery compartment, the access panel adjacent to the fuse box will be closed during testing.

f. Procedure: discharge battery current into test cable and allow cable to ignite, 30 seconds after cable ignition, discharge suppression system and record observations.

g. Ventilation: conduct test without the fan running.

When a test is conducted with the fan running, the average air velocity measured at the outlet of the fan after the louvered radiator enclosure will be approximately 6 m/s and the volumetric airflow will be approximately 3 m^3/s.

Figure 4 – Figure 13 provide drawings of each fire scenario location within the test fixture.

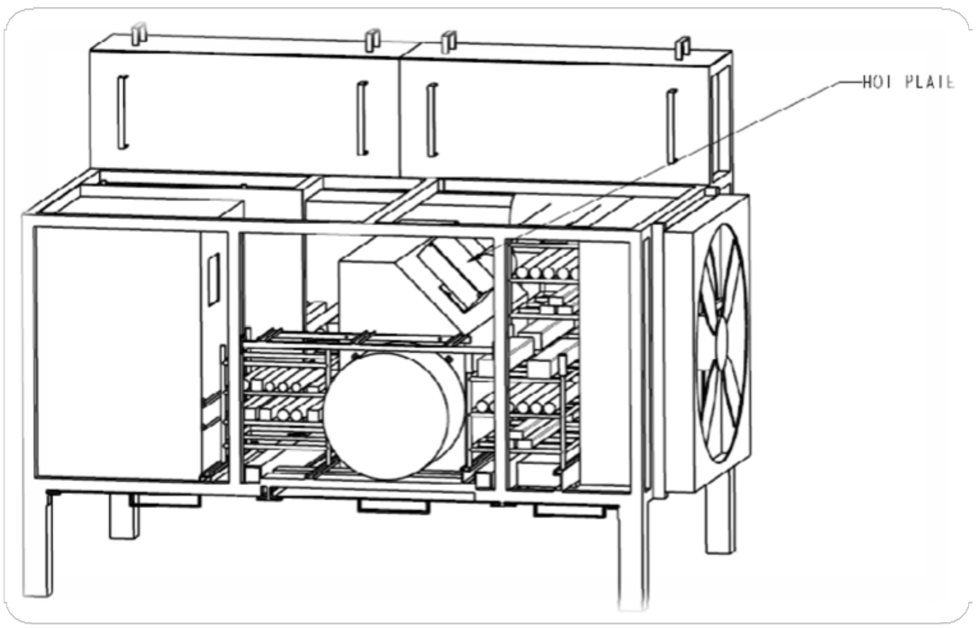


Figure 4. Hot Surface Re-Ignition Fire Scenario (View of Forward Side).

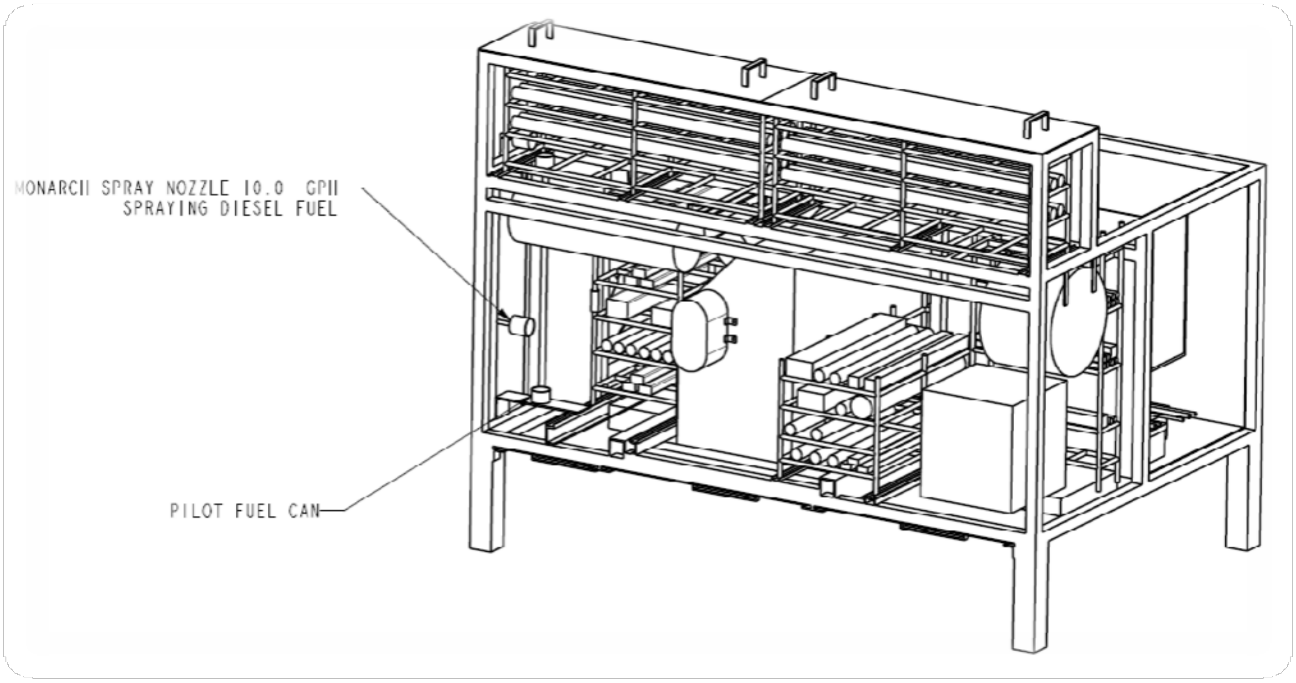


Figure 5. Diesel Spray Fire Scenario (View of Rear Side: Lower Position).

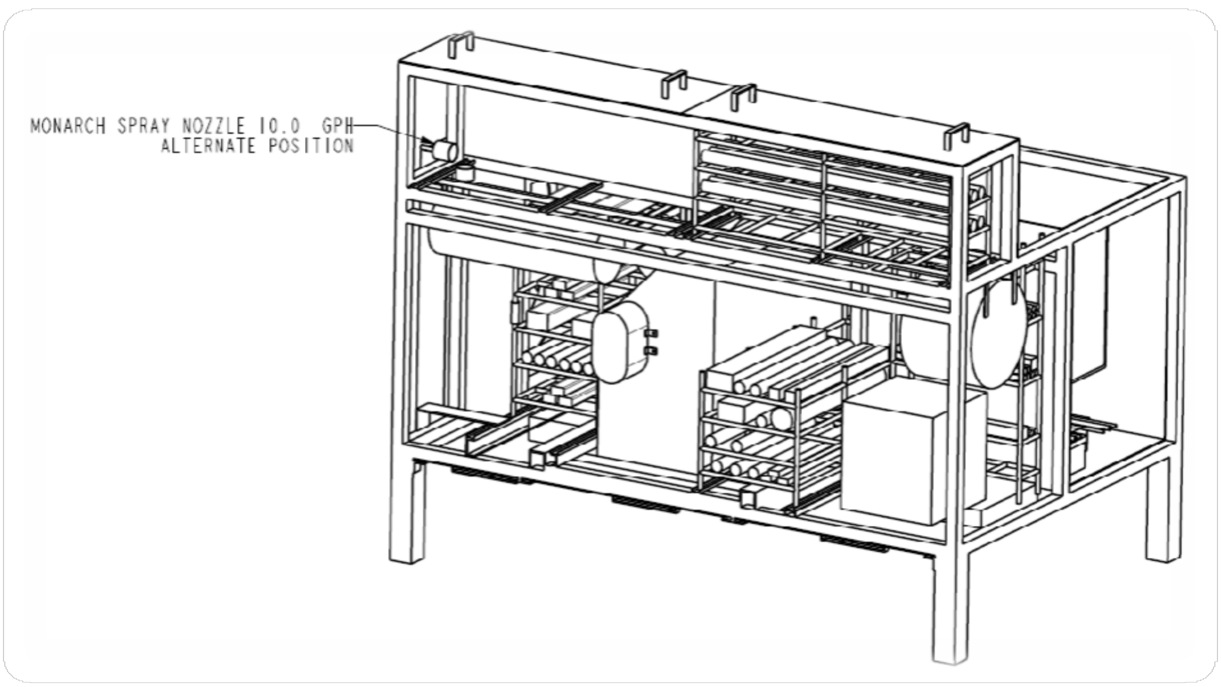


Figure 6. Diesel Spray Fire Scenario (View of Rear Side: Upper Position).

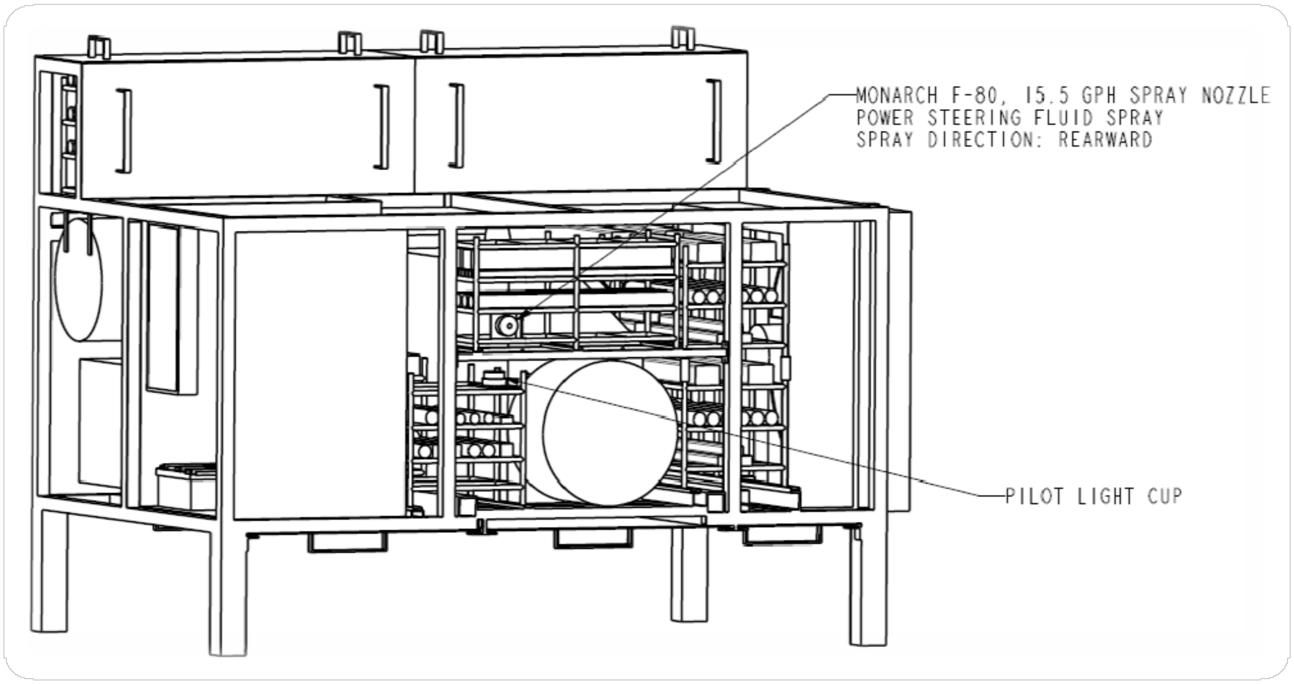


Figure 7. PSF Spray Fire Scenario (View of Forward Side).

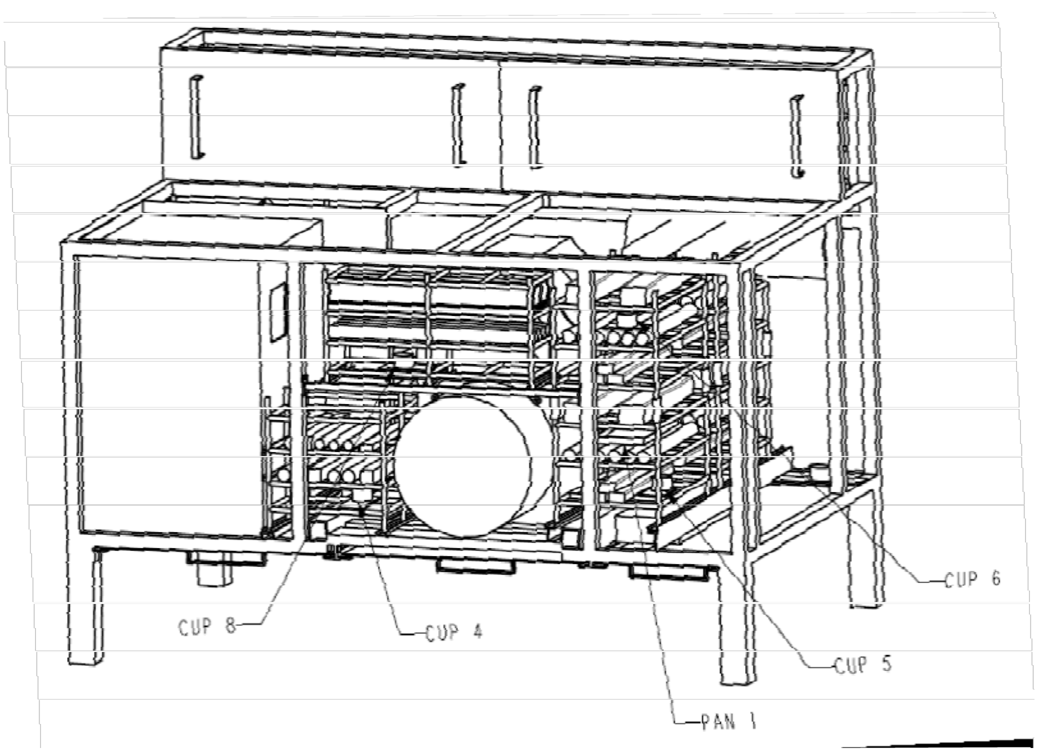


Figure 8. Distributed Pool Fire Scenario (View of Forward Side).

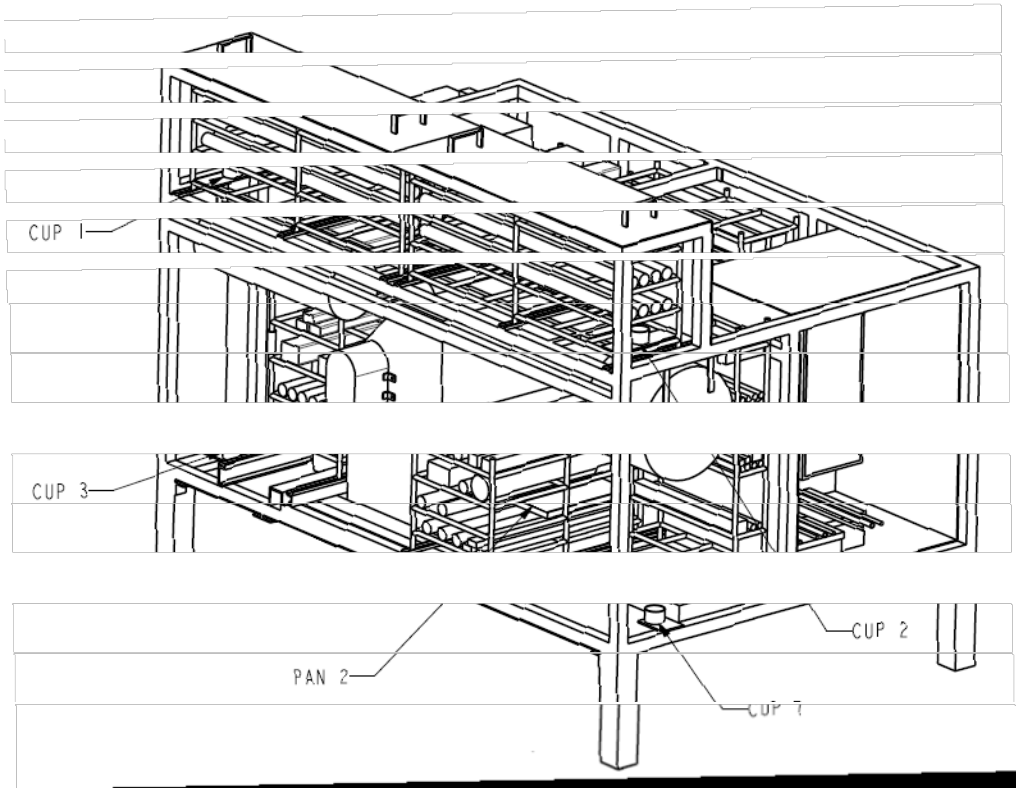


Figure 9. Distributed Pool Fire Scenario (View of Rear Side).

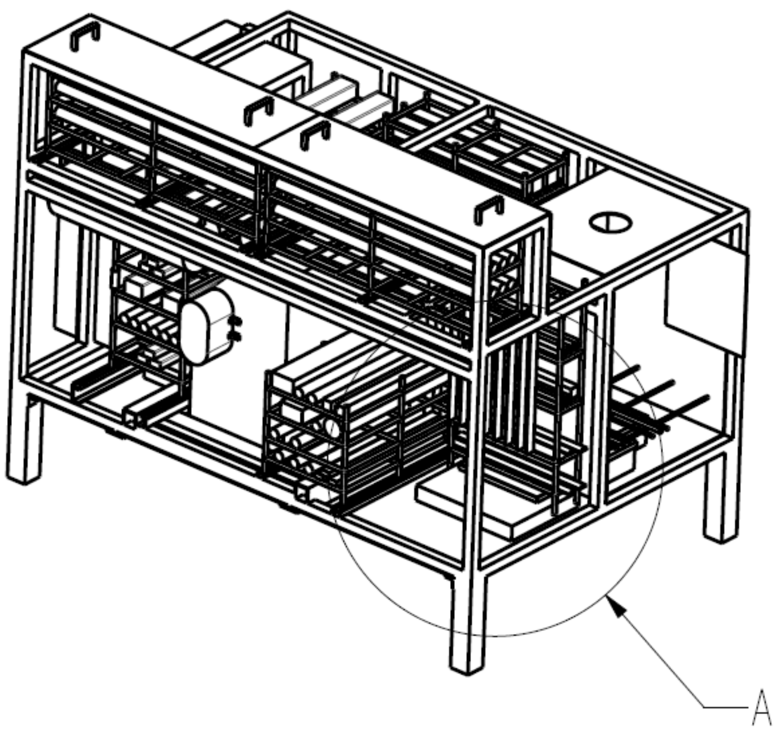


Figure 10. Plastics Fire Scenario (Wide Angle View).

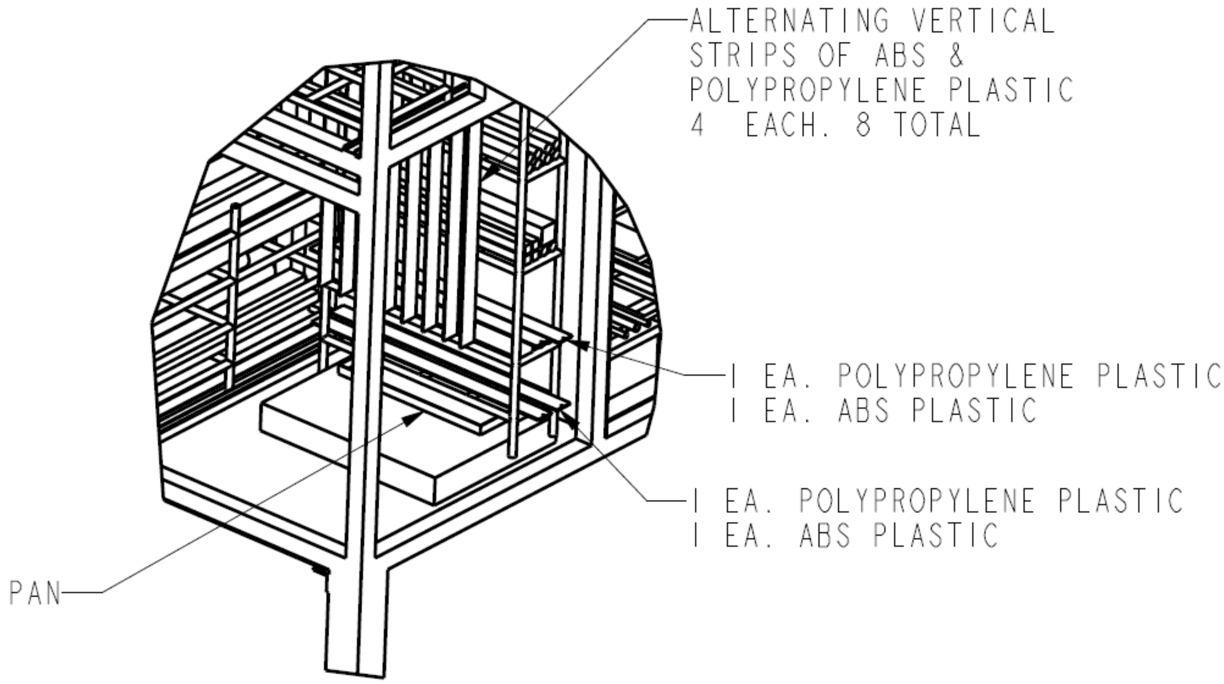


Figure 11. Plastics Fire Scenario (Close-up View).

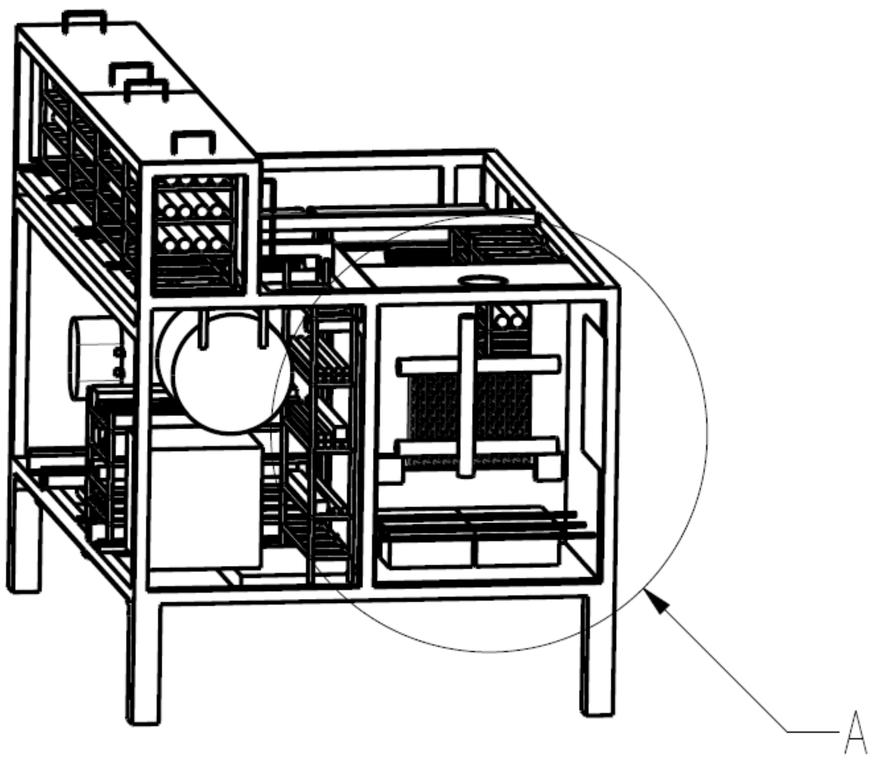


Figure 12. Battery Compartment Fire Scenario (Wide Angle View).

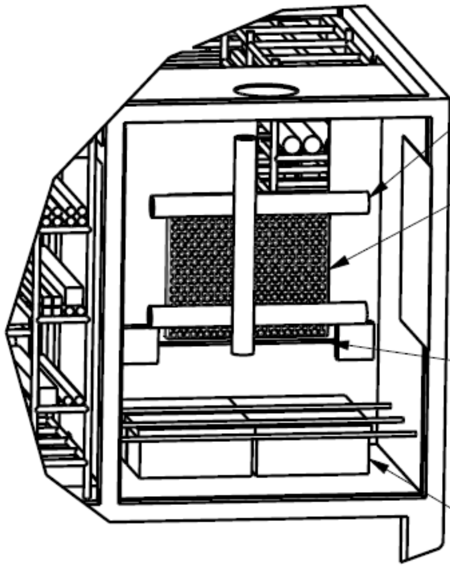


Figure 13. Battery Compartment Fire Scenario (Close-up View).

Test Criteria:

The following test criteria apply for evaluating detection and suppression systems in motorcoach engine compartments.

- The detection and suppression system will be installed per manufacturer direction and/or specifications.
- The installation will not be changed for any of the twelve fire tests. In other words for a given single system configuration, all the tests will be conducted with the same detector and suppression system (nozzle) locations. If the system design/configuration is changed, all tests will be conducted again for that new design/configuration.
- For all of tests described above, with the exception of the hot surface re-ignition test, the design fire must be extinguished.

- For all of tests described above, with the exception of the hot surface re-ignition test, the detection system must have activated prior to the end of the pre-burn time of the design fire.
- For the hot surface re-ignition test, the installed system must prevent re-ignition for a minimum of 150 seconds.
- Detection and suppression systems that meet these test criteria also must test and approve the individual components of the system. An example of this type of component testing method can be referenced in FM 5320, *Approval Standard for Dry Chemical Extinguishing Systems, December 2013*.

APPENDIX I
WHEEL WELL TEST FIXTURE DRAWINGS
(CONSISTING OF 21 PAGES)

REVISIONS				
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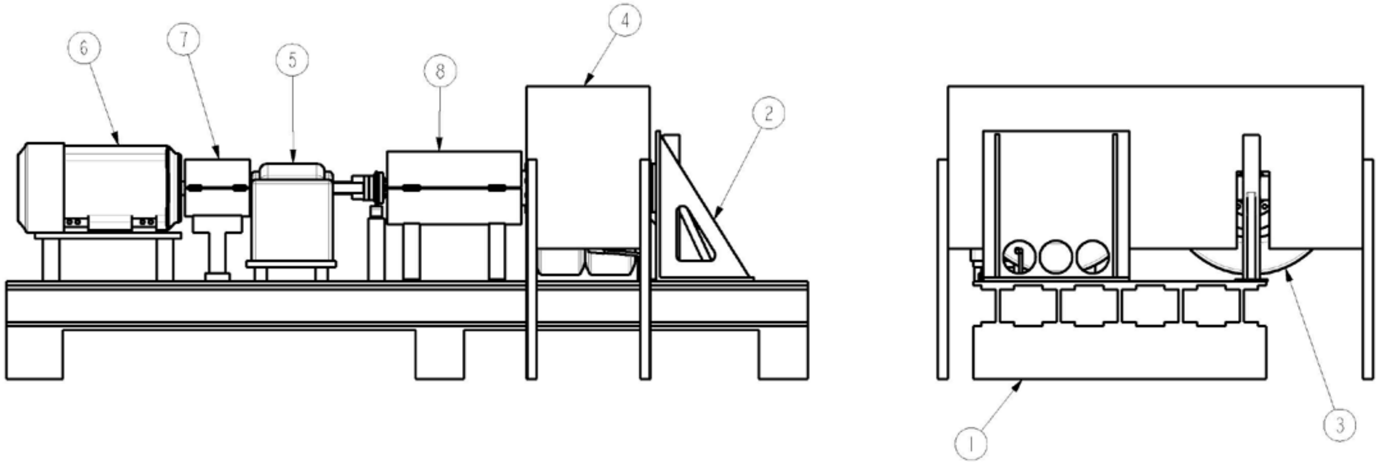
A			INITIAL RELEASE	07-16-14



APPROVED
FOR PRODUCTION

1	TORQUE METER	STOCK ITEM	11
1	SHEAR COUPLING ASS'Y	SEE DRAWING 17914-200-100	10
1	GEAR BOX HUB	SEE DRAWING 17914-200-208	9
1	U-JOINT SHAFT GAURD	STOCK ITEM	8
1	DRIVE SHAFT GAURD	STOCK ITEM	7
1	DRIVE MOTOR	STOCK ITEM	6
1	GEAR BOX	STOCK ITEM	5
1	WHEEL WELL	SEE DRAWING 17914-200-214	4
1	TAG WHEEL ASSEMBLY	SEE DRAWING 17914-100-100	3
1	DRIVE WHEEL ASSEMBLY	SEE DRAWING 17914-200-200	2
1	BED PLATE	SEE DRAWING 17914-200-215	1
P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) : ± 0.1	B SCHULTZ
TWO PLACES (X.XX) : ± 0.01	C WRAY
THREE PLACES (X.XXX) : ± 0.005	C WRAY
FOUR PLACES (X.XXXX) : ± 0.0005	J HUCZEK
ANGLES : ± 0.5 DEGREE	COMPLETION DATE: 08-28-13
SURFACE FINISHES <= 125 MICROINCH RA	MODEL: TEST.ASM
THIRD ANGLE PROJECTION	

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6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238

WHEEL WELL ASSEMBLY

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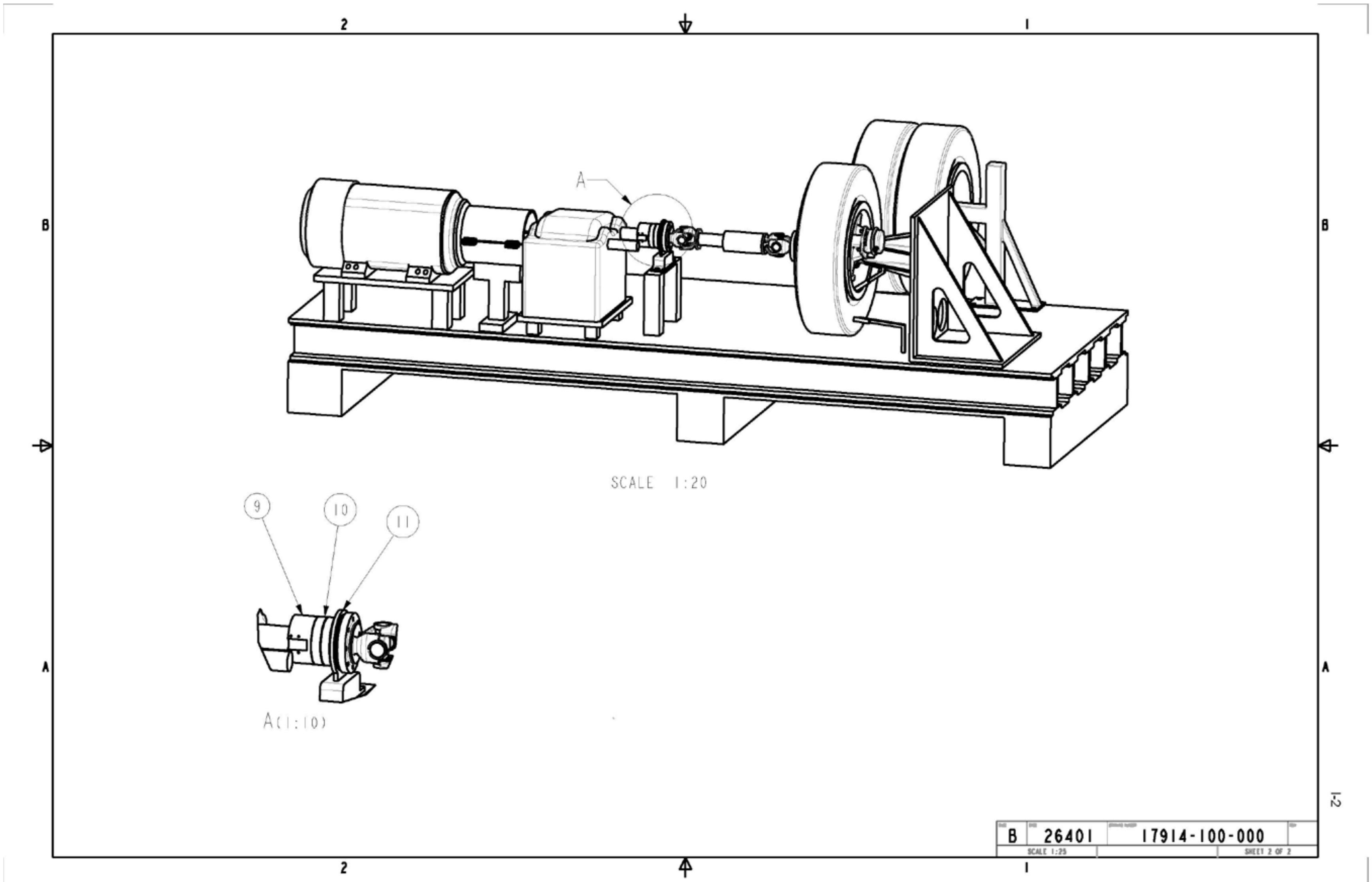
2
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B
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SCALE 1:20
9
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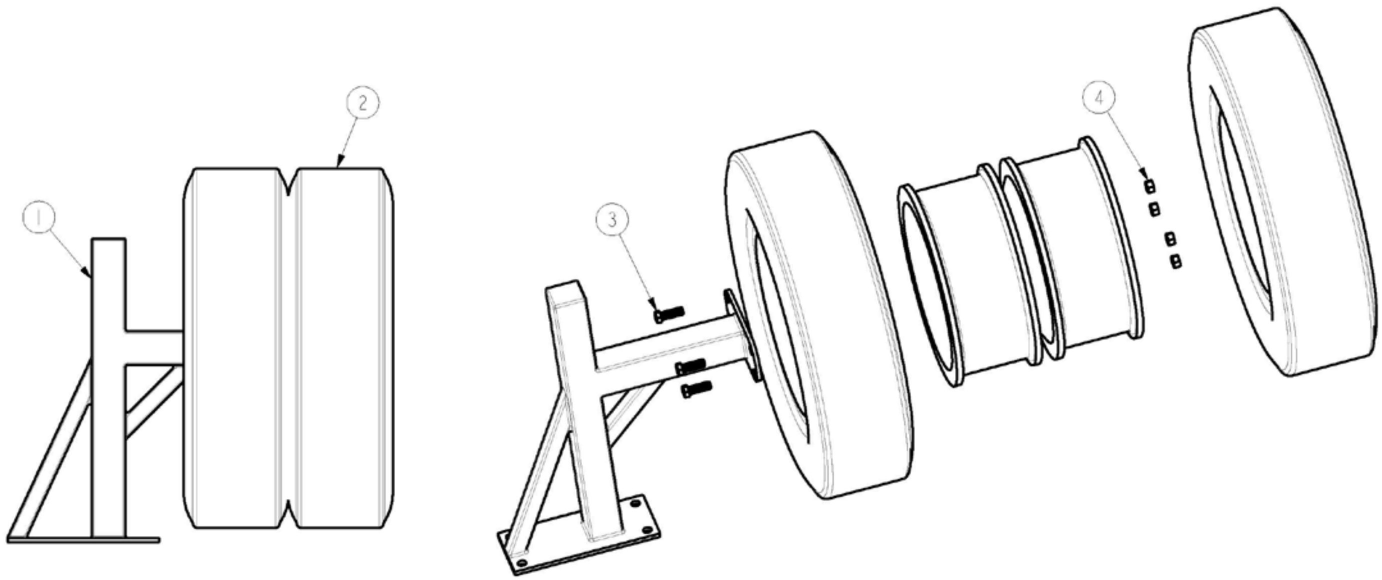
26401
17914-100-000
SCALE 1:25
SHEET 2 OF 2



APPROVED FOR PRODUCTION

QTY	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
4	NUT	7/8 HEX NUT	4
4	BOLT	7/8-9 X 3 HEX BOLT	3
2	WHEEL	WHEEL ASS'Y	2
1	WHEEL MOUNT	SEE DRAWING 17914-200-216	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) : ± 0.1	B SCHULTZ
TWO PLACES (X.XX) : ± 0.01	C WAY
THREE PLACES (X.XXX) : ± 0.005	C WRAY
FOUR PLACES (X.XXXX) : ± 0.0005	J HUCZEK
ANGLES : ± 0.5 DEGREE	COMPLETION DATE: 07-16-14
SURFACE FINISHES <= 125 MICROINCH RA	MODEL: WHEEL.MOUNT
THIRD ANGLE PROJECTION	

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6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238

TAG WHEEL MOUNT ASSEMBLY

B	26401	17914-100-100	A
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REV	SHT	ZONE	DESCRIPTION	DATE
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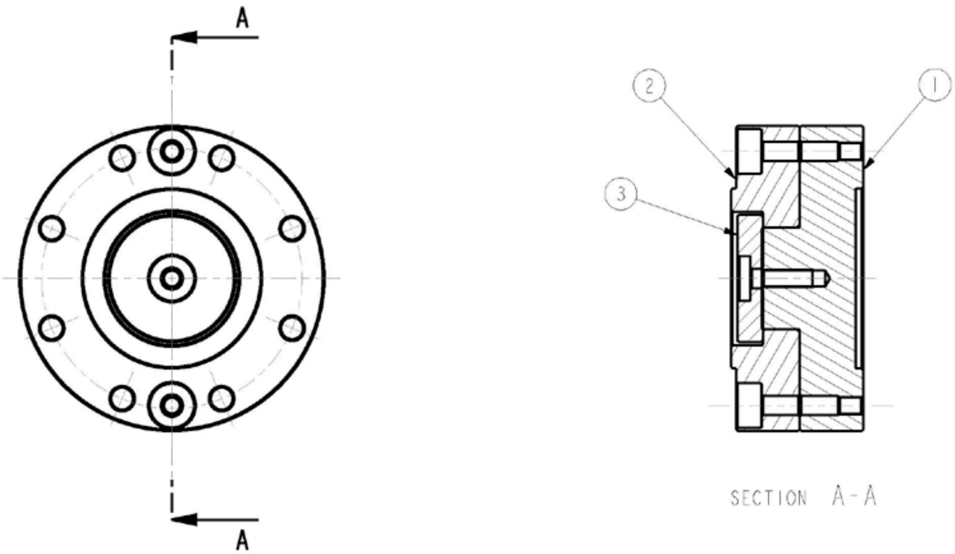

APPROVED
FOR PRODUCTION

BILL OF MATERIAL/PARTS LIST

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1	COUPLING WASHER	SEE DRAWING 17914-200-213	3
1	COUPLING FEMALE	SEE DRAWING 17914-200-211	2
1	COUPLING MALE	SEE DRAWING 17914-200-210	1

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) : ± 0.1	B SCHULTZ
TWO PLACES (X.XX) : ± 0.01	C WRAY
THREE PLACES (X.XXX) : ± 0.005	C WRAY
FOUR PLACES (X.XXXX) : ± 0.0005	J MUCZEK
ANGLES : ± 0.5 DEGREE	COMPLETION DATE: 07-16-14
SURFACE FINISHES <= 125 MICROINCH RA	MODEL: SHEAR.HUB.COUPLING

THIRD ANGLE PROJECTION

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SHEAR COUPLING ASSEMBLY

B	26401	17914-200-100	A
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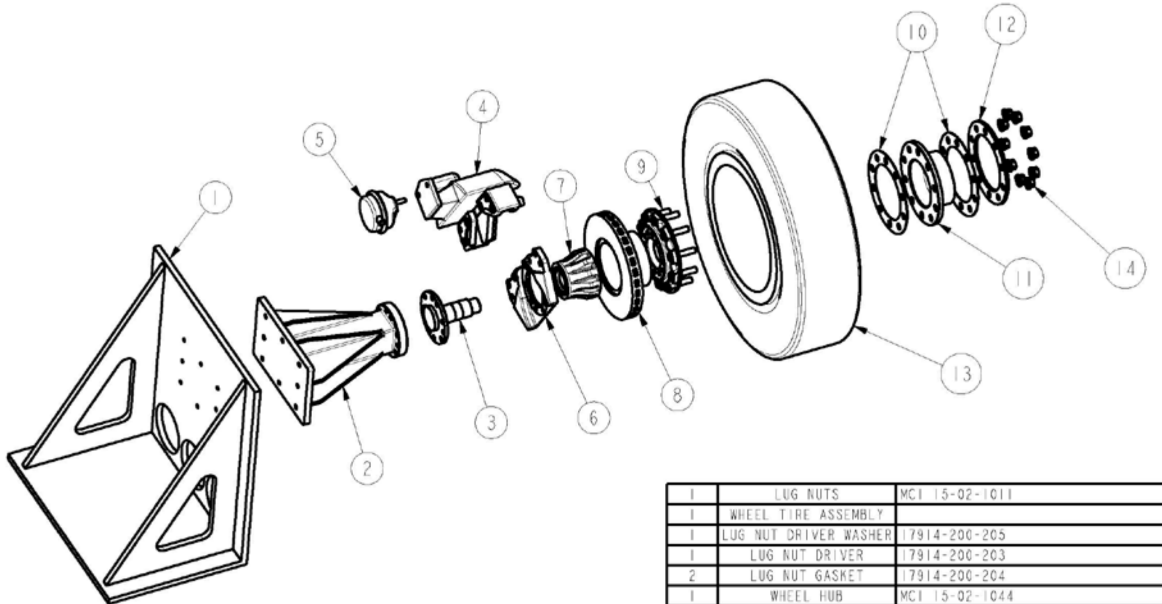
REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	09-24-13



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1	LUG NUTS	MCI 15-02-1011	14
1	WHEEL TIRE ASSEMBLY		13
1	LUG NUT DRIVER WASHER	17914-200-205	12
1	LUG NUT DRIVER	17914-200-203	11
2	LUG NUT GASKET	17914-200-204	10
1	WHEEL HUB	MCI 15-02-1044	9
1	BRAKE ROTOR	MCI 15-02-1067	8
1	BEARING ASSEMBLY	MCI 15-02-1038	7
1	TORQUE PLATE	MCI 02-07-1079	6
1	BRAKE CHAMBER ASSEMBLY	MCI 04-04-1011	5
1	CALIPER	MCI 04-01-1115	4
1	WHEEL DRIVE ASM	MCI 02-06-1023	3
1	SPINDLE ADAPTER	17914-200-202	2
1	SPINDLE SUPPORT	17914-200-201	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) : ± 0.1	B SCHULTZ
TWO PLACES (X.XX) : ± 0.01	C WRAY
THREE PLACES (X.XXX) : ± 0.005	C WRAY
FOUR PLACES (X.XXXX) : ± 0.0005	J HUCZEK
ANGLES : ± 0.5 DEGREE	COMPLETION DATE: 08-27-13
SURFACE FINISHES <= 125 MICROINCH RA	MODEL: WHEEL.DRIVE
THIRD ANGLE PROJECTION	

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WHEEL MOUNTING ASSEMBLY

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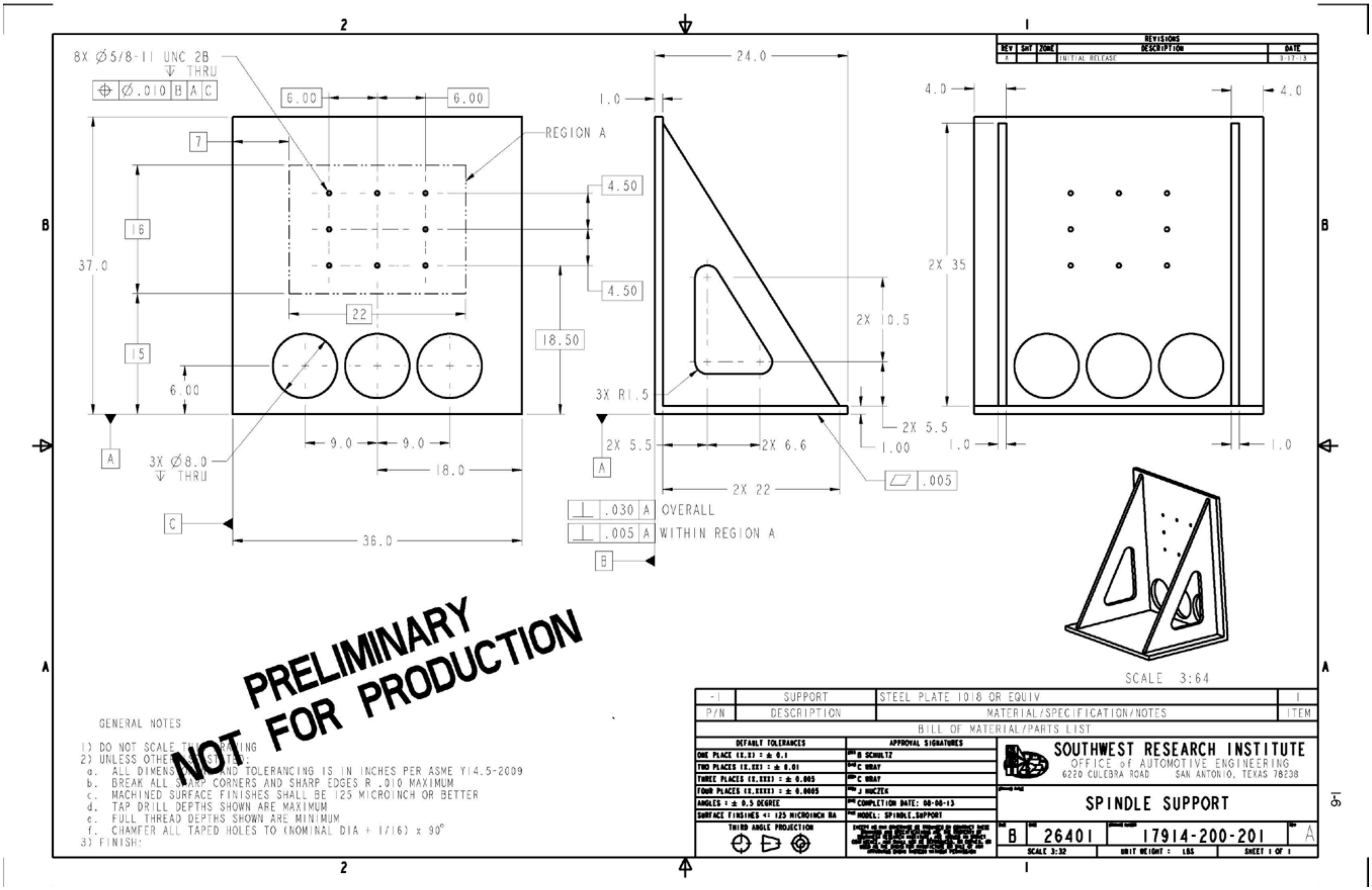

REVISIONS
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6.00
6.00
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REGION A
16
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37.0
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3X Ø8.0 THRU
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C
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⊥ .005 A WITHIN REGION A
B
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2X 35
1.0
1.0
SCALE 3:64
PRELIMINARY
NOT FOR PRODUCTION
GENERAL NOTES
1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
a. ALL DIMENSIONS AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:
-1 | SUPPORT | STEEL PLATE 1018 OR EQUIV | 1
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BILL OF MATERIAL/PARTS LIST
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ONE PLACE (X.X) : ± 0.1
TWO PLACES (X.XX) : ± 0.01
THREE PLACES (X.XXX) : ± 0.005
FOUR PLACES (X.XXXX) : ± 0.0005
ANGLES : ± 0.5 DEGREE
SURFACE FINSIHES <= 125 MICROINCH RA
THIRD ANGLE PROJECTION
APPROVAL SIGNATURES
B SCHULTZ
C WRAY
C WRAY
J HUCZEK
COMPLETION DATE: 08-08-13
MODEL: SPINDLE.SUPPORT
SOUTHWEST RESEARCH INSTITUTE
OFFICE of AUTOMOTIVE ENGINEERING
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238
SPINDLE SUPPORT
B
26401
17914-200-201
A
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UNIT WEIGHT : LBS
SHEET 1 OF 1

REVISIONS				
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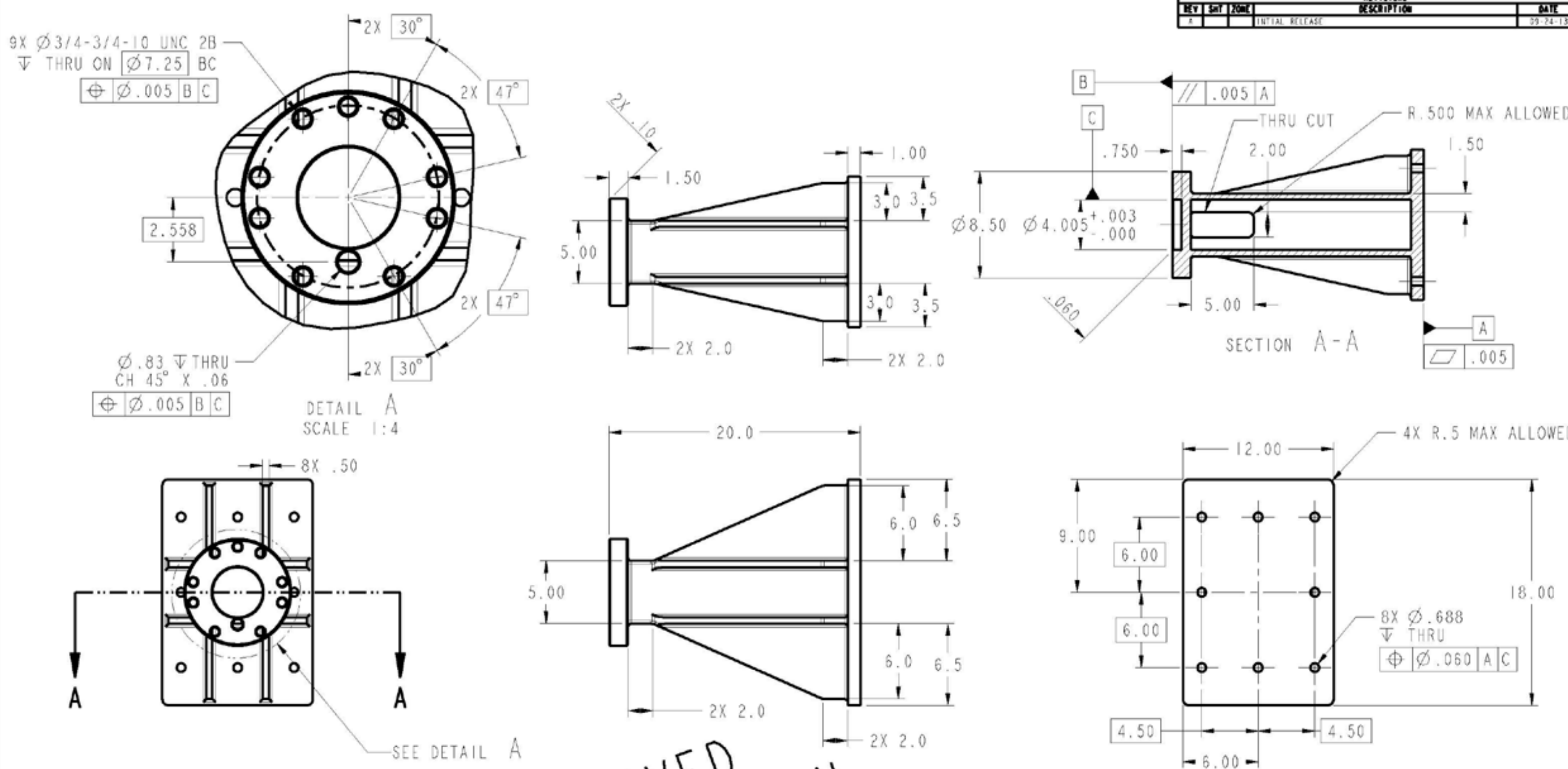

APPROVED FOR PRODUCTION

GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
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  b. BREAK ALL SHARP CORNERS AND SHARP EDGES R.01 MAXIMUM
  c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
  d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
  e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
  f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

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-1	ADAPTER	STEEL 1018 OR EQUIV	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) : ± 0.1	B SCHULTZ
TWO PLACES (X.XX) : ± 0.01	C WRAY
THREE PLACES (X.XXX) : ± 0.005	C WRAY
FOUR PLACES (X.XXXX) : ± 0.0005	J HUCZEK
ANGLES : ± 0.5 DEGREE	COMPLETION DATE: 08-27-13
SURFACE FINISHES <= 125 MICROINCH RA	MODEL: SPINDLE_ADAPTER

THIRD ANGLE PROJECTION

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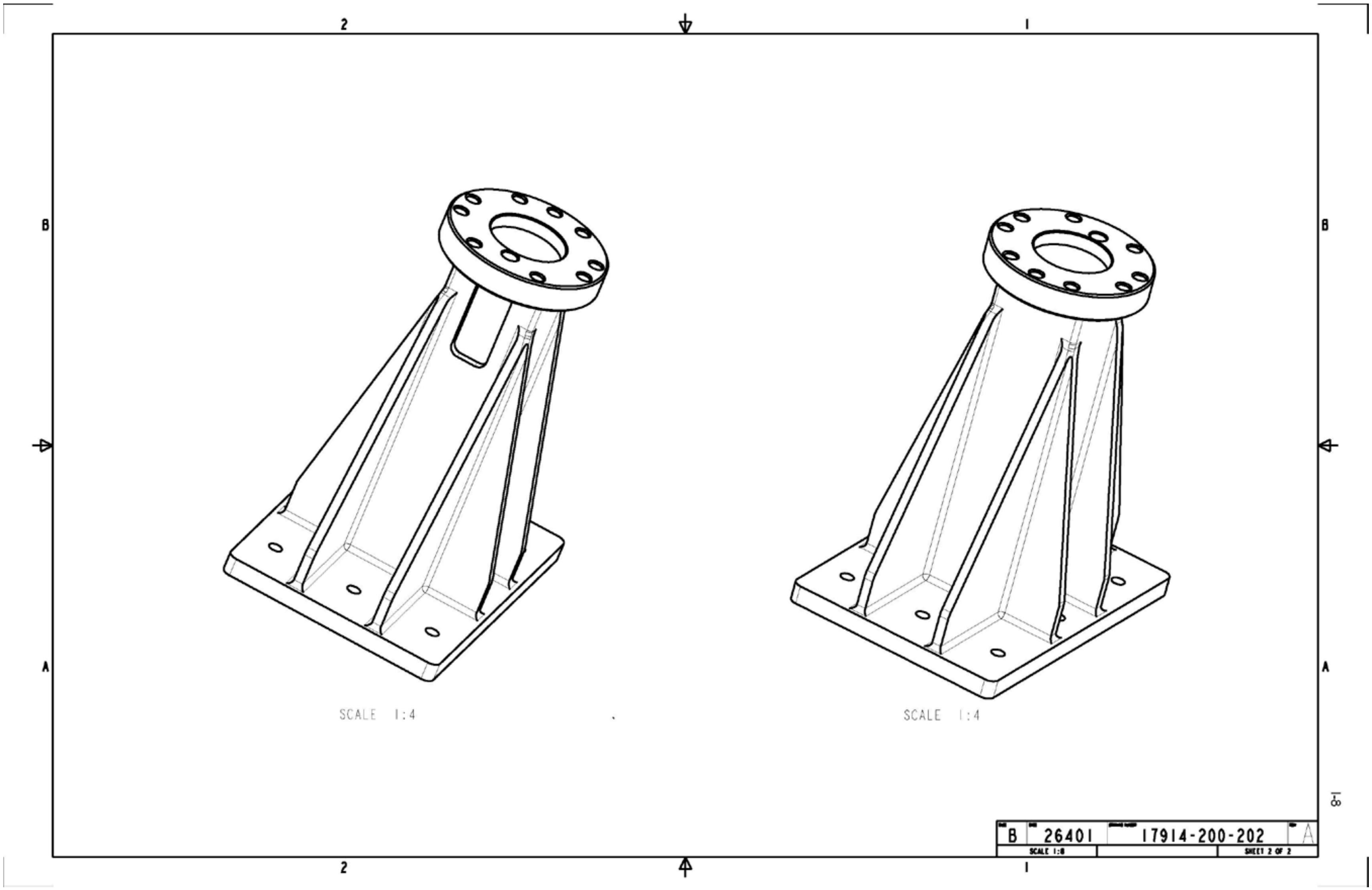
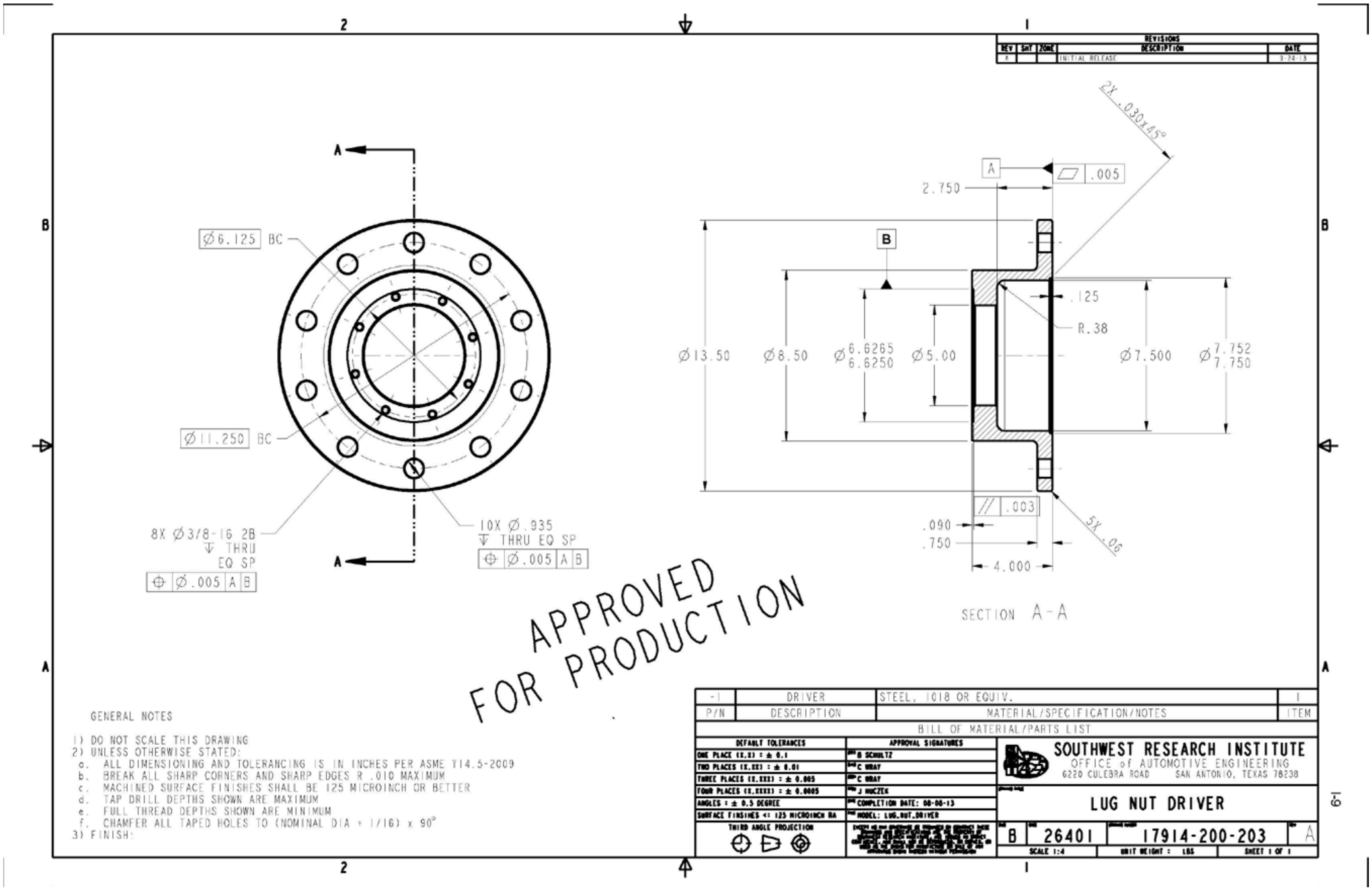
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238

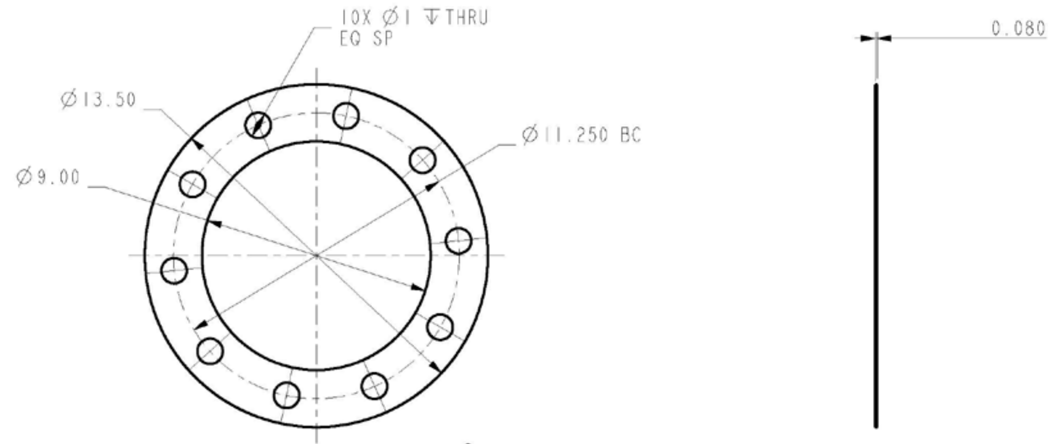
SPINDLE ADAPTER

B	26401	17914-200-202	A
SCALE 1:8	UNIT WEIGHT : LBS	SHEET 1 OF 2	


SCALE 1:4
SCALE 1:4
B
26401
17914-200-202
A
SCALE 1:8
SHEET 2 OF 2


REVISIONS
REV | SHT | ZONE | DESCRIPTION | DATE
A | | | INITIAL RELEASE | 3-24-13
Ø6.125 BC
Ø11.250 BC
8X Ø3/8-16 2B
THRU
EQ SP
Ø.005 A B
10X Ø.935
THRU EQ SP
Ø.005 A B
A
A
2X .030x45°
A
.005
2.750
B
.125
R.38
Ø13.50
Ø8.50
Ø 6.6265 6.6250
Ø5.00
Ø7.500
Ø 7.752 7.750
.003
.090
.750
4.000
5X .06
SECTION A-A
APPROVED FOR PRODUCTION
GENERAL NOTES
1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:
-1 | DRIVER | STEEL, 1018 OR EQUIV. | 1
P/N | DESCRIPTION | MATERIAL/SPECIFICATION/NOTES | ITEM
BILL OF MATERIAL/PARTS LIST
DEFAULT TOLERANCES
ONE PLACE (X.X) : ± 0.1
TWO PLACES (X.XX) : ± 0.01
THREE PLACES (X.XXX) : ± 0.005
FOUR PLACES (X.XXXX) : ± 0.0005
ANGLES : ± 0.5 DEGREE
SURFACE FINISHES <: 125 MICROINCH RA
THIRD ANGLE PROJECTION
APPROVAL SIGNATURES
B SCHULTZ
C WRAY
C WRAY
J MUCZEK
COMPLETION DATE: 08-08-13
MODEL: LUG_NUT_DRIVER
SOUTHWEST RESEARCH INSTITUTE
OFFICE of AUTOMOTIVE ENGINEERING
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238
LUG NUT DRIVER
B 26401 17914-200-203 A
SCALE 1:4
UNIT WEIGHT : LBS
SHEET 1 OF 1

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	09-24-13



APPROVED
FOR PRODUCTION

GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1		REINFORCED NON ASBESTOS COMPOSITE EXHAUST GASKET SHEET	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) : ± 0.1	B SCHULTZ
TWO PLACES (X.XX) : ± 0.01	C WRAY
THREE PLACES (X.XXX) : ± 0.005	C WRAY
FOUR PLACES (X.XXXX) : ± 0.0005	J HUCZEK
ANGLES : ± 0.5 DEGREE	COMPLETION DATE: 08-27-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: LUG.NUT.GASKET
THIRD ANGLE PROJECTION	

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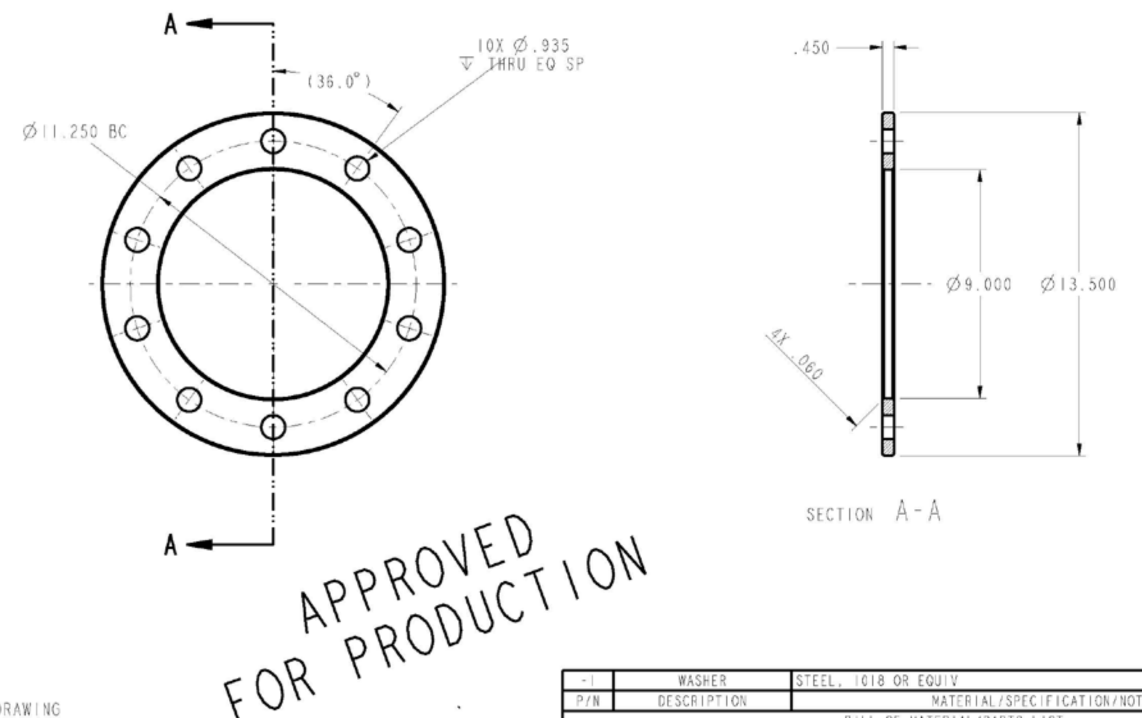
OFFICE of AUTOMOTIVE ENGINEERING
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238

LUG NUT GASKET

B	26401	17914-200-204	A
SCALE 1:4	UNIT WEIGHT : LBS	SHEET 1 OF 1	

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	09-24-13



GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	WASHER	STEEL, 1018 OR EQUIV	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) : ± 0.1	B SCHULTZ
TWO PLACES (X.XX) : ± 0.01	C WRAY
THREE PLACES (X.XXX) : ± 0.005	C WRAY
FOUR PLACES (X.XXXX) : ± 0.0005	J HUCZEK
ANGLES : ± 0.5 DEGREE	COMPLETION DATE: 08-27-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: LUG.NUT.DRIVER.WASHER
THIRD ANGLE PROJECTION	

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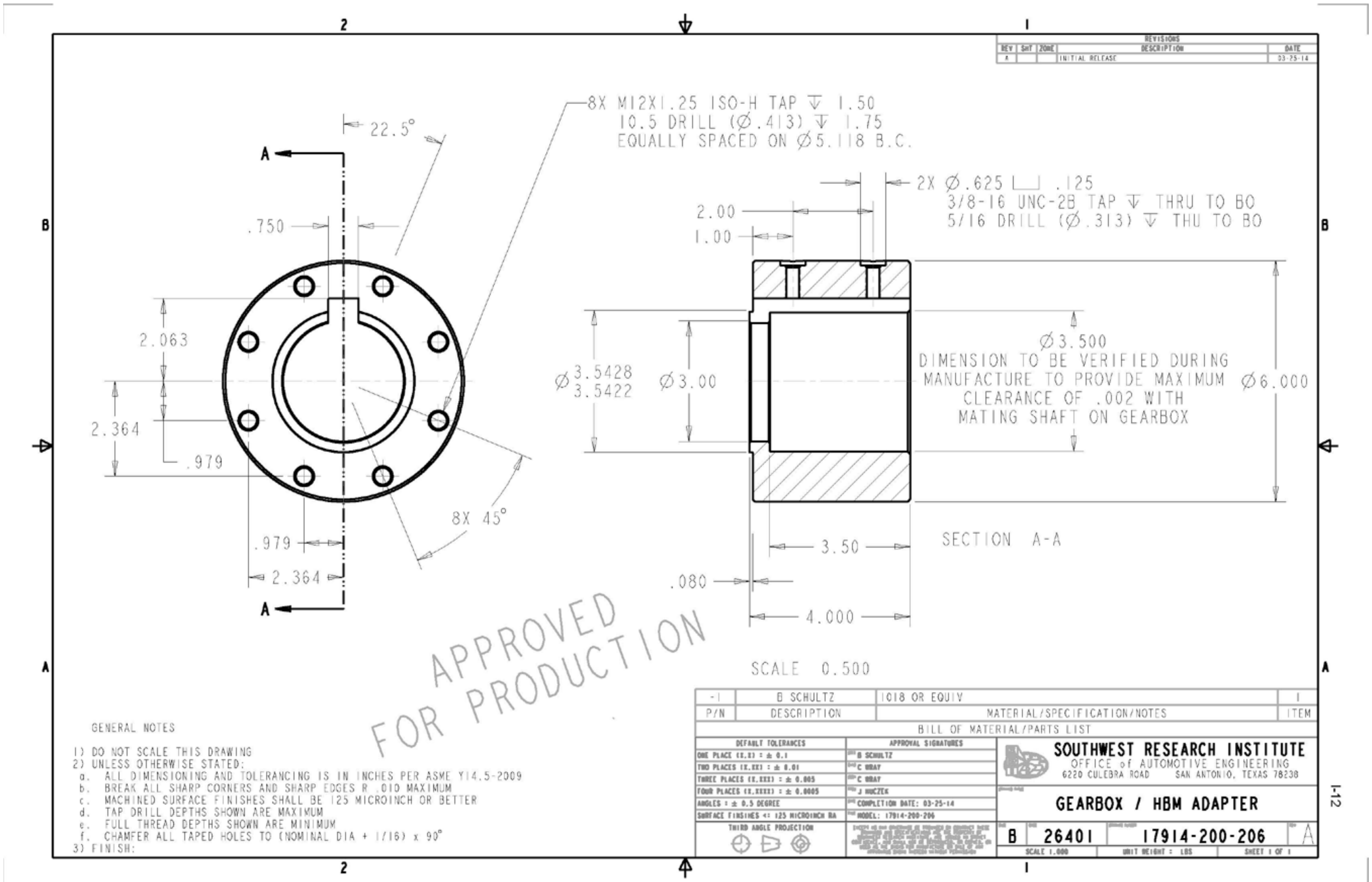
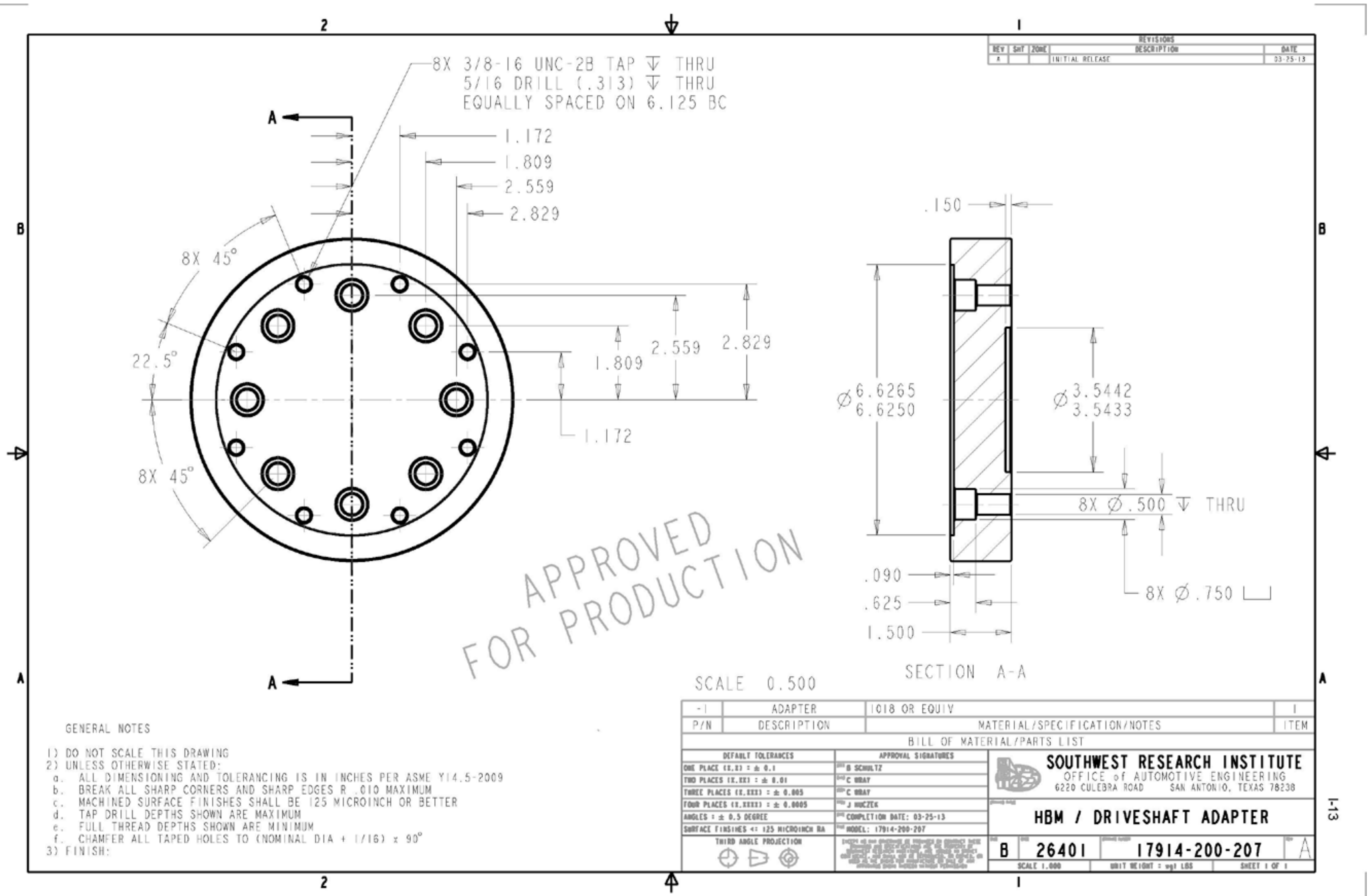
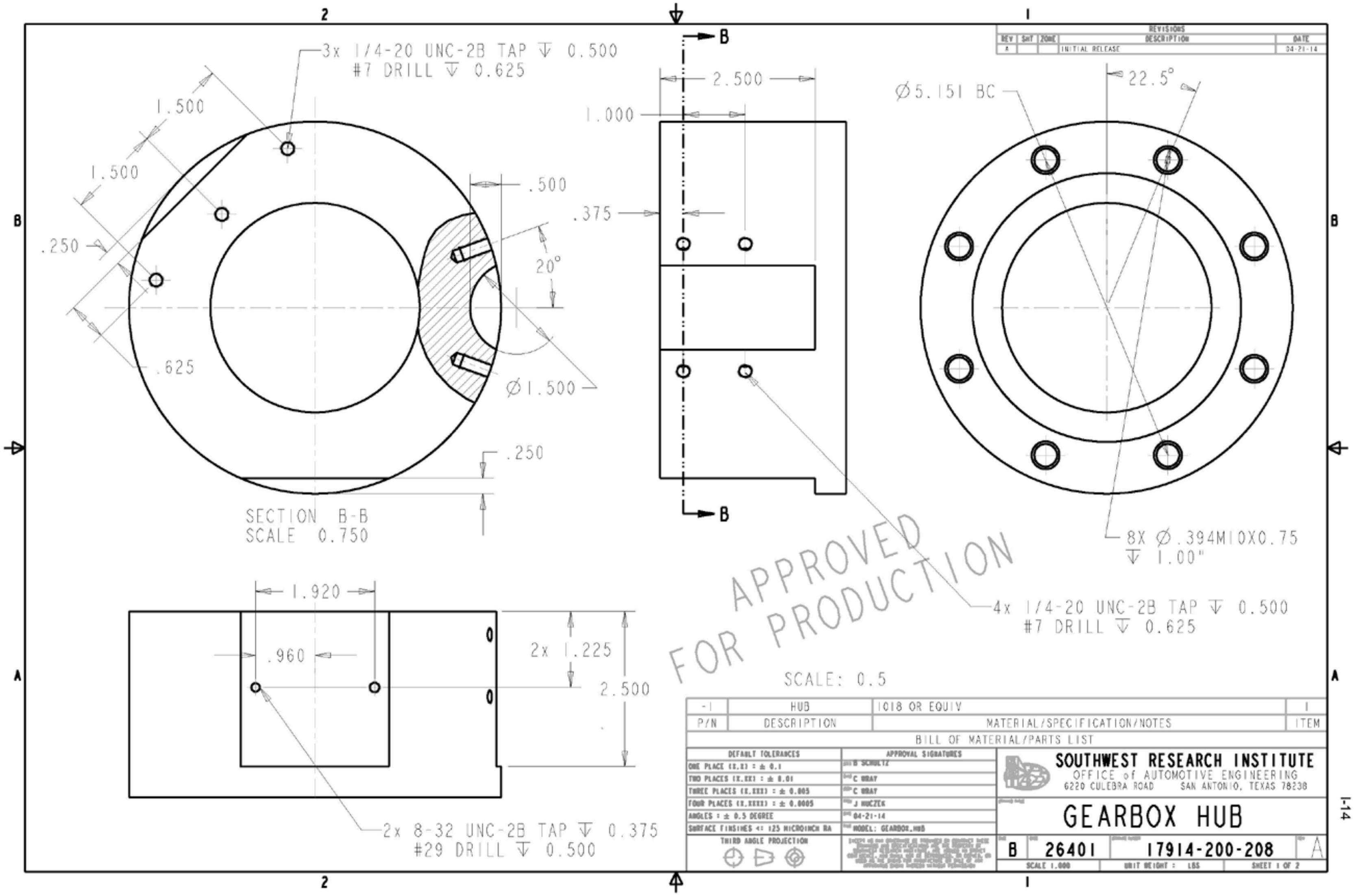
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238

LUG NUT DRIVER WASHER

B	26401	17914-200-205	A
SCALE 1:4	UNIT WEIGHT : LBS	SHEET 1 OF 1	

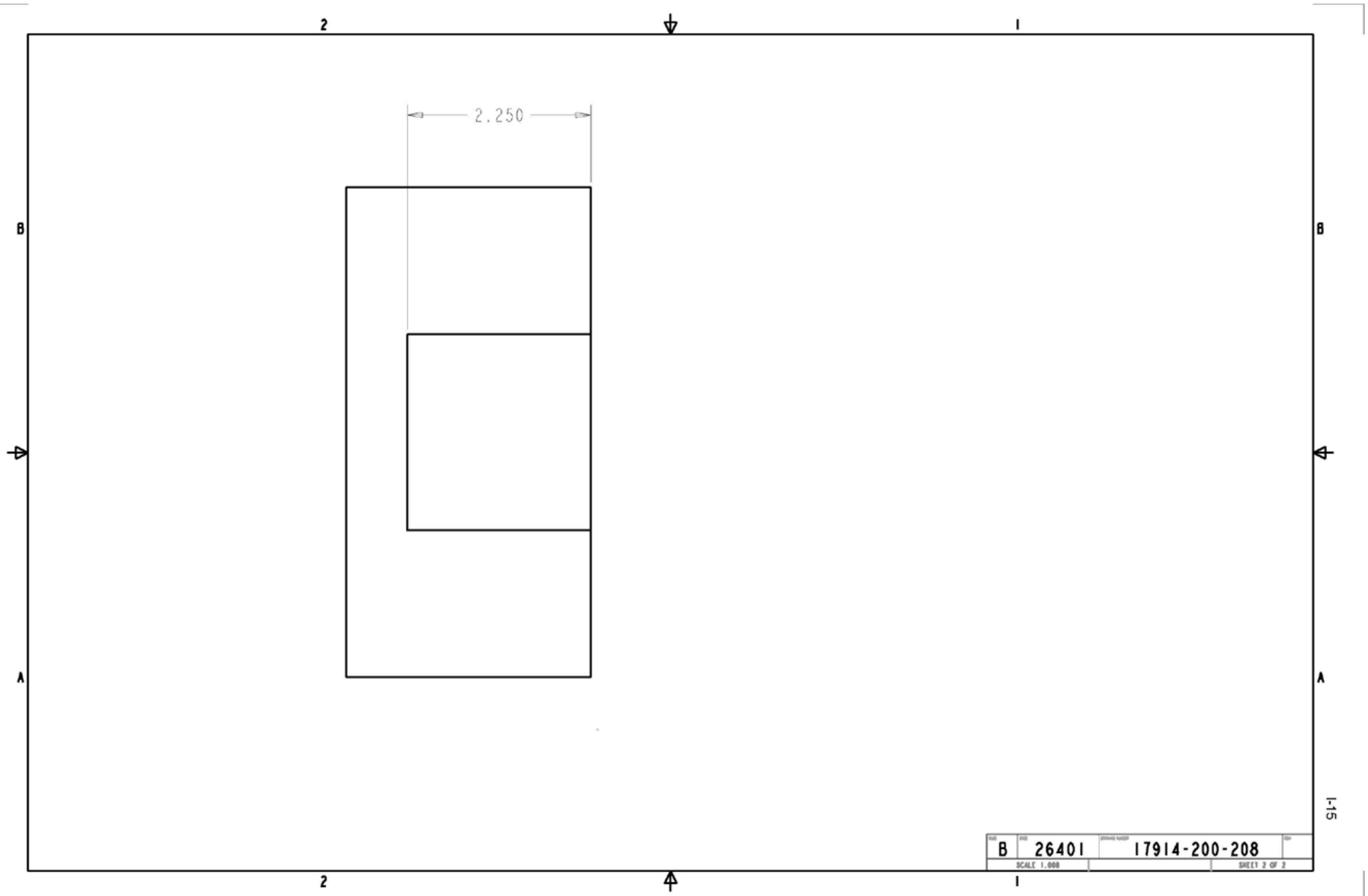

8X M12X1.25 ISO-H TAP ⩔ 1.50
10.5 DRILL (∅.413) ⩔ 1.75
EQUALLY SPACED ON ∅5.118 B.C.
22.5°
A
.750
2.063
2.364
.979
8X 45°
.979
2.364
A
2X ∅.625 ⌴ .125
3/8-16 UNC-2B TAP ⩔ THRU TO BO
5/16 DRILL (∅.313) ⩔ THU TO BO
2.00
1.00
∅3.5428
3.5422
∅3.00
∅3.500
DIMENSION TO BE VERIFIED DURING
MANUFACTURE TO PROVIDE MAXIMUM
CLEARANCE OF .002 WITH
MATING SHAFT ON GEARBOX
∅6.000
3.50
SECTION A-A
.080
4.000
SCALE 0.500
APPROVED
FOR PRODUCTION
GENERAL NOTES
1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:
REVISIONS
REV | SHT | ZONE | DESCRIPTION | DATE
A | INITIAL RELEASE | 03-25-14
-1 | B SCHULTZ | 1018 OR EQUIV | 1
P/N | DESCRIPTION | MATERIAL/SPECIFICATION/NOTES | ITEM
BILL OF MATERIAL/PARTS LIST
DEFAULT TOLERANCES
ONE PLACE (X.X) : ± 0.1
TWO PLACES (X.XX) : ± 0.01
THREE PLACES (X.XXX) : ± 0.005
FOUR PLACES (X.XXXX) : ± 0.0005
ANGLES : ± 0.5 DEGREE
SURFACE FINISHES <= 125 MICROINCH RA
THIRD ANGLE PROJECTION
APPROVAL SIGNATURES
B SCHULTZ
C WRAY
C WRAY
J HUCZEK
COMPLETION DATE: 03-25-14
MODEL: 17914-200-206
SOUTHWEST RESEARCH INSTITUTE
OFFICE of AUTOMOTIVE ENGINEERING
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238
GEARBOX / HBM ADAPTER
B 26401 17914-200-206 A
SCALE 1.000
UNIT WEIGHT : LBS
SHEET 1 OF 1

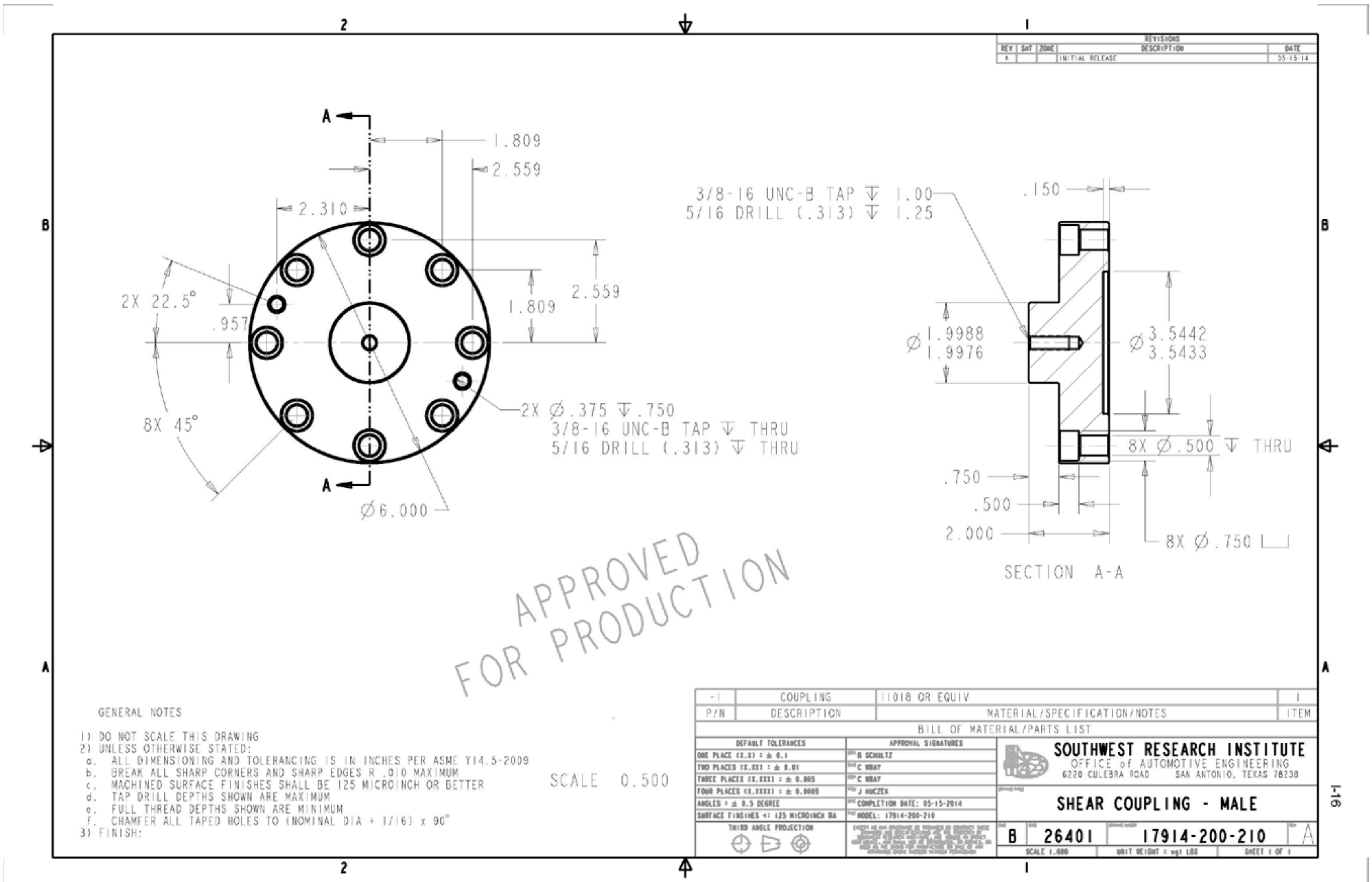

REVISIONS
REV | SHT | ZONE | DESCRIPTION | DATE
A | INITIAL RELEASE | 03-25-13
8X 3/8-16 UNC-2B TAP ↧ THRU
5/16 DRILL (.313) ↧ THRU
EQUALLY SPACED ON 6.125 BC
A
1.172
1.809
2.559
2.829
8X 45°
22.5°
8X 45°
1.809
2.559
2.829
1.172
.150
Ø 6.6265
6.6250
Ø 3.5442
3.5433
8X Ø .500 ↧ THRU
8X Ø .750 ⌴
.090
.625
1.500
SECTION A-A
APPROVED FOR PRODUCTION
SCALE 0.500
-1 | ADAPTER | 1018 OR EQUIV | 1
P/N | DESCRIPTION | MATERIAL/SPECIFICATION/NOTES | ITEM
BILL OF MATERIAL/PARTS LIST
GENERAL NOTES
1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:
DEFAULT TOLERANCES
ONE PLACE (X.X) : ± 0.1
TWO PLACES (X.XX) : ± 0.01
THREE PLACES (X.XXX) : ± 0.005
FOUR PLACES (X.XXXX) : ± 0.0005
ANGLES : ± 0.5 DEGREE
SURFACE FINSIHES <= 125 MICROINCH RA
THIRD ANGLE PROJECTION
APPROVAL SIGNATURES
B SCHULTZ
C WRAY
C WRAY
J HUCZEK
COMPLETION DATE: 03-25-13
MODEL: 17914-200-207
SOUTHWEST RESEARCH INSTITUTE
OFFICE of AUTOMOTIVE ENGINEERING
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238
HBM / DRIVESHAFT ADAPTER
B 26401 17914-200-207 A
SCALE 1.000
UNIT WEIGHT = wgt LBS
SHEET 1 OF 1



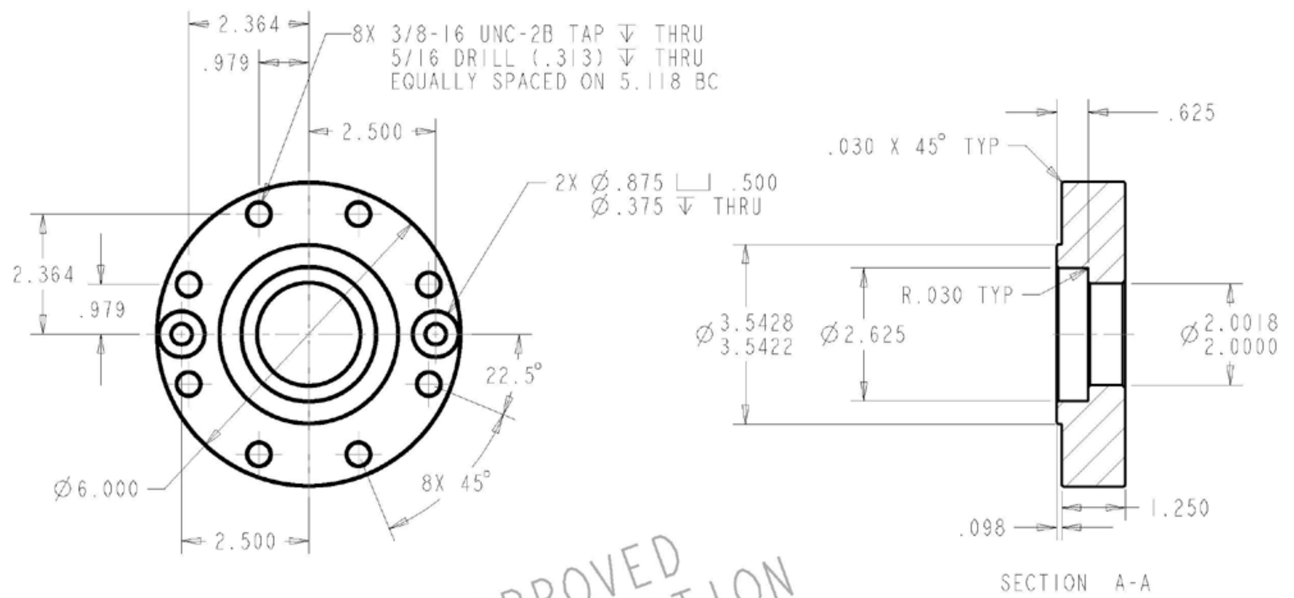
3x 1/4-20 UNC-2B TAP ↧ 0.500
#7 DRILL ↧ 0.625
1.500
1.500
.250
.625
.500
20°
Ø1.500
.250
SECTION B-B
SCALE 0.750
2.500
1.000
.375
B
B
Ø5.151 BC
22.5°
8X Ø.394M10X0.75
↧ 1.00"
4x 1/4-20 UNC-2B TAP ↧ 0.500
#7 DRILL ↧ 0.625
APPROVED
FOR PRODUCTION
1.920
.960
2x 1.225
2.500
2x 8-32 UNC-2B TAP ↧ 0.375
#29 DRILL ↧ 0.500
SCALE: 0.5
REVISIONS
REV | SHT | ZONE | DESCRIPTION | DATE
A | | | INITIAL RELEASE | 04-21-14
-1 | HUB | 1018 OR EQUIV | 1
P/N | DESCRIPTION | MATERIAL/SPECIFICATION/NOTES | ITEM
BILL OF MATERIAL/PARTS LIST
DEFAULT TOLERANCES
ONE PLACE (X.X) : ± 0.1
TWO PLACES (X.XX) : ± 0.01
THREE PLACES (X.XXX) : ± 0.005
FOUR PLACES (X.XXXX) : ± 0.0005
ANGLES : ± 0.5 DEGREE
SURFACE FINISHES <= 125 MICROINCH RA
THIRD ANGLE PROJECTION
APPROVAL SIGNATURES
B SCHULTZ
C WRAY
C WRAY
J MUCZEK
04-21-14
MODEL: GEARBOX_HUB
SOUTHWEST RESEARCH INSTITUTE
OFFICE of AUTOMOTIVE ENGINEERING
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238
GEARBOX HUB
B
26401
17914-200-208
A
SCALE 1.000
UNIT WEIGHT : LBS
SHEET 1 OF 2
2
1
B
A

I-14


2.250
B
26401
17914-200-208
SCALE 1.000
SHEET 2 OF 2


REVISIONS
REV | SHT | ZONE | DESCRIPTION | DATE
A | INITIAL RELEASE | 05-15-14
A
1.809
2.559
2.310
2X 22.5°
.957
2.559
1.809
8X 45°
2X Ø.375 ↧.750
3/8-16 UNC-B TAP ↧ THRU
5/16 DRILL (.313) ↧ THRU
Ø6.000
3/8-16 UNC-B TAP ↧ 1.00
5/16 DRILL (.313) ↧ 1.25
.150
Ø1.9988
1.9976
Ø3.5442
3.5433
8X Ø.500 ↧ THRU
.750
.500
2.000
8X Ø.750
SECTION A-A
APPROVED FOR PRODUCTION
GENERAL NOTES
1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:
SCALE 0.500
-1 | COUPLING | 11018 OR EQUIV | 1
P/N | DESCRIPTION | MATERIAL/SPECIFICATION/NOTES | ITEM
BILL OF MATERIAL/PARTS LIST
DEFAULT TOLERANCES
ONE PLACE (X.X) : ± 0.1
TWO PLACES (X.XX) : ± 0.01
THREE PLACES (X.XXX) : ± 0.005
FOUR PLACES (X.XXXX) : ± 0.0005
ANGLES : ± 0.5 DEGREE
SURFACE FINISHES <: 125 MICROINCH RA
THIRD ANGLE PROJECTION
APPROVAL SIGNATURES
B SCHULTZ
C WRAY
C WRAY
J HUCZEK
COMPLETION DATE: 05-15-2014
MODEL: 17914-200-210
SOUTHWEST RESEARCH INSTITUTE
OFFICE of AUTOMOTIVE ENGINEERING
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238
SHEAR COUPLING - MALE
B
26401
17914-200-210
A
SCALE 1.000
UNIT WEIGHT : wgt LBS
SHEET 1 OF 1
I-16

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	05-15-14



GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

SCALE 0.500

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	COUPLING	1018 OR EQUIV	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) : ± 0.1	B SCHULTZ
TWO PLACES (X.XX) : ± 0.01	C WRAY
THREE PLACES (X.XXX) : ± 0.005	C WRAY
FOUR PLACES (X.XXXX) : ± 0.0005	J HUCZEK
ANGLES : ± 0.5 DEGREE	COMPLETION DATE: 05-15-2014
SURFACE FINISHES <= 125 MICROINCH RA	MODEL: 17914-200-211
THIRD ANGLE PROJECTION	

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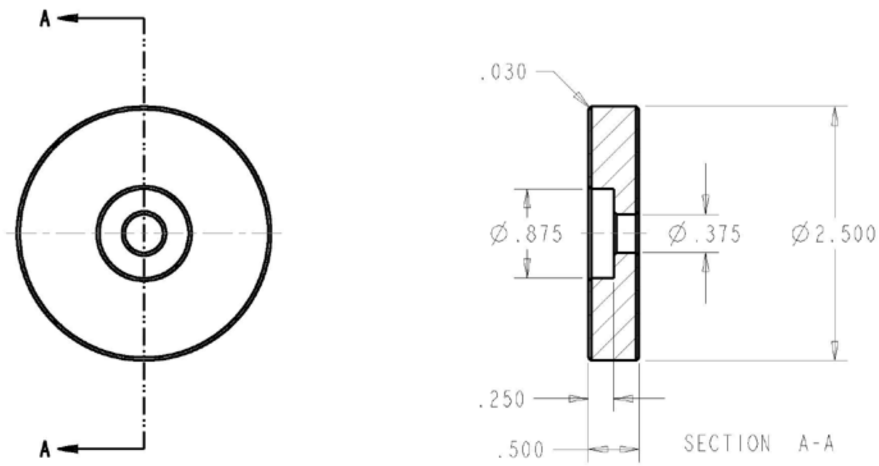
OFFICE of AUTOMOTIVE ENGINEERING
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238

SHEAR COUPLING - FEMALE

B	26401	17914-200-211	A
SCALE 1.000	UNIT WEIGHT : wgt LBS	SHEET 1 OF 1	

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	05-15-14



APPROVED FOR PRODUCTION

GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
  a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
  b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
  c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
  d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
  e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
  f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	WASHER	1018 OR EQUIV	1

BILL OF MATERIAL/PARTS LIST

DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) : ± 0.1	B SCHULTZ
TWO PLACES (X.XX) : ± 0.01	C WRAY
THREE PLACES (X.XXX) : ± 0.005	C WRAY
FOUR PLACES (X.XXXX) : ± 0.0005	J HUCZEK
ANGLES : ± 0.5 DEGREE	COMPLETION DATE: 05-15-2014
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: 17914-200-213

THIRD ANGLE PROJECTION

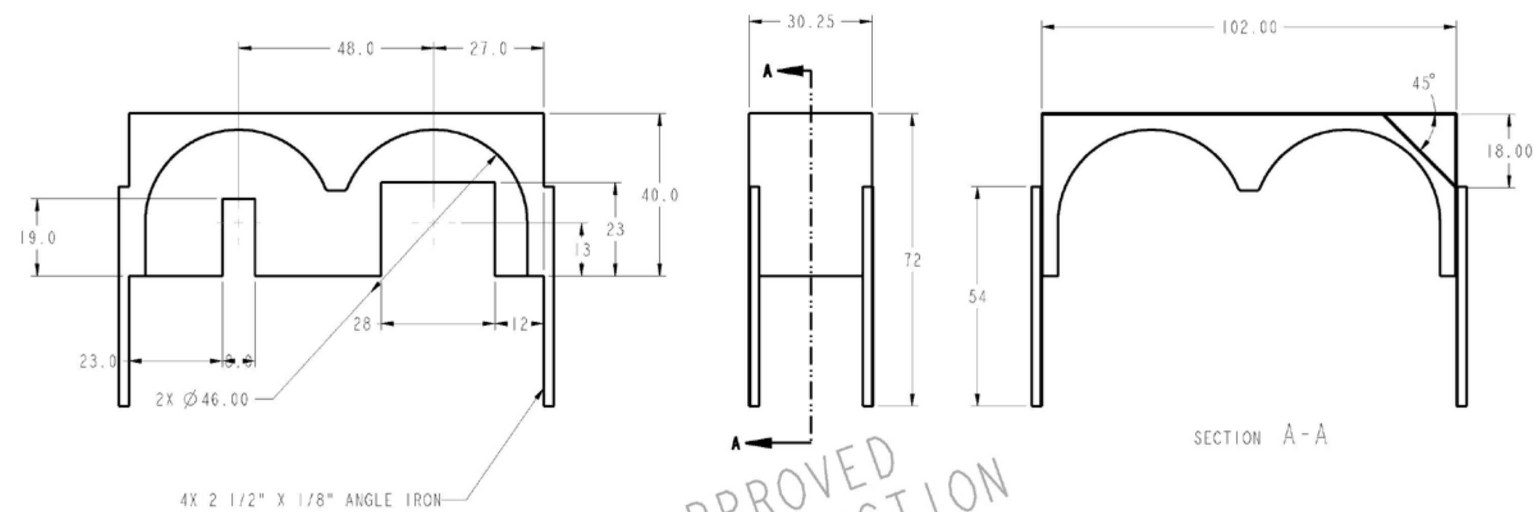
SOUTHWEST RESEARCH INSTITUTE
OFFICE of AUTOMOTIVE ENGINEERING
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238

SHEAR COUPLING WASHER

B | 26401 | 17914-200-213 | A

SCALE 1.000 | UNIT WEIGHT : 0.000 LBS | SHEET 1 OF 1

REVISIONS				
REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	08-27-13



APPROVED FOR PRODUCTION

GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM
-1	WHEEL WELL FAB	3/16 SHEET METAL & 2" SQ TUBING WELDMENT	1

BILL OF MATERIAL/PARTS LIST

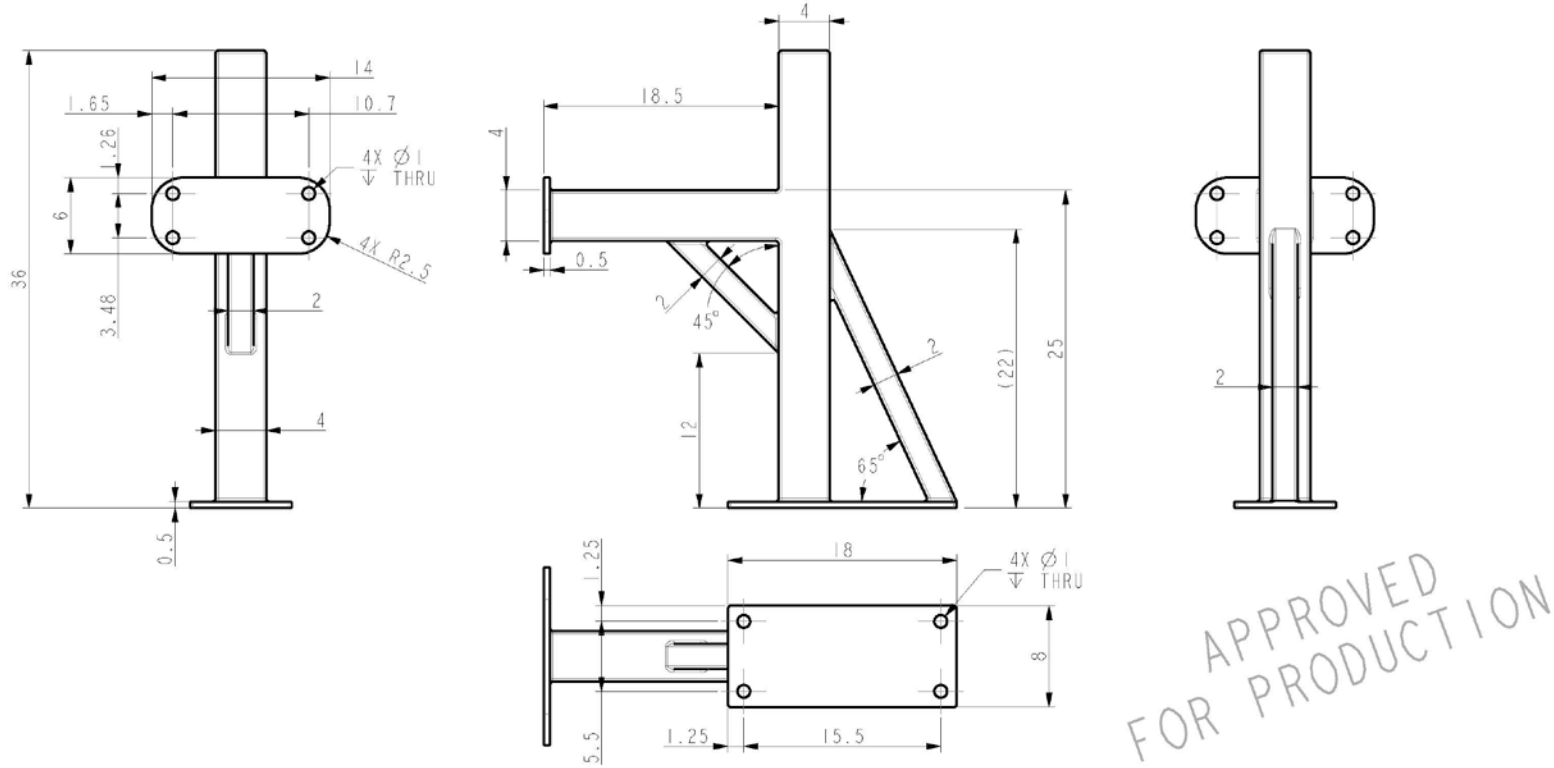
DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) : ± 0.1	B SCHULTZ
TWO PLACES (X.XX) : ± 0.01	C WRAY
THREE PLACES (X.XXX) : ± 0.005	C WRAY
FOUR PLACES (X.XXXX) : ± 0.0005	J HUCZEK
ANGLES : ± 0.5 DEGREE	COMPLETION DATE: 08-27-13
SURFACE FINSIHES <= 125 MICROINCH RA	MODEL: WHEEL.WELL
THIRD ANGLE PROJECTION	

SOUTHWEST RESEARCH INSTITUTE
OFFICE of AUTOMOTIVE ENGINEERING
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238

WHEEL WELL

B	26401	17914-200-214	A
SCALE 3:64	UNIT WEIGHT : LBS	SHEET 1 OF 1	

REV	SHT	ZONE	DESCRIPTION	DATE
A			INITIAL RELEASE	07-15-15



GENERAL NOTES

1) DO NOT SCALE THIS DRAWING
2) UNLESS OTHERWISE STATED:
 a. ALL DIMENSIONING AND TOLERANCING IS IN INCHES PER ASME Y14.5-2009
 b. BREAK ALL SHARP CORNERS AND SHARP EDGES R .010 MAXIMUM
 c. MACHINED SURFACE FINISHES SHALL BE 125 MICROINCH OR BETTER
 d. TAP DRILL DEPTHS SHOWN ARE MAXIMUM
 e. FULL THREAD DEPTHS SHOWN ARE MINIMUM
 f. CHAMFER ALL TAPED HOLES TO (NOMINAL DIA + 1/16) x 90°
3) FINISH:

-1	MOUNT	STEEL WELDMENT	1
P/N	DESCRIPTION	MATERIAL/SPECIFICATION/NOTES	ITEM

BILL OF MATERIAL/PARTS LIST

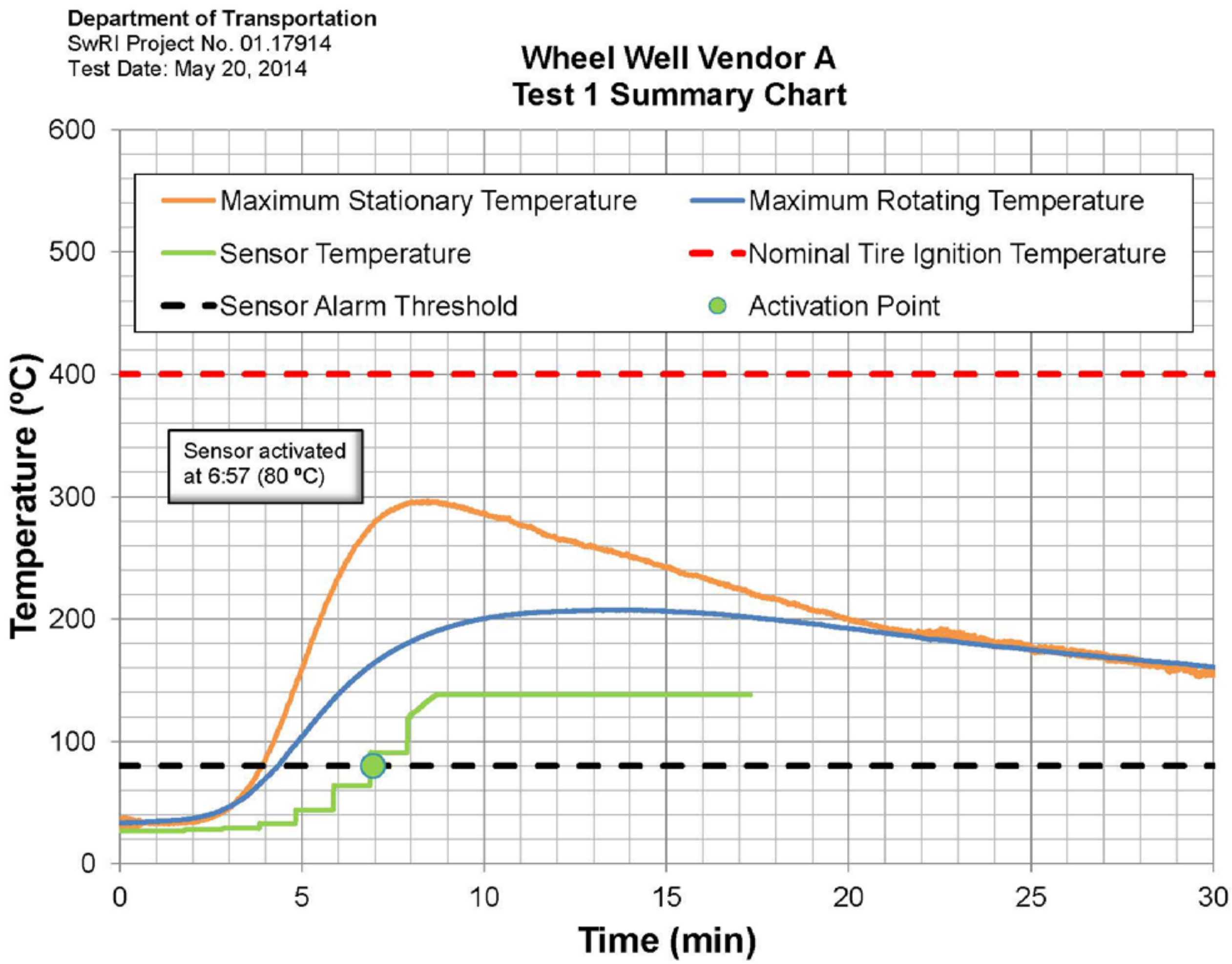
DEFAULT TOLERANCES	APPROVAL SIGNATURES
ONE PLACE (X.X) : ± 0.1	B SCHULTZ
TWO PLACES (X.XX) : ± 0.01	C WRAY
THREE PLACES (X.XXX) : ± 0.005	C WRAY
FOUR PLACES (X.XXXX) : ± 0.0005	J HUCZEK
ANGLES : ± 0.5 DEGREE	COMPLETION DATE: 07-15-14
SURFACE FINISHES <= 125 MICROINCH RA	MODEL: WHEEL.MOUNT
THIRD ANGLE PROJECTION	

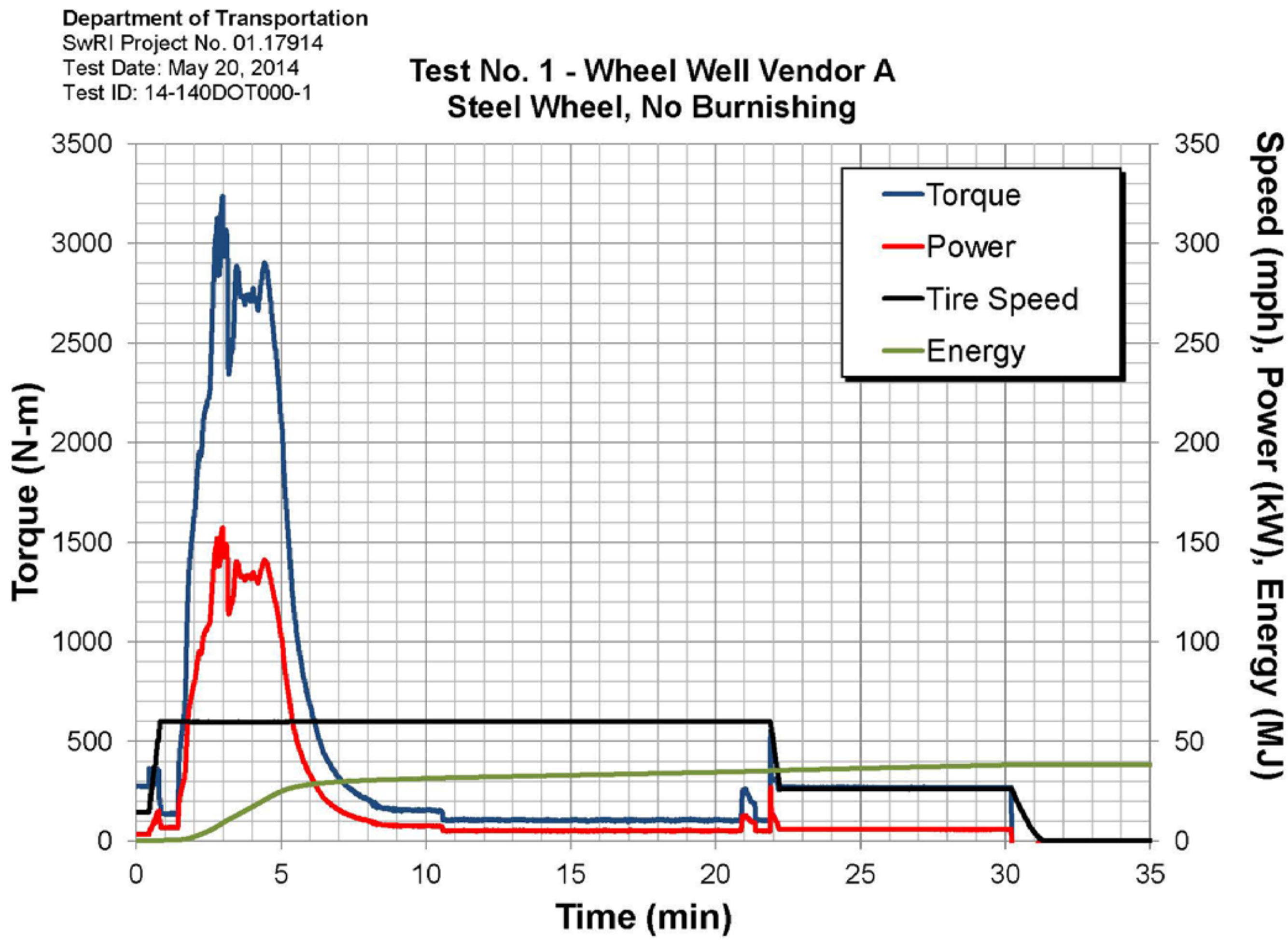
SOUTHWEST RESEARCH INSTITUTE
OFFICE of AUTOMOTIVE ENGINEERING
6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78238

WHEEL MOUNT

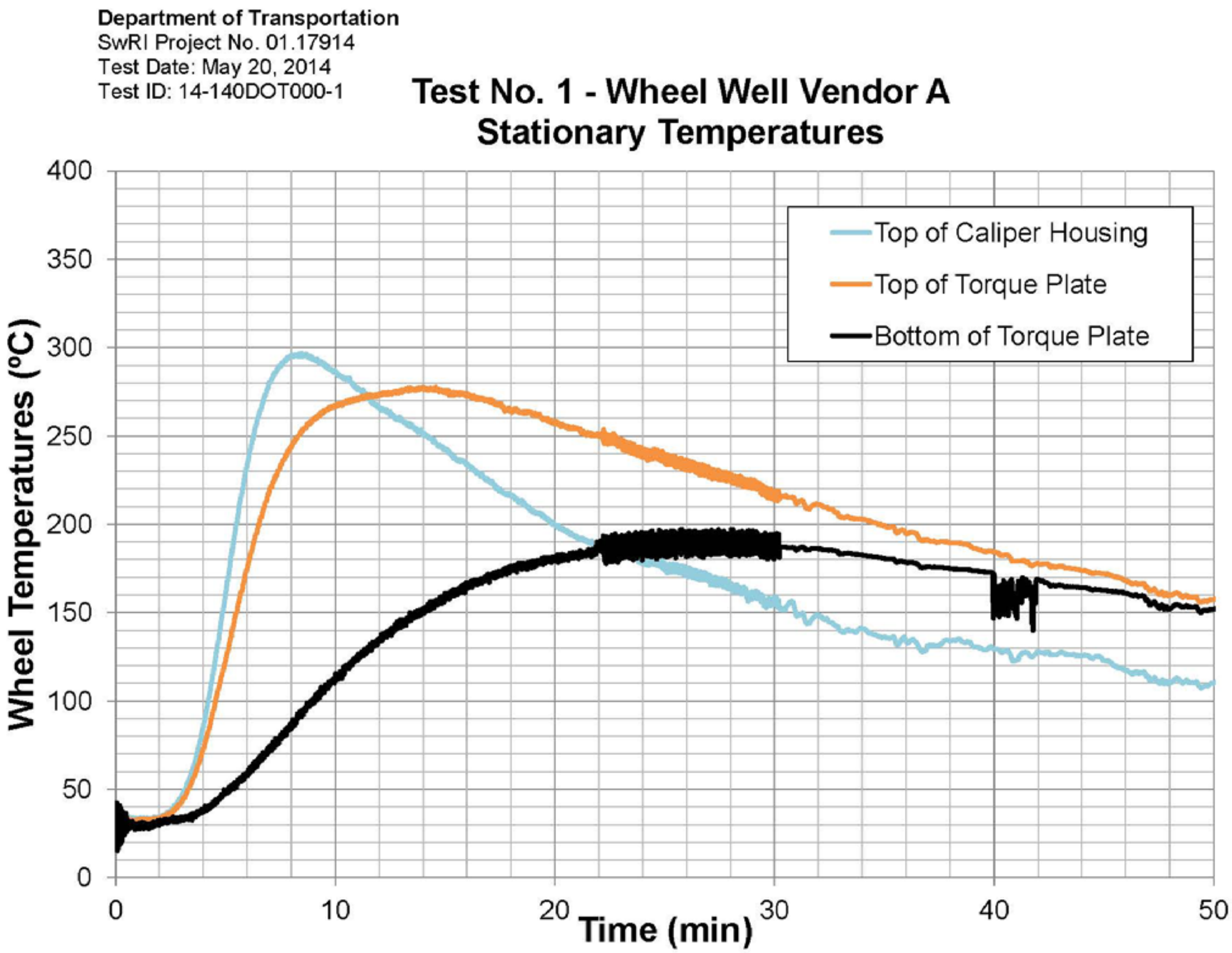
B	26401	17914-200-216	A
SCALE 1:8	UNIT WEIGHT : LBS	SHEET 1 OF 1	

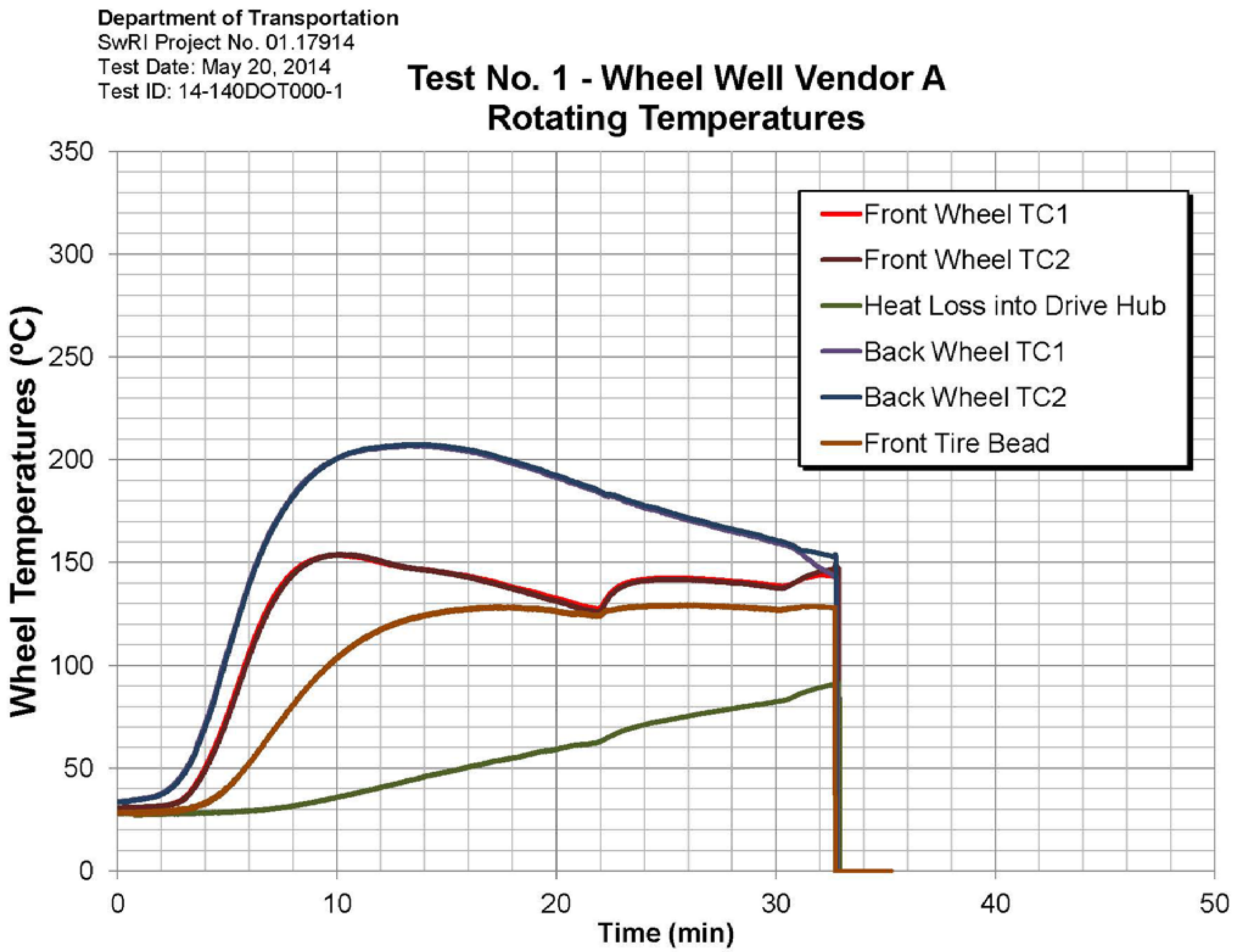
APPENDIX J
WHEEL WELL VENDOR A TEST DATA
(CONSISTING OF 8 PAGES)


Department of Transportation
SwRI Project No. 01.17914
Test Date: May 20, 2014
Wheel Well Vendor A
Test 1 Summary Chart
Maximum Stationary Temperature
Maximum Rotating Temperature
Sensor Temperature
Nominal Tire Ignition Temperature
Sensor Alarm Threshold
Activation Point
Sensor activated at 6:57 (80 ºC)
Temperature (ºC)
Time (min)
0
100
200
300
400
500
600
0
5
10
15
20
25
30

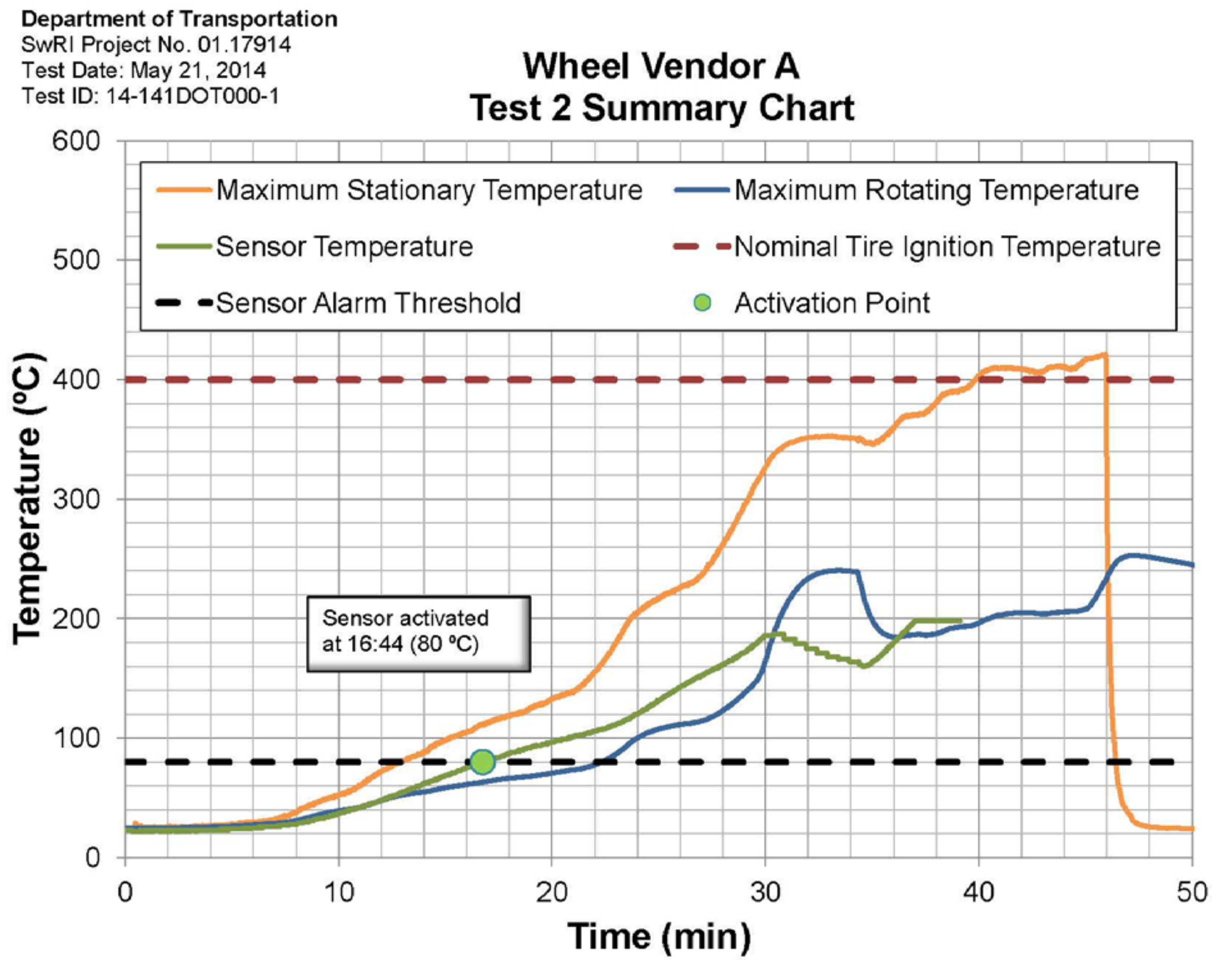


Department of Transportation
SwRI Project No. 01.17914
Test Date: May 20, 2014
Test ID: 14-140DOT000-1
Test No. 1 - Wheel Well Vendor A
Steel Wheel, No Burnishing
Torque
Power
Tire Speed
Energy
Torque (N-m)
Speed (mph), Power (kW), Energy (MJ)
Time (min)

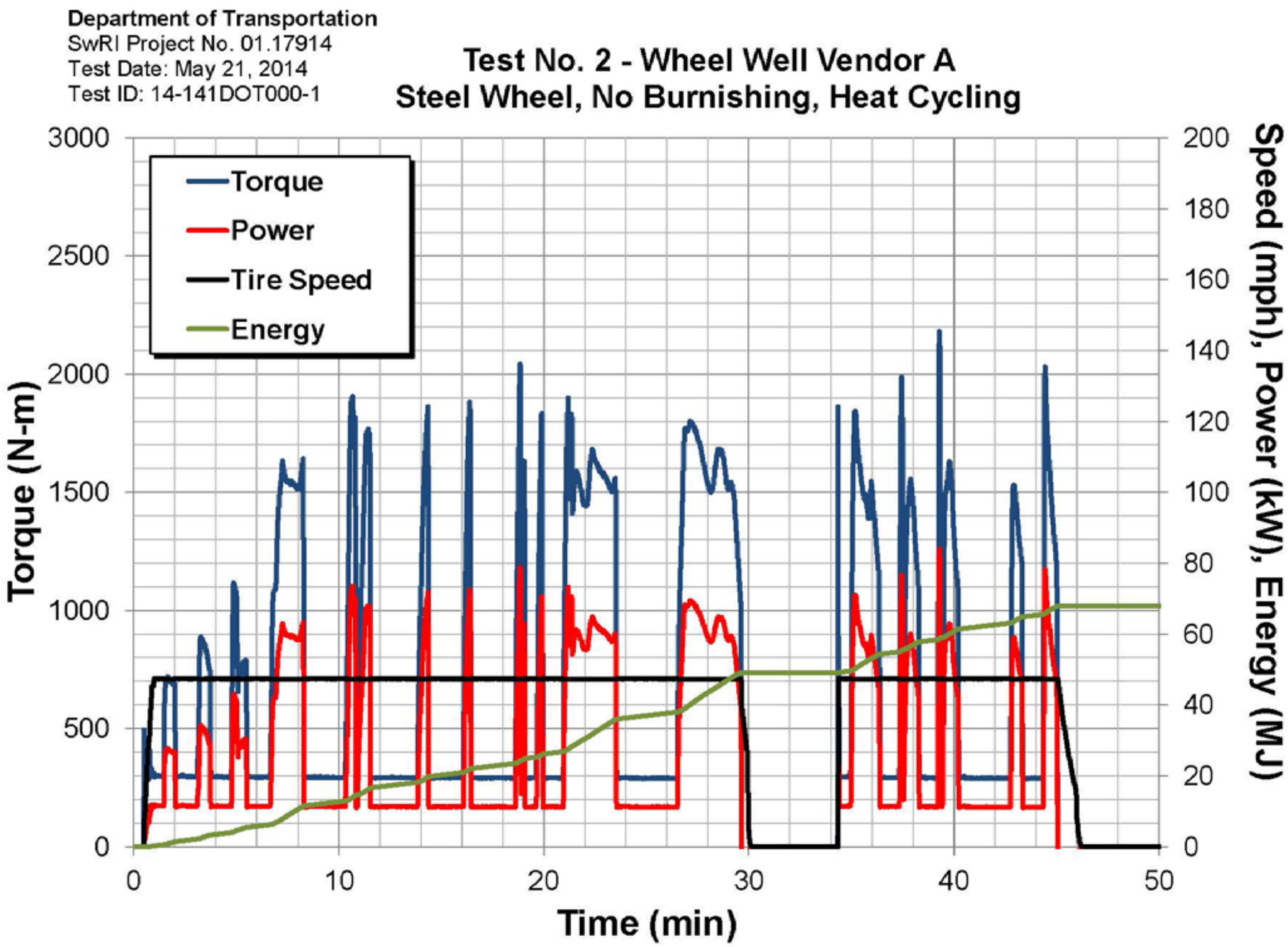

Department of Transportation
SwRI Project No. 01.17914
Test Date: May 20, 2014
Test ID: 14-140DOT000-1
Test No. 1 - Wheel Well Vendor A
Stationary Temperatures
Wheel Temperatures (ºC)
Time (min)
Top of Caliper Housing
Top of Torque Plate
Bottom of Torque Plate
400
350
300
250
200
150
100
50
0
0
10
20
30
40
50

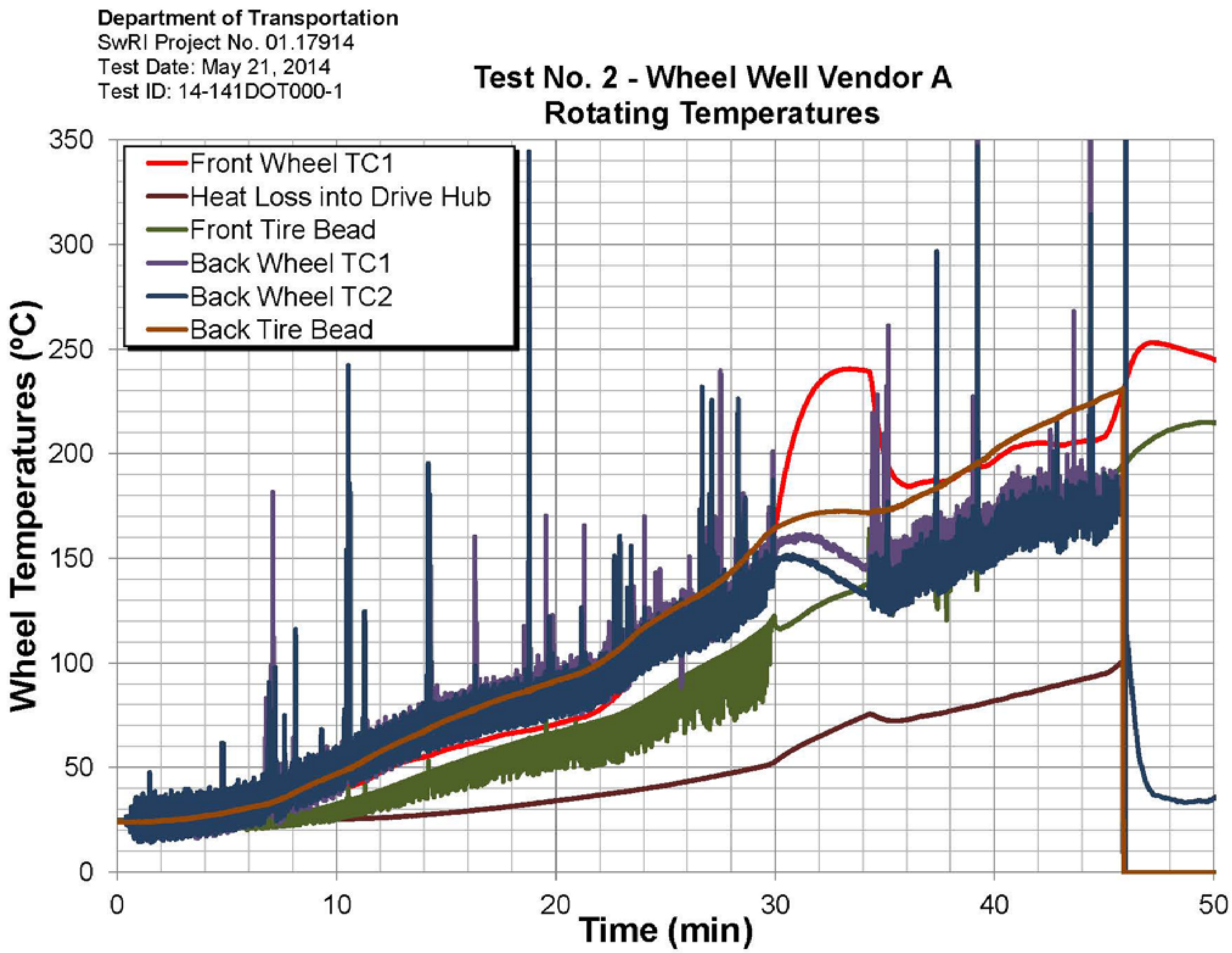


Department of Transportation
SwRI Project No. 01.17914
Test Date: May 20, 2014
Test ID: 14-140DOT000-1
Test No. 1 - Wheel Well Vendor A
Rotating Temperatures
Wheel Temperatures (ºC)
Time (min)
Front Wheel TC1
Front Wheel TC2
Heat Loss into Drive Hub
Back Wheel TC1
Back Wheel TC2
Front Tire Bead



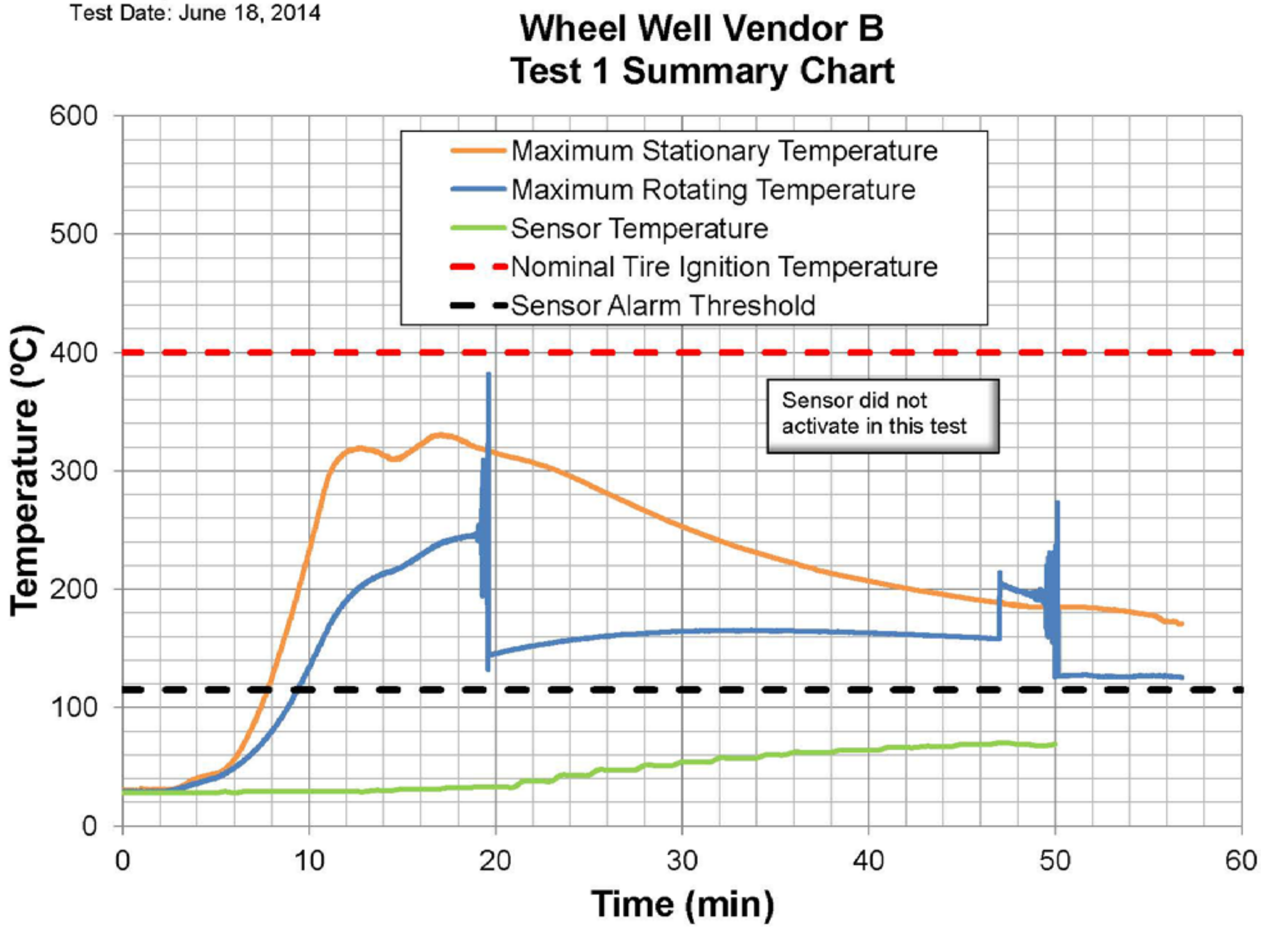
Department of Transportation
SwRI Project No. 01.17914
Test Date: May 21, 2014
Test ID: 14-141DOT000-1
Wheel Vendor A
Test 2 Summary Chart
Maximum Stationary Temperature
Maximum Rotating Temperature
Sensor Temperature
Nominal Tire Ignition Temperature
Sensor Alarm Threshold
Activation Point
Sensor activated at 16:44 (80 ºC)
Temperature (ºC)
Time (min)
0
100
200
300
400
500
600
0
10
20
30
40
50

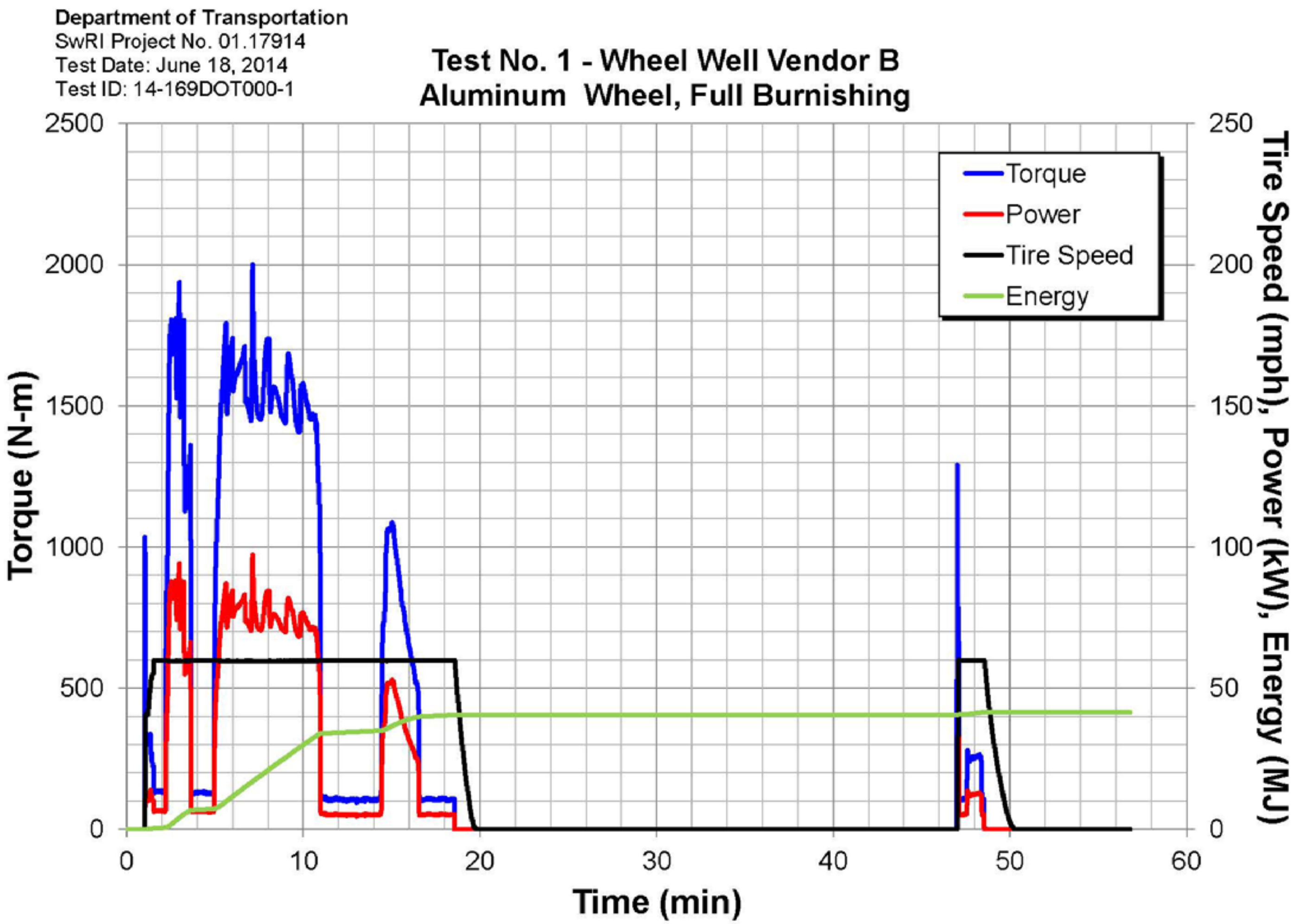

Department of Transportation
SwRI Project No. 01.17914
Test Date: May 21, 2014
Test ID: 14-141DOT000-1
Test No. 2 - Wheel Well Vendor A
Steel Wheel, No Burnishing, Heat Cycling
Torque
Power
Tire Speed
Energy
Torque (N-m)
Speed (mph), Power (kW), Energy (MJ)
Time (min)
0
500
1000
1500
2000
2500
3000
0
20
40
60
80
100
120
140
160
180
200
0
10
20
30
40
50

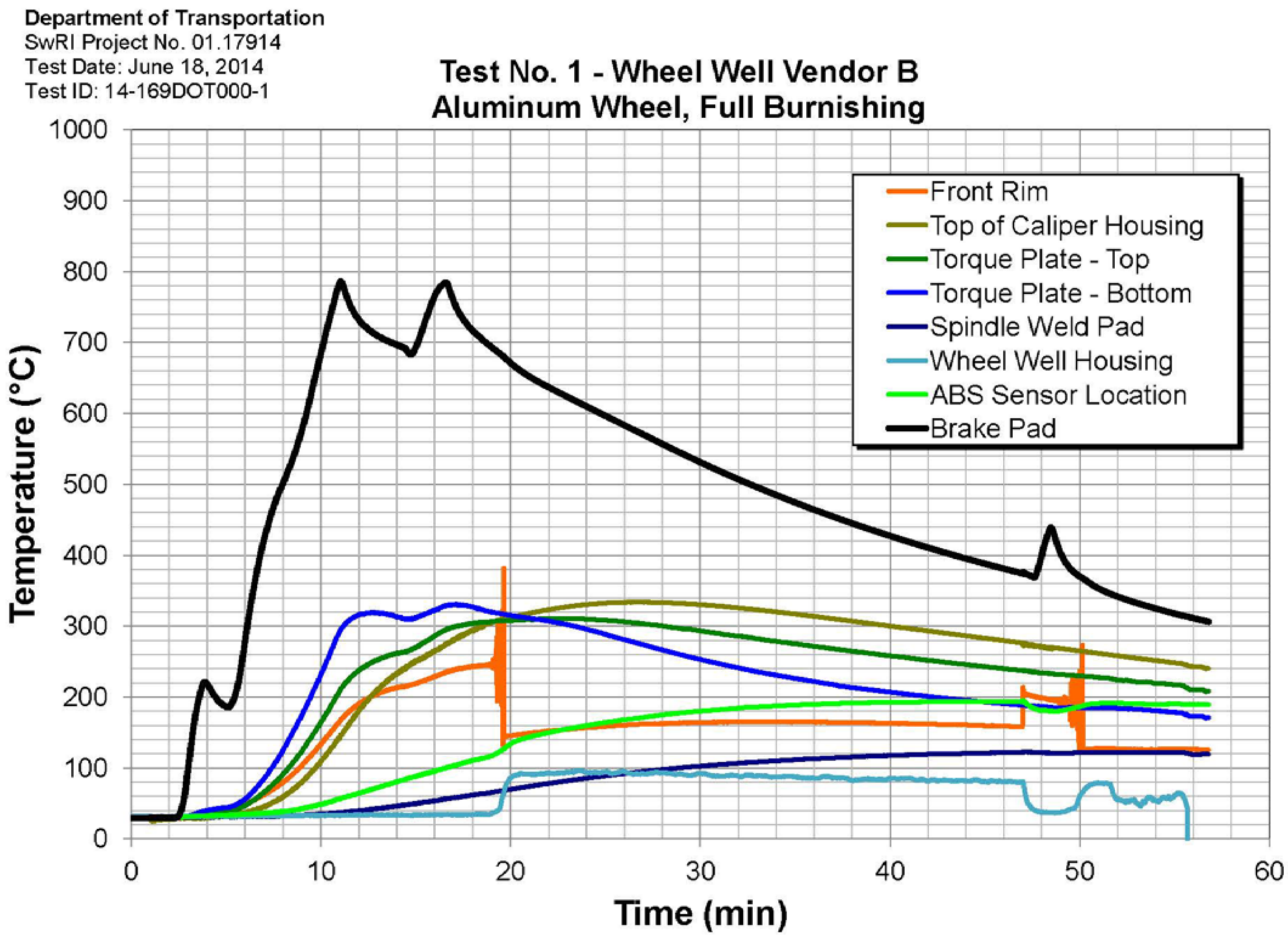

Department of Transportation
SwRI Project No. 01.17914
Test Date: May 21, 2014
Test ID: 14-141DOT000-1
Test No. 2 - Wheel Well Vendor A
Rotating Temperatures
Front Wheel TC1
Heat Loss into Drive Hub
Front Tire Bead
Back Wheel TC1
Back Wheel TC2
Back Tire Bead
Wheel Temperatures (°C)
Time (min)
0
50
100
150
200
250
300
350
10
20
30
40
50

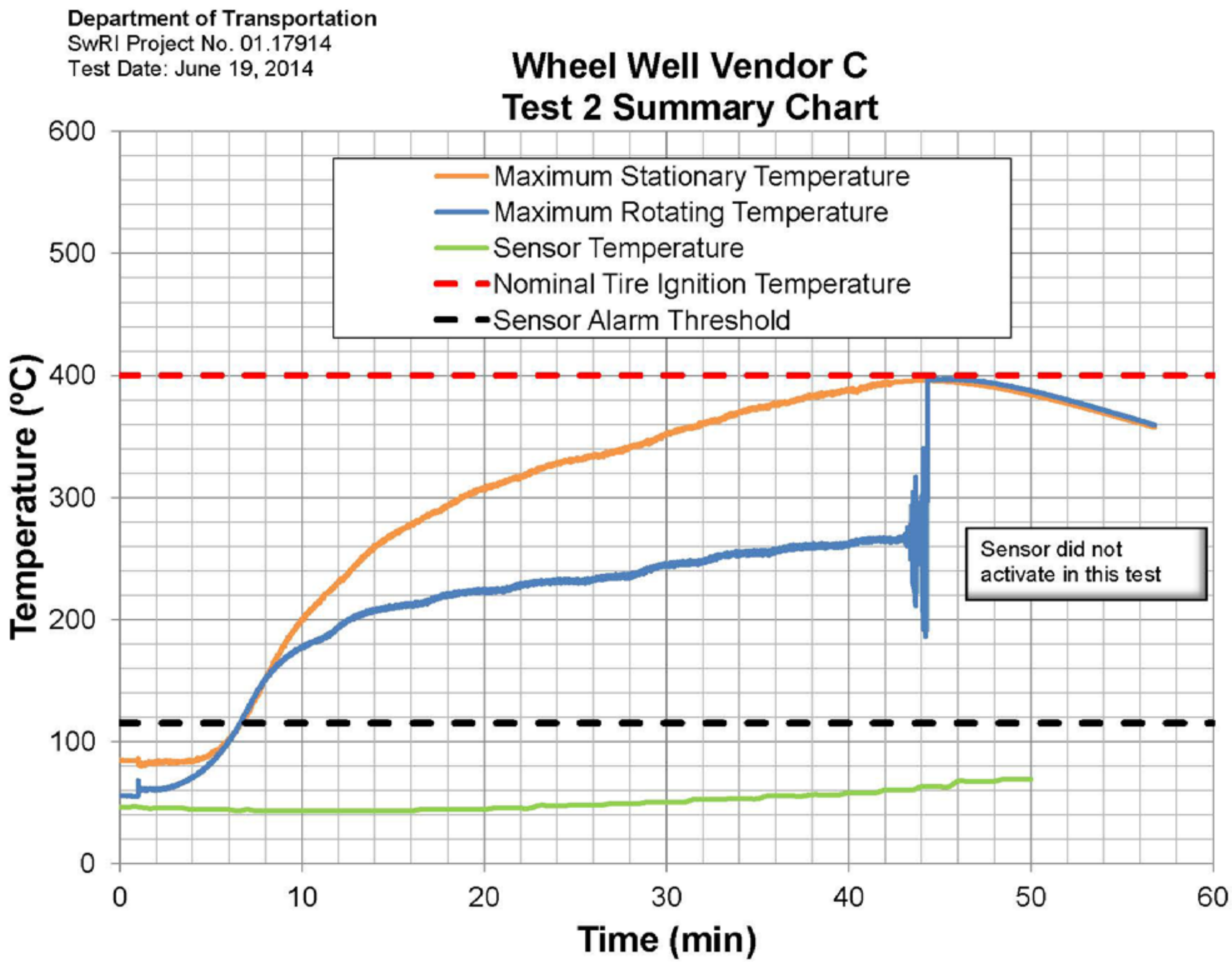
APPENDIX K
WHEEL WELL VENDOR B TEST DATA
(CONSISTING OF 9 PAGES)

Department of Transportation
SwRI Project No. 01.17914
Test Date: June 18, 2014

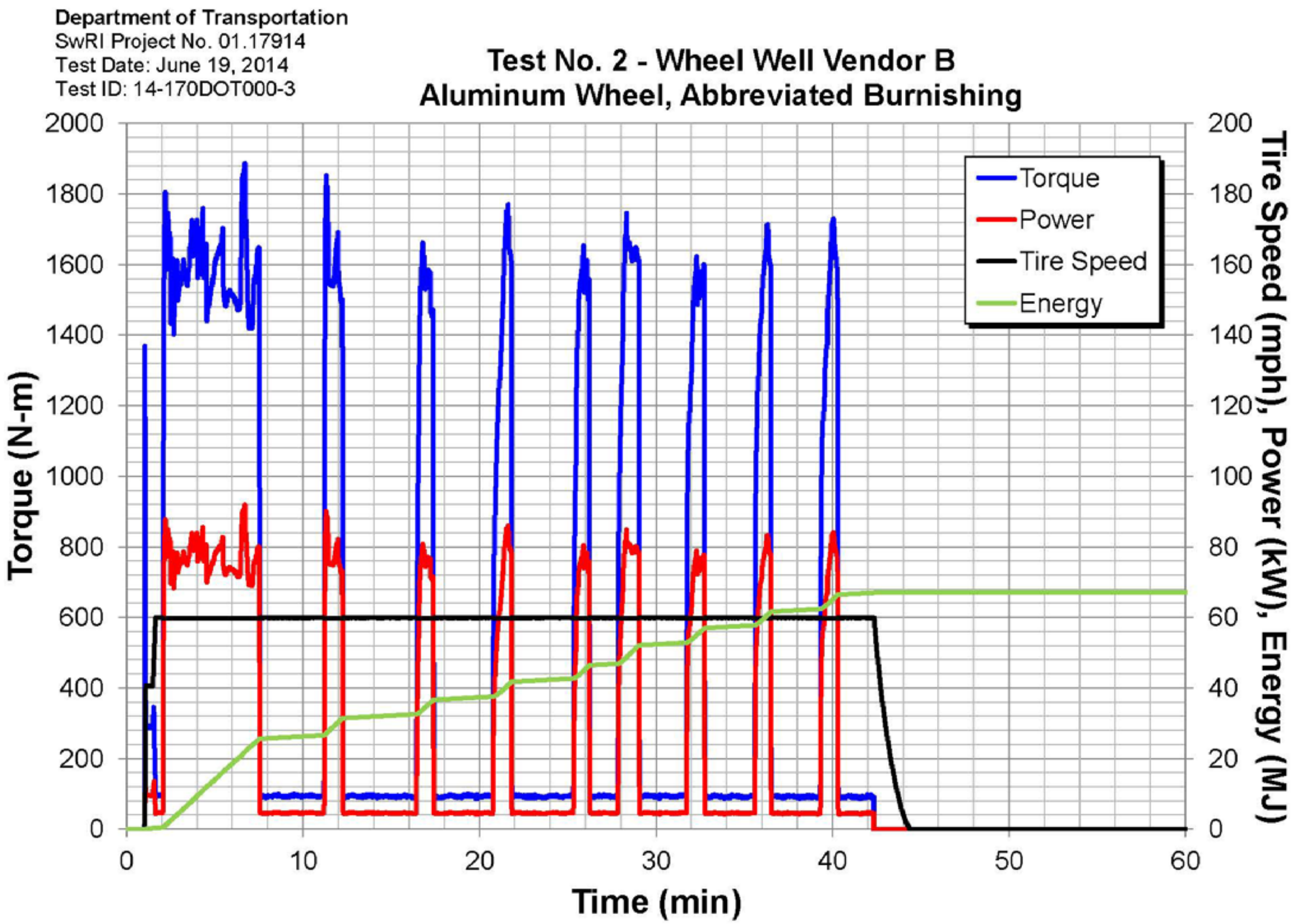



Department of Transportation
SwRI Project No. 01.17914
Test Date: June 18, 2014
Test ID: 14-169DOT000-1
Test No. 1 - Wheel Well Vendor B
Aluminum Wheel, Full Burnishing
Torque
Power
Tire Speed
Energy
Torque (N-m)
Tire Speed (mph), Power (kW), Energy (MJ)
Time (min)
0
500
1000
1500
2000
2500
0
50
100
150
200
250
0
10
20
30
40
50
60

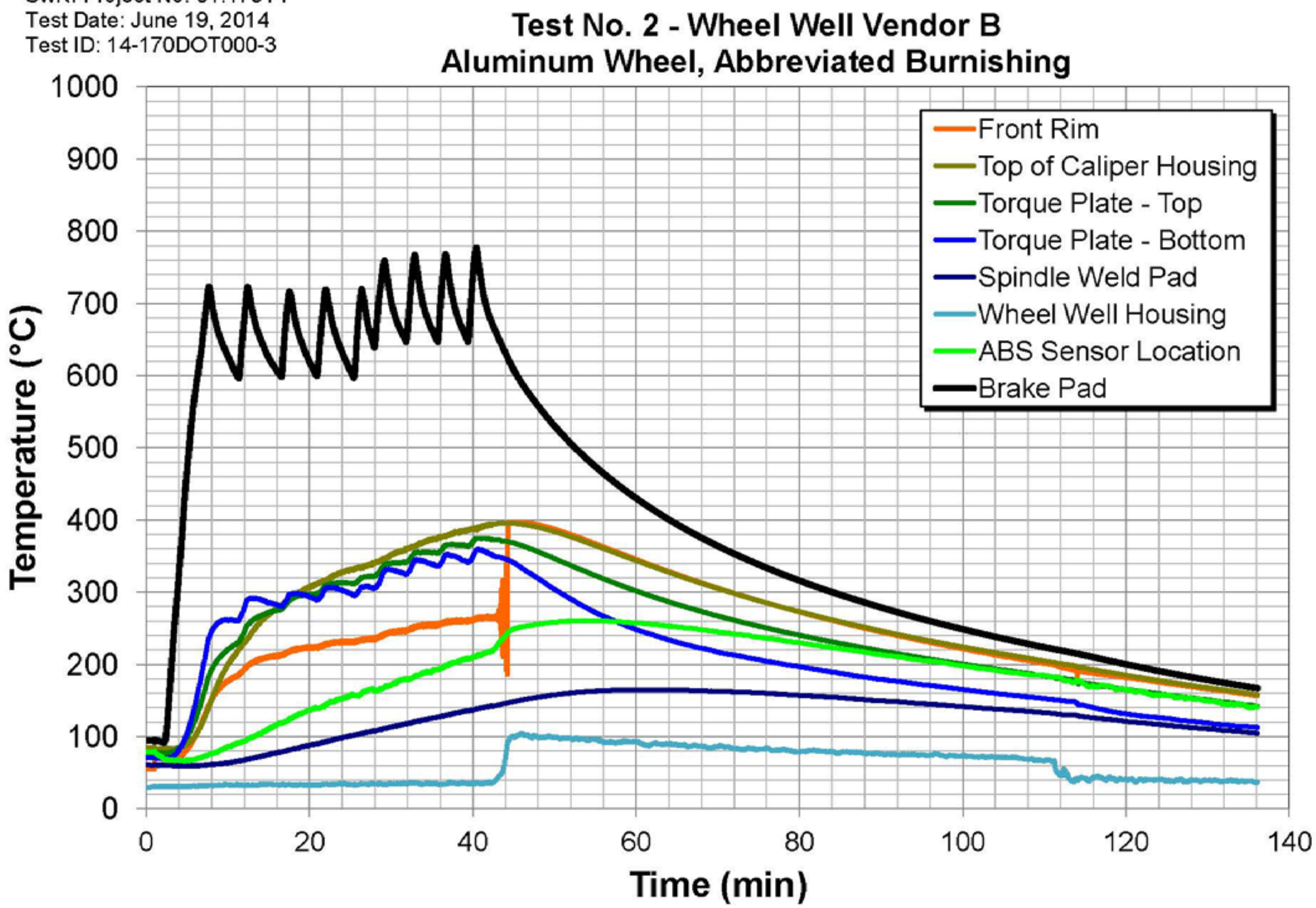

Department of Transportation
SwRI Project No. 01.17914
Test Date: June 18, 2014
Test ID: 14-169DOT000-1
Test No. 1 - Wheel Well Vendor B
Aluminum Wheel, Full Burnishing
Temperature (°C)
Time (min)
Front Rim
Top of Caliper Housing
Torque Plate - Top
Torque Plate - Bottom
Spindle Weld Pad
Wheel Well Housing
ABS Sensor Location
Brake Pad
0
100
200
300
400
500
600
700
800
900
1000
0
10
20
30
40
50
60

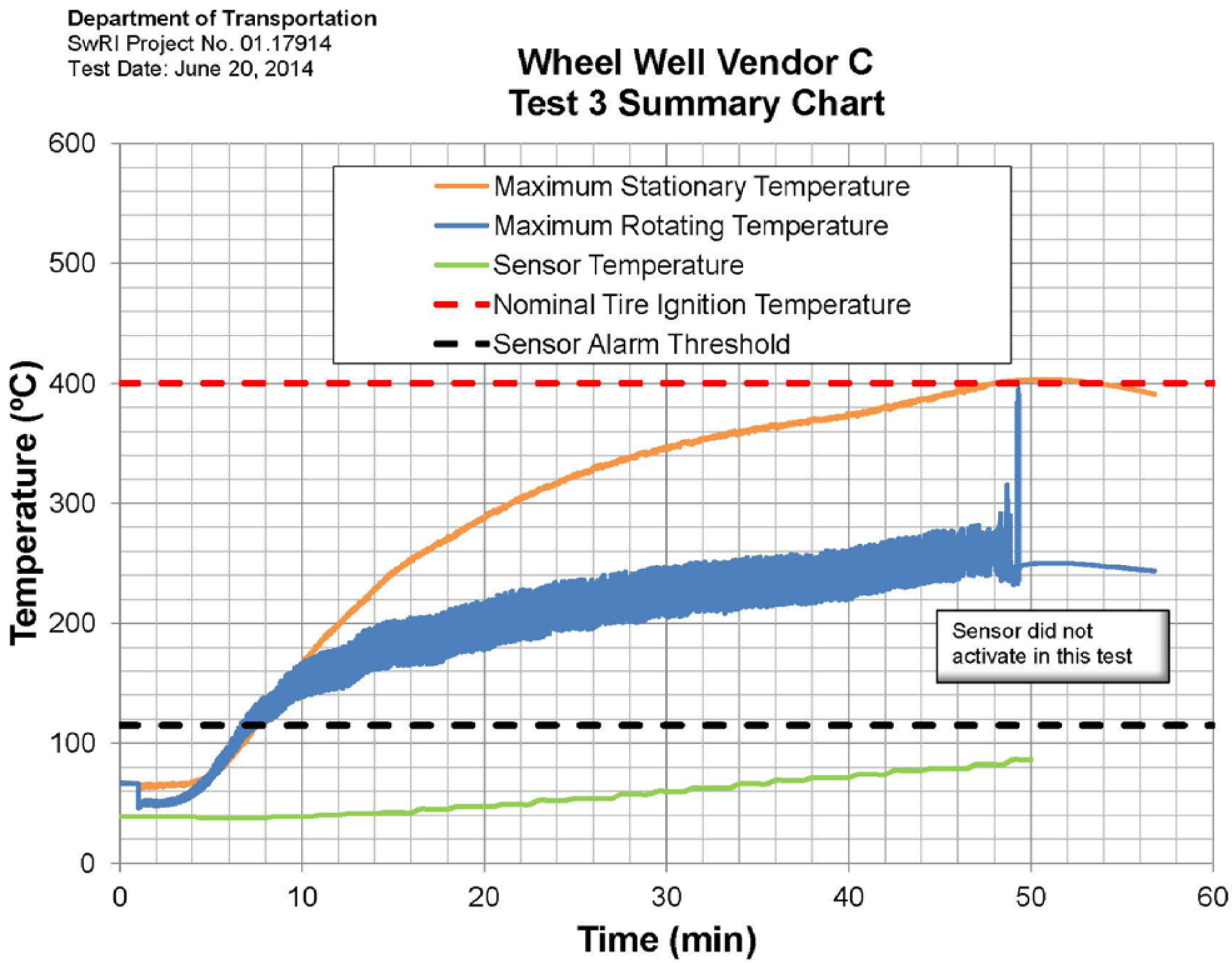


Department of Transportation
SwRI Project No. 01.17914
Test Date: June 19, 2014
Wheel Well Vendor C
Test 2 Summary Chart
Maximum Stationary Temperature
Maximum Rotating Temperature
Sensor Temperature
Nominal Tire Ignition Temperature
Sensor Alarm Threshold
Sensor did not activate in this test
Temperature (ºC)
Time (min)
0
100
200
300
400
500
600
0
10
20
30
40
50
60

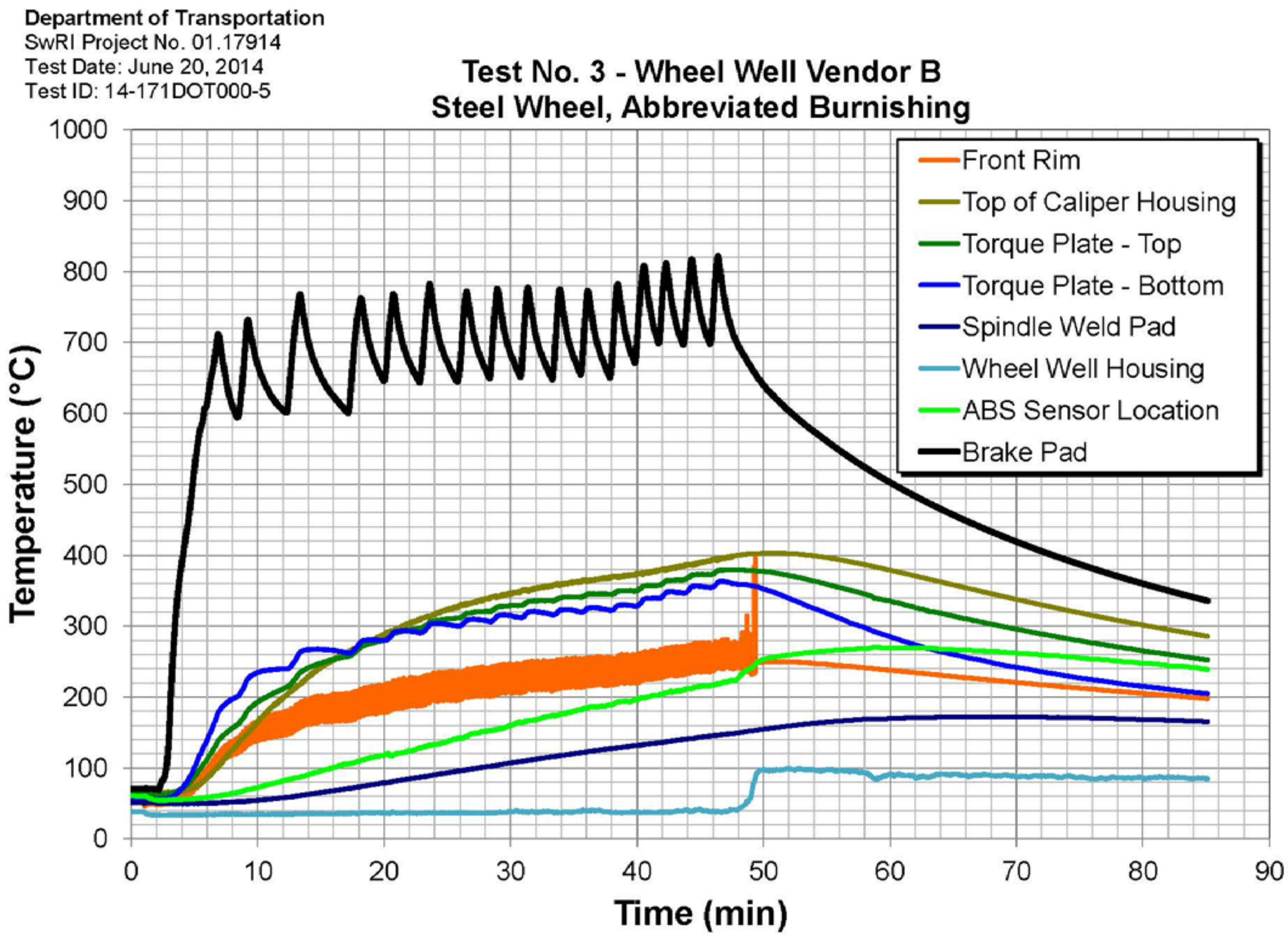

Department of Transportation
SwRI Project No. 01.17914
Test Date: June 19, 2014
Test ID: 14-170DOT000-3
Test No. 2 - Wheel Well Vendor B
Aluminum Wheel, Abbreviated Burnishing
Torque (N-m)
Tire Speed (mph), Power (kW), Energy (MJ)
Time (min)
Torque
Power
Tire Speed
Energy
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
20
40
60
80
100
120
140
160
180
200
0
10
20
30
40
50
60

Department of Transportation
SwRI Project No. 01.17914
Test Date: June 19, 2014
Test ID: 14-170DOT000-3



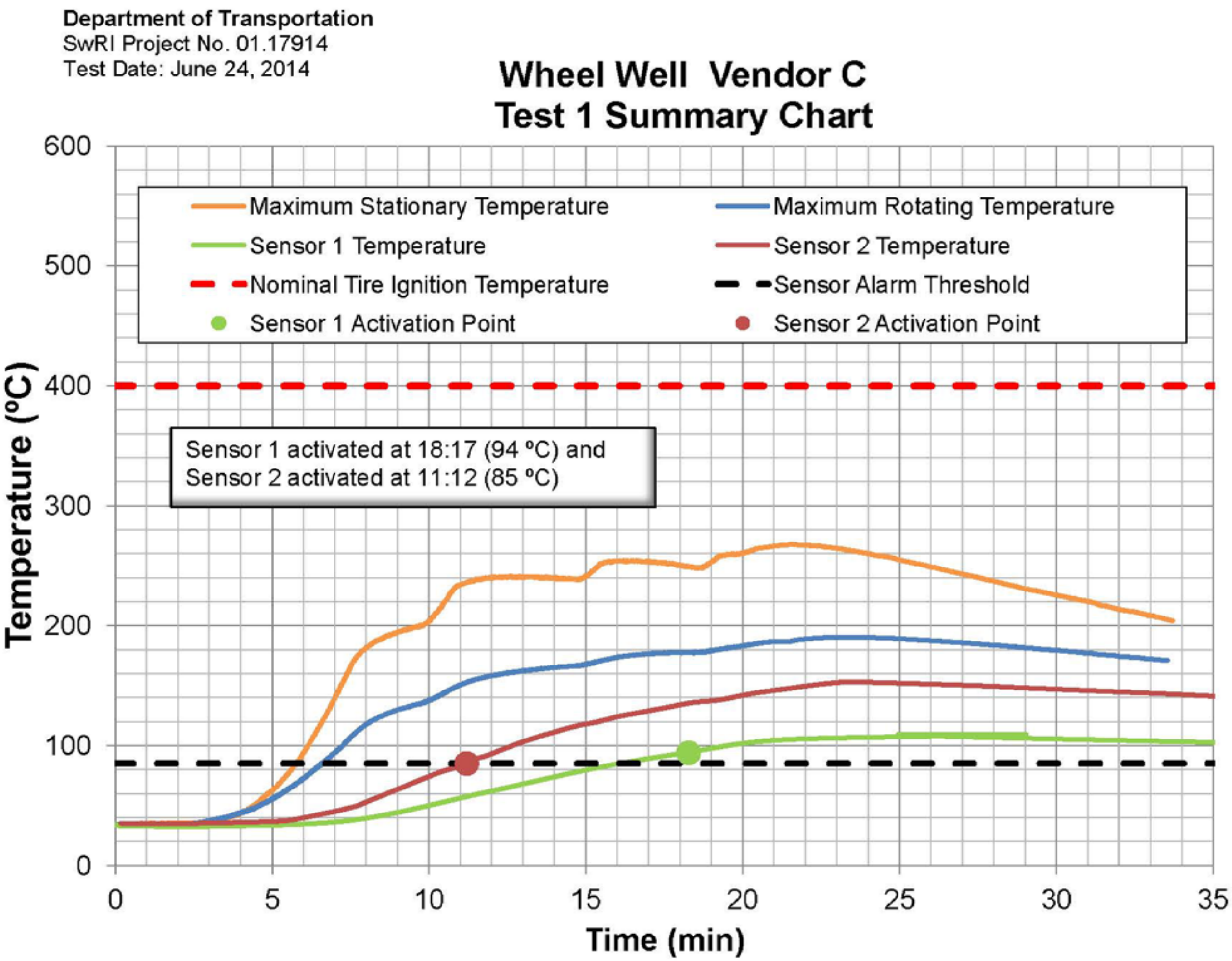


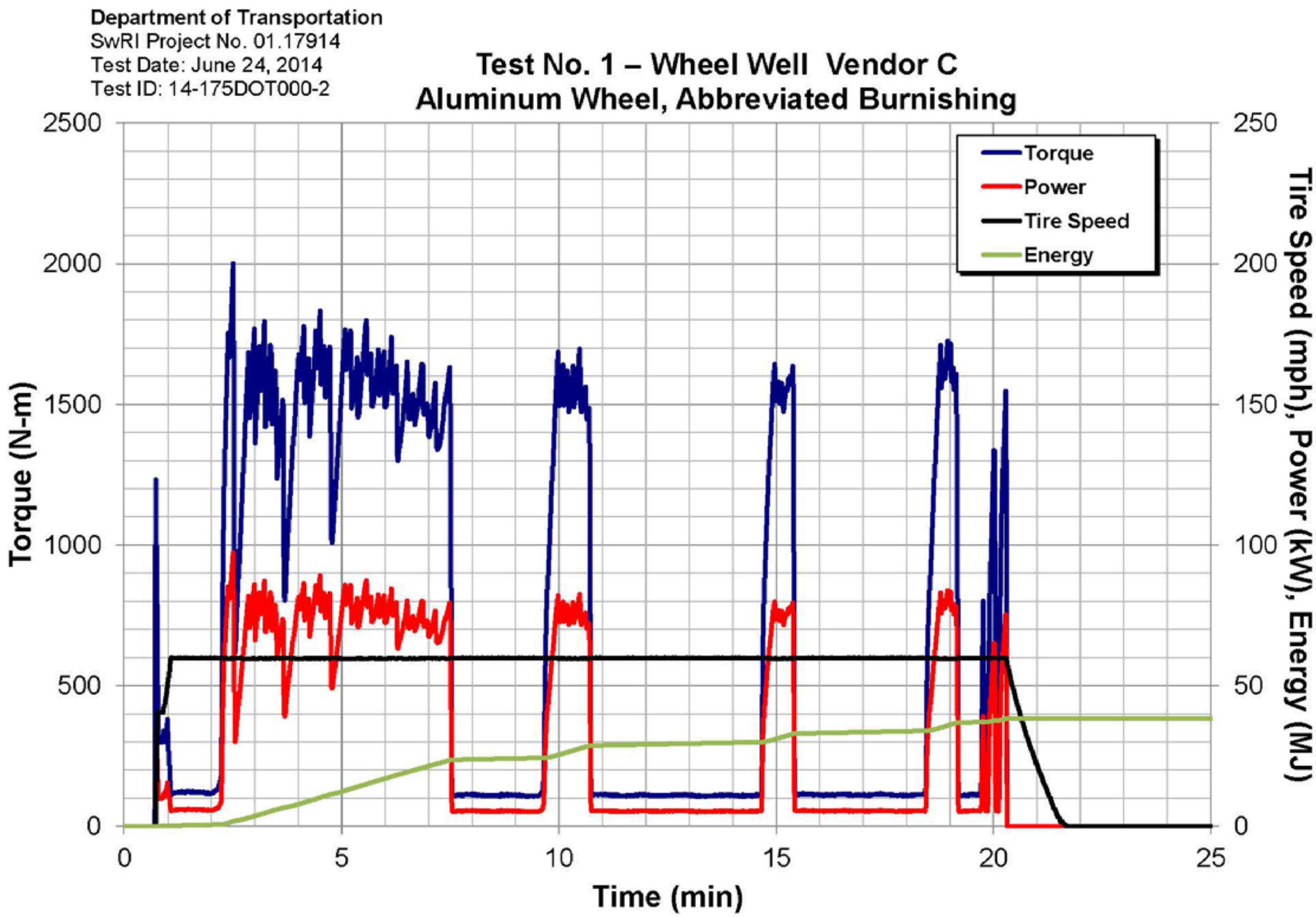
Department of Transportation
SwRI Project No. 01.17914
Test Date: June 20, 2014
Wheel Well Vendor C
Test 3 Summary Chart
Maximum Stationary Temperature
Maximum Rotating Temperature
Sensor Temperature
Nominal Tire Ignition Temperature
Sensor Alarm Threshold
Sensor did not activate in this test
Temperature (°C)
Time (min)
0
100
200
300
400
500
600
0
10
20
30
40
50
60

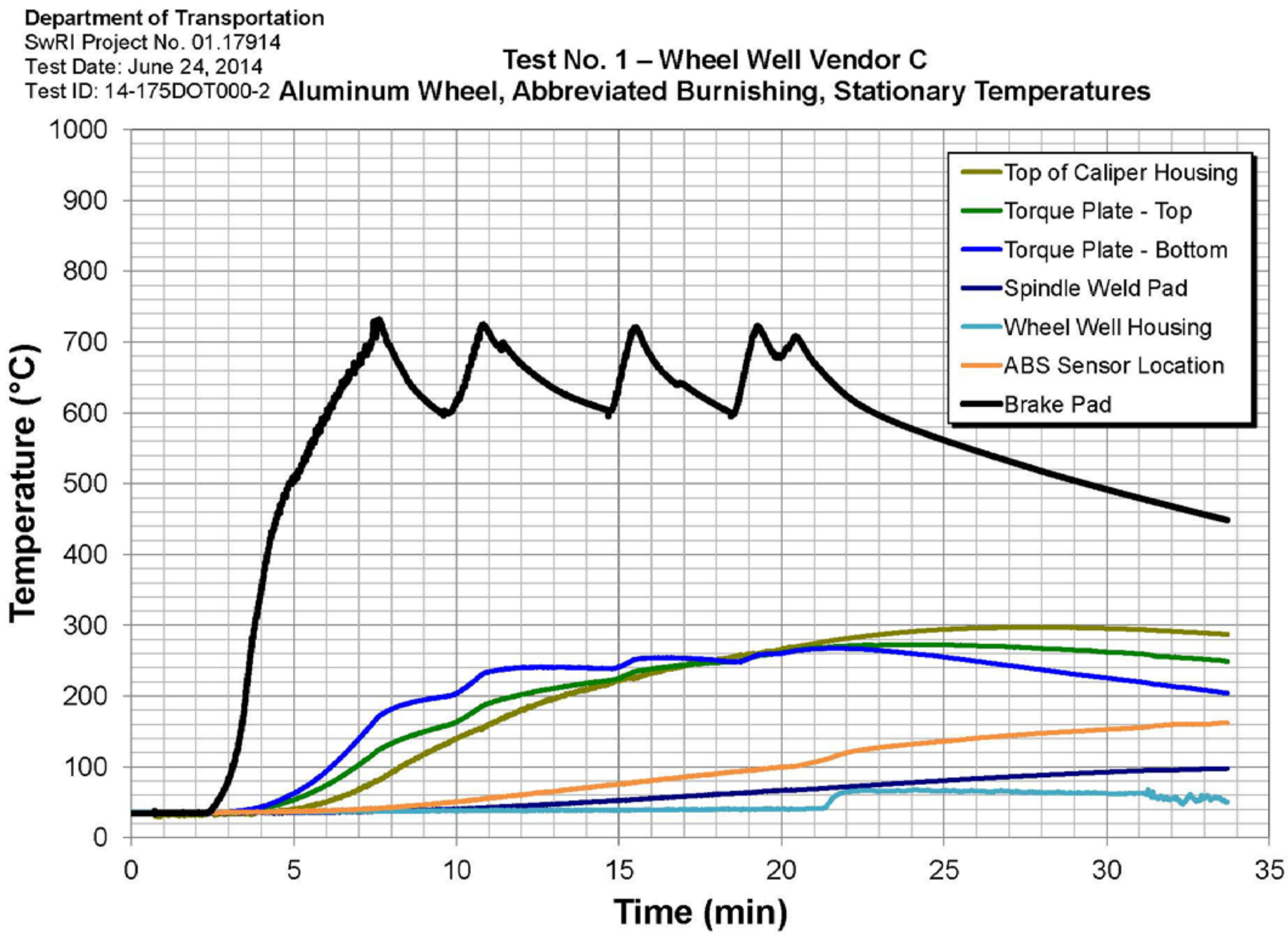


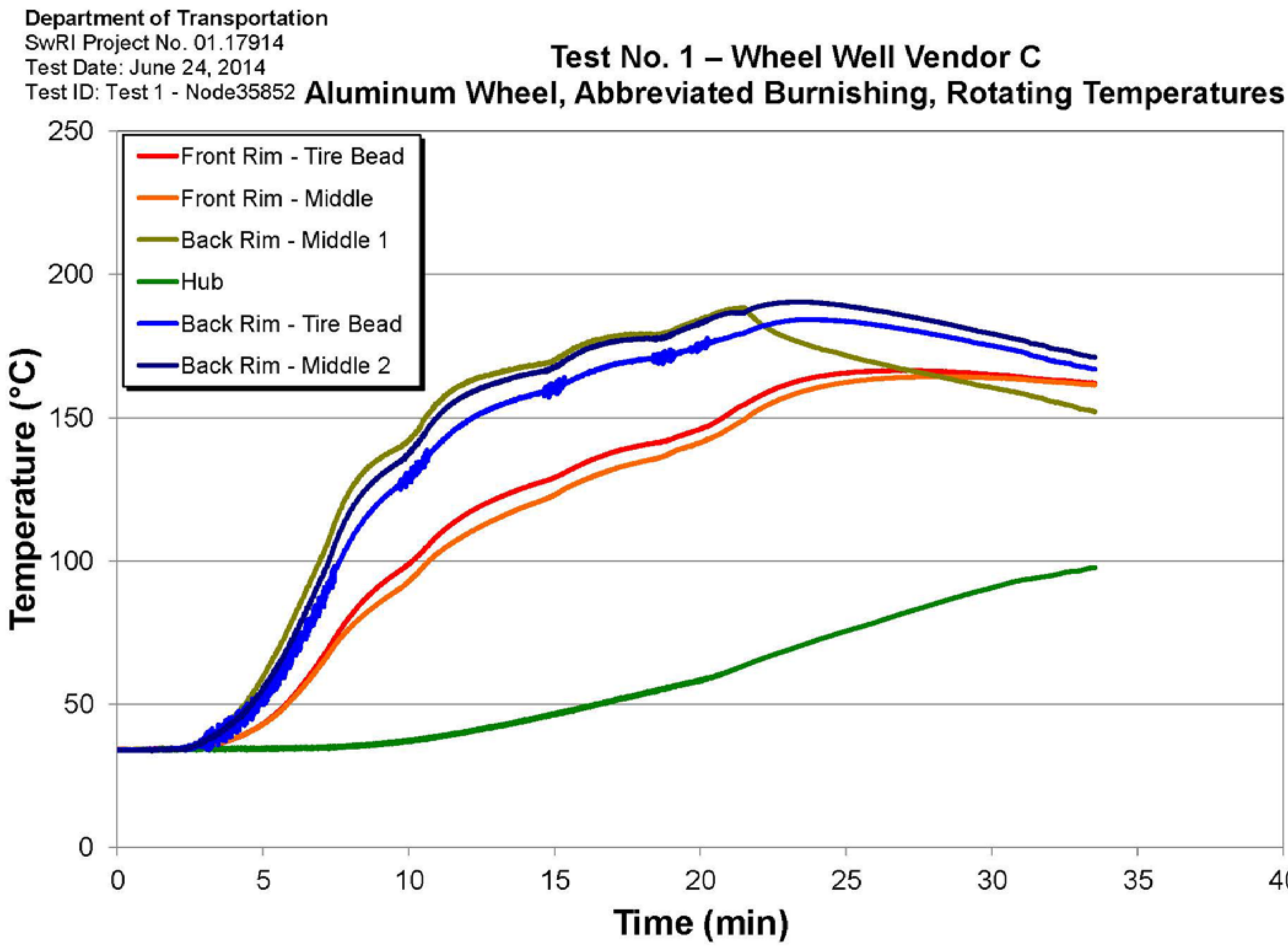
Department of Transportation
SwRI Project No. 01.17914
Test Date: June 20, 2014
Test ID: 14-171DOT000-5
Test No. 3 - Wheel Well Vendor B
Steel Wheel, Abbreviated Burnishing
Temperature (°C)
Time (min)
Front Rim
Top of Caliper Housing
Torque Plate - Top
Torque Plate - Bottom
Spindle Weld Pad
Wheel Well Housing
ABS Sensor Location
Brake Pad
0
100
200
300
400
500
600
700
800
900
1000
0
10
20
30
40
50
60
70
80
90

APPENDIX L
WHEEL WELL VENDOR C TEST DATA
(CONSISTING OF 12 PAGES)

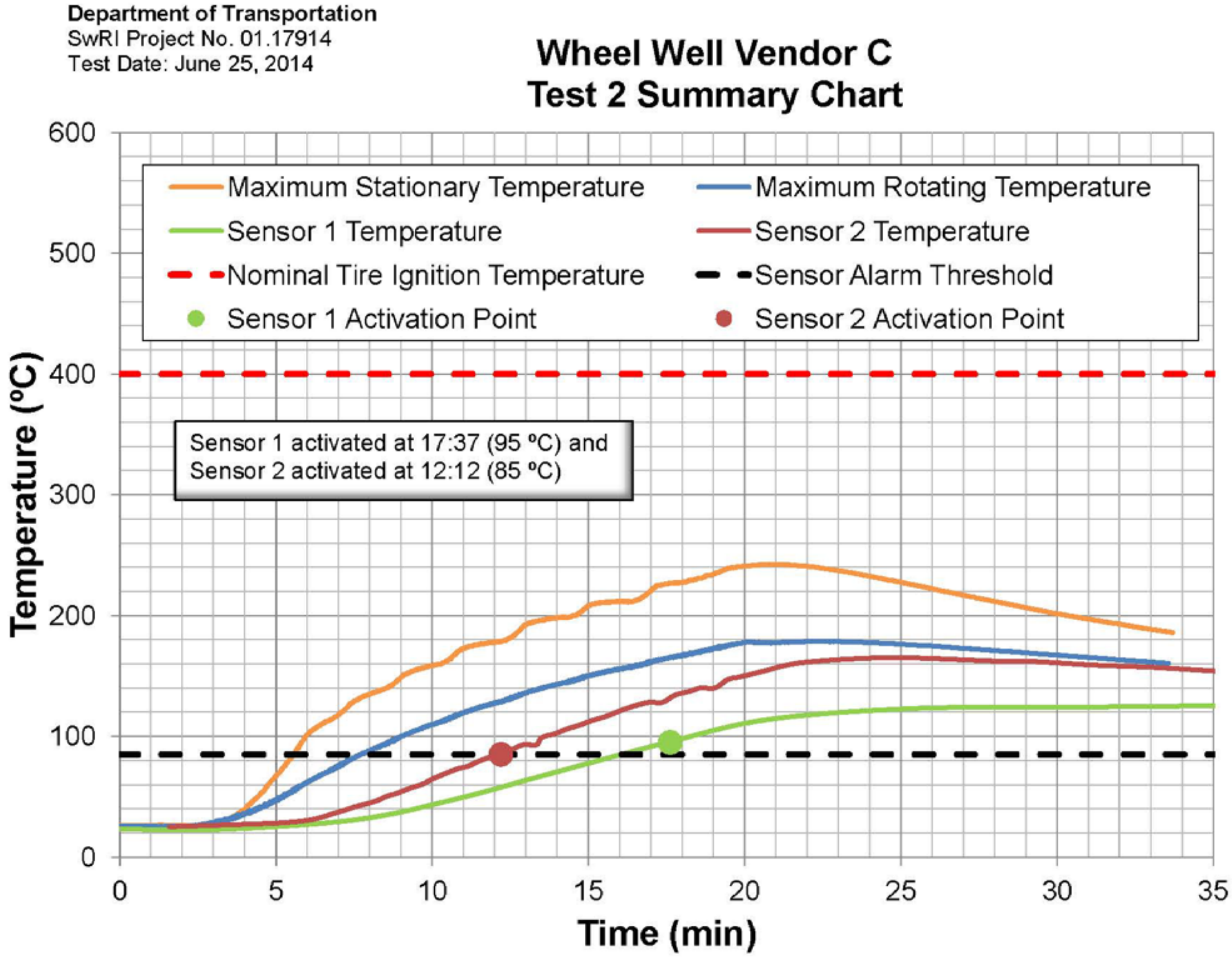

Department of Transportation
SwRI Project No. 01.17914
Test Date: June 24, 2014
Wheel Well Vendor C
Test 1 Summary Chart
Maximum Stationary Temperature
Maximum Rotating Temperature
Sensor 1 Temperature
Sensor 2 Temperature
Nominal Tire Ignition Temperature
Sensor Alarm Threshold
Sensor 1 Activation Point
Sensor 2 Activation Point
Sensor 1 activated at 18:17 (94 ºC) and
Sensor 2 activated at 11:12 (85 ºC)
Temperature (ºC)
Time (min)
0
100
200
300
400
500
600
0
5
10
15
20
25
30
35

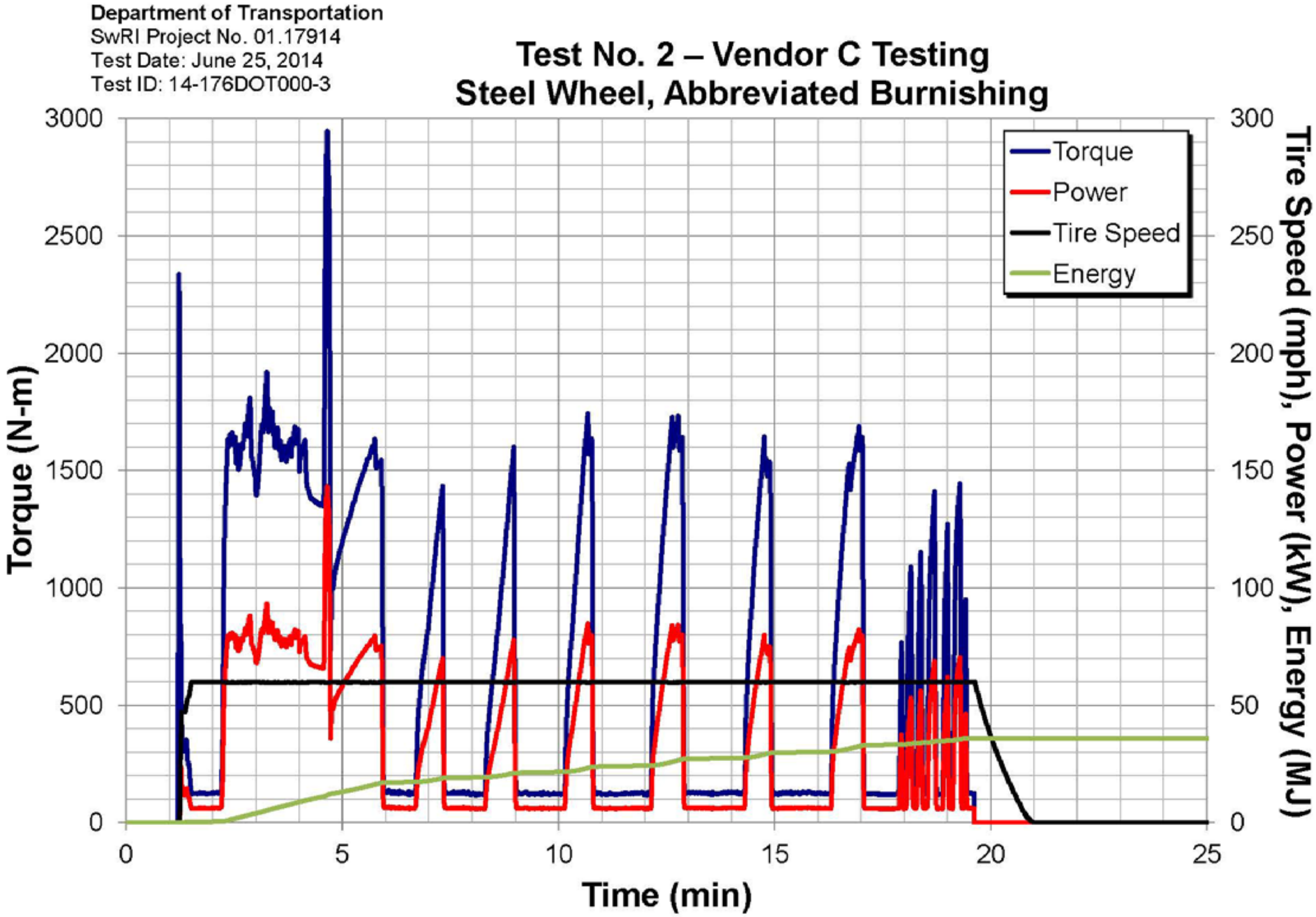

Department of Transportation
SwRI Project No. 01.17914
Test Date: June 24, 2014
Test ID: 14-175DOT000-2
Test No. 1 – Wheel Well Vendor C
Aluminum Wheel, Abbreviated Burnishing
Torque
Power
Tire Speed
Energy
Torque (N-m)
Tire Speed (mph), Power (kW), Energy (MJ)
Time (min)
2500
2000
1500
1000
500
0
250
200
150
100
50
0
5
10
15
20
25

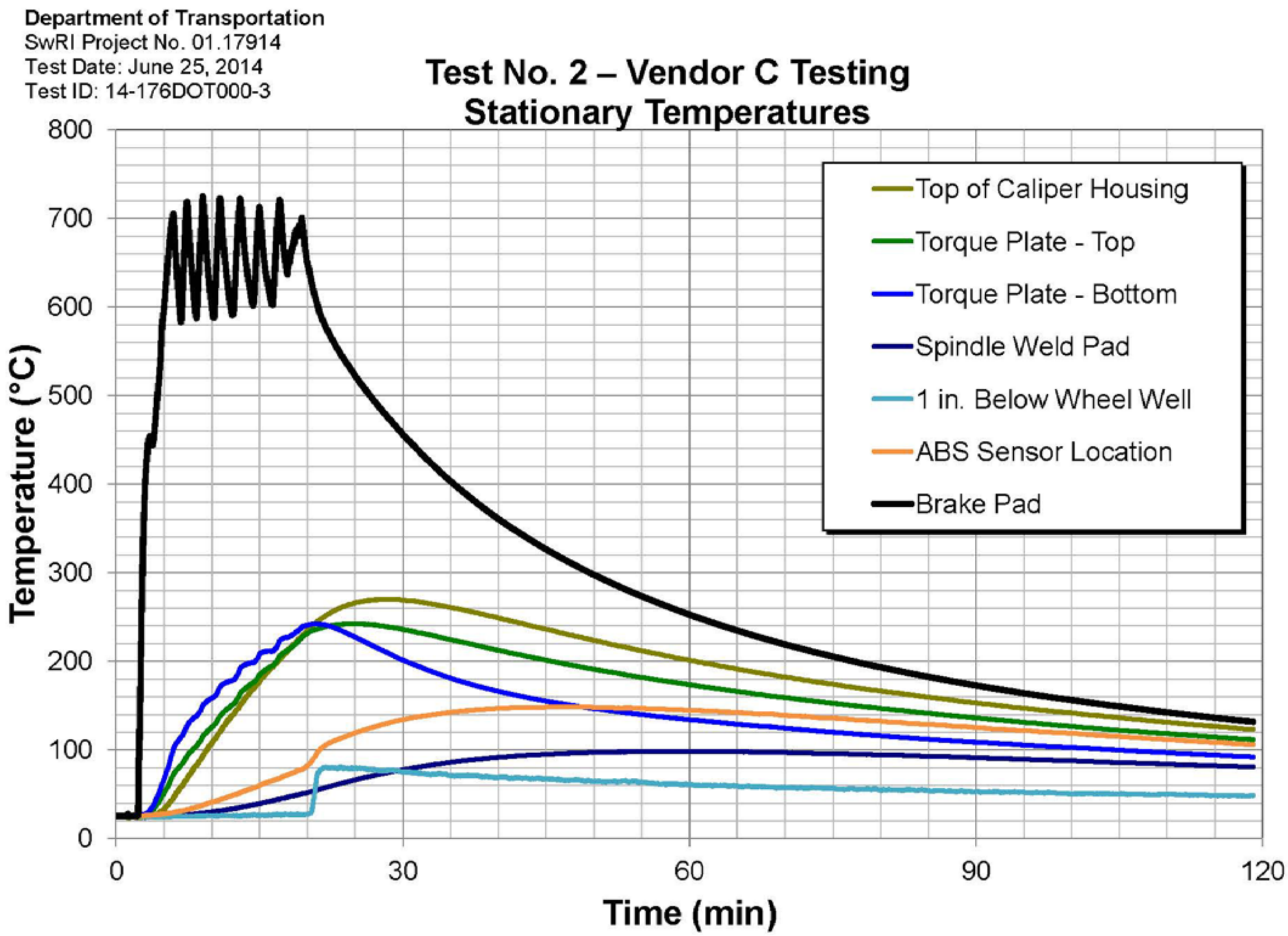

Department of Transportation
SwRI Project No. 01.17914
Test Date: June 24, 2014
Test ID: 14-175DOT000-2
Test No. 1 – Wheel Well Vendor C
Aluminum Wheel, Abbreviated Burnishing, Stationary Temperatures
Temperature (°C)
Time (min)
Top of Caliper Housing
Torque Plate - Top
Torque Plate - Bottom
Spindle Weld Pad
Wheel Well Housing
ABS Sensor Location
Brake Pad
0
100
200
300
400
500
600
700
800
900
1000
0
5
10
15
20
25
30
35



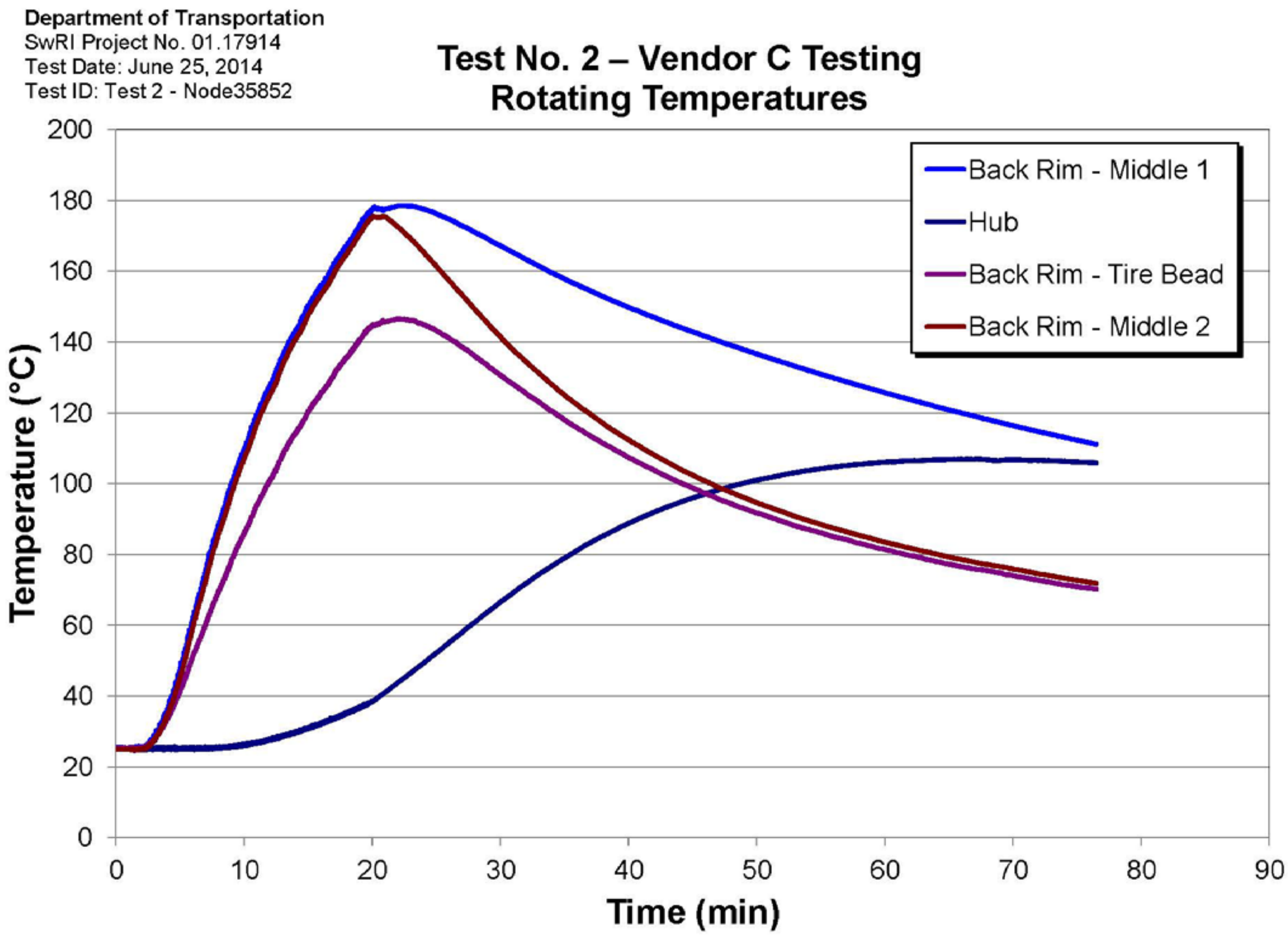
Department of Transportation
SwRI Project No. 01.17914
Test Date: June 24, 2014
Test ID: Test 1 - Node35852
Test No. 1 – Wheel Well Vendor C
Aluminum Wheel, Abbreviated Burnishing, Rotating Temperatures
Front Rim - Tire Bead
Front Rim - Middle
Back Rim - Middle 1
Hub
Back Rim - Tire Bead
Back Rim - Middle 2
Temperature (°C)
Time (min)
0
50
100
150
200
250
0
5
10
15
20
25
30
35
40

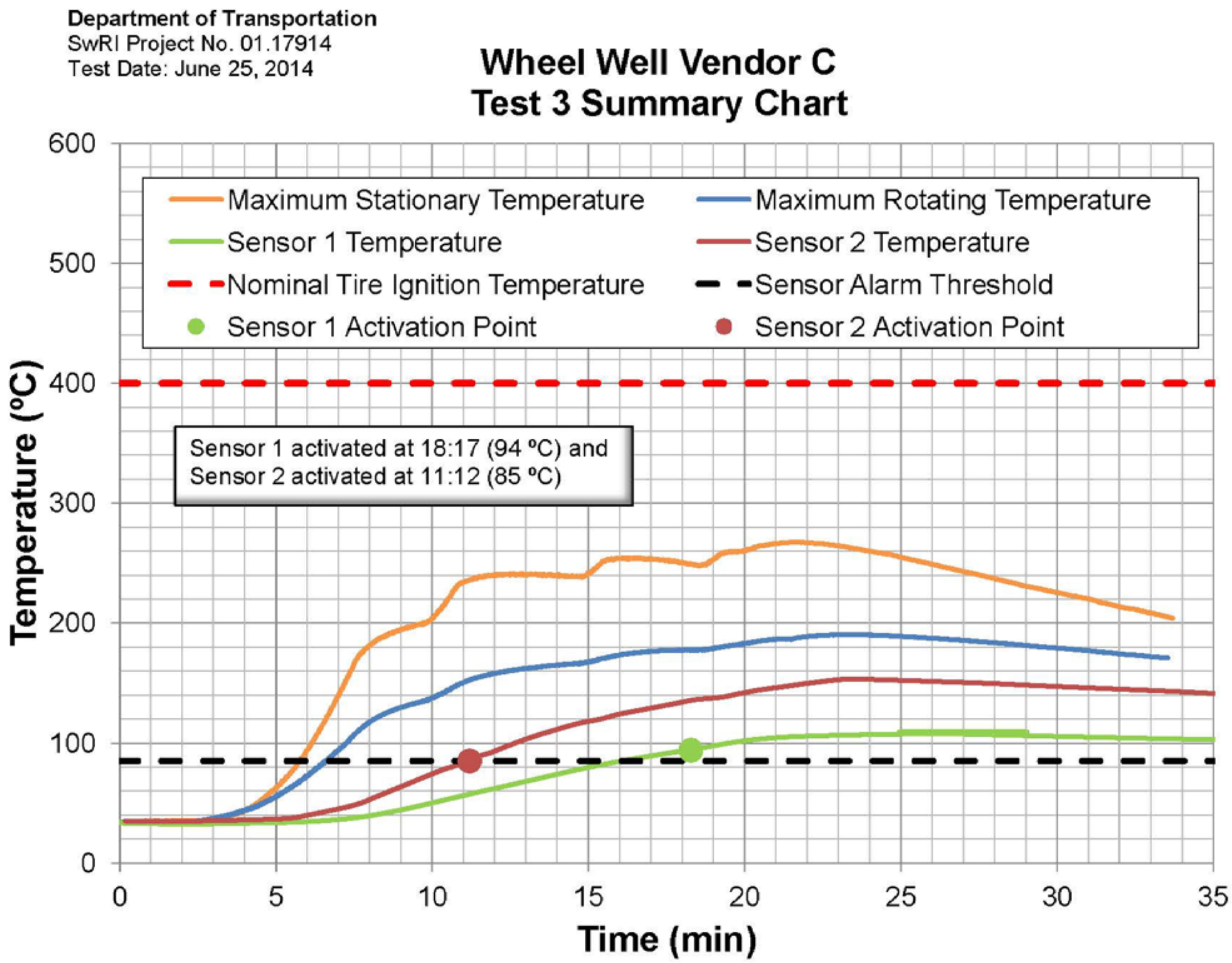

Department of Transportation
SwRI Project No. 01.17914
Test Date: June 25, 2014
Wheel Well Vendor C
Test 2 Summary Chart
Maximum Stationary Temperature
Maximum Rotating Temperature
Sensor 1 Temperature
Sensor 2 Temperature
Nominal Tire Ignition Temperature
Sensor Alarm Threshold
Sensor 1 Activation Point
Sensor 2 Activation Point
Sensor 1 activated at 17:37 (95 ºC) and
Sensor 2 activated at 12:12 (85 ºC)
Temperature (ºC)
0
100
200
300
400
500
600
Time (min)
0
5
10
15
20
25
30
35

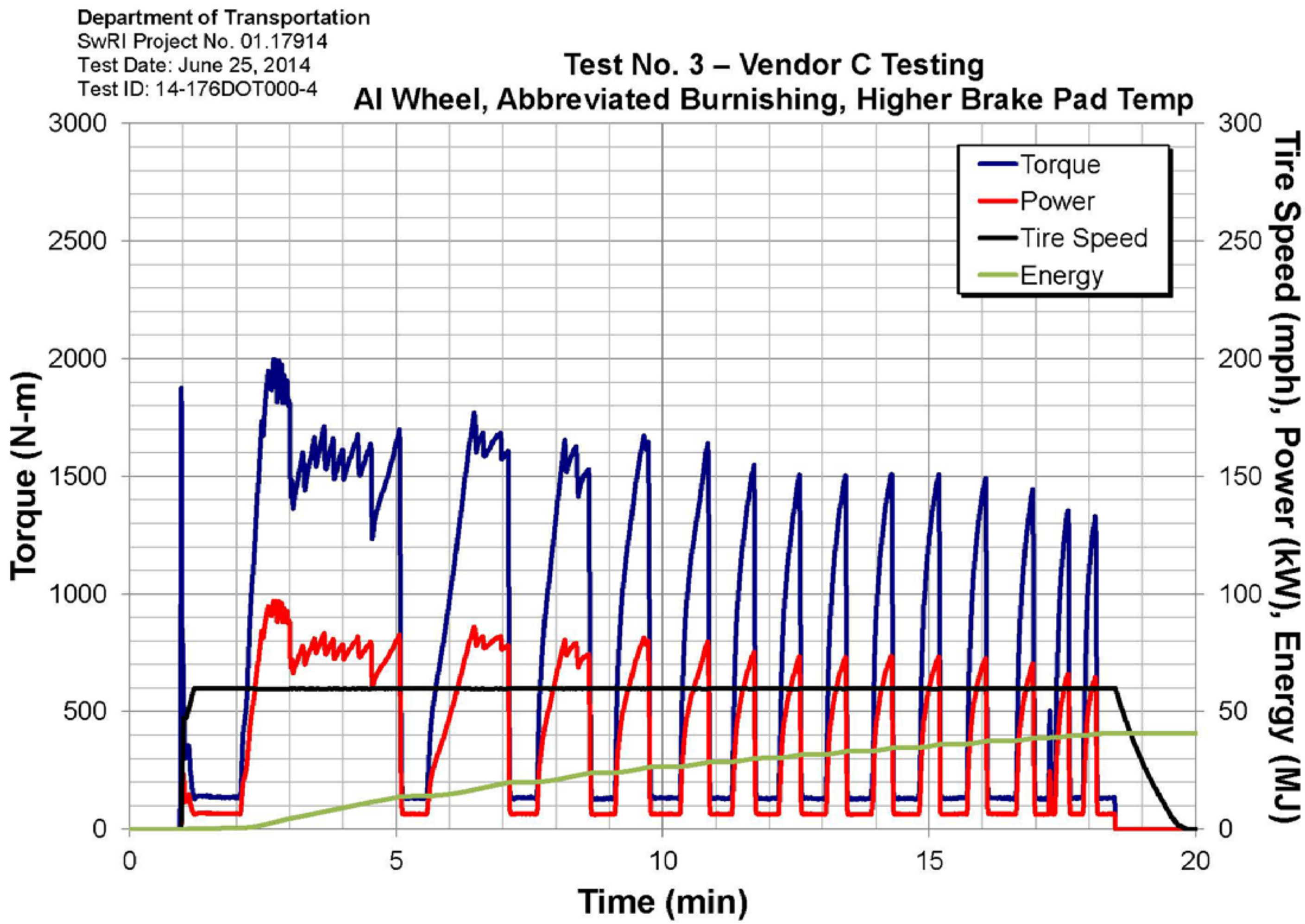

Department of Transportation
SwRI Project No. 01.17914
Test Date: June 25, 2014
Test ID: 14-176DOT000-3
Test No. 2 – Vendor C Testing
Steel Wheel, Abbreviated Burnishing
Torque
Power
Tire Speed
Energy
Torque (N-m)
Tire Speed (mph), Power (kW), Energy (MJ)
Time (min)

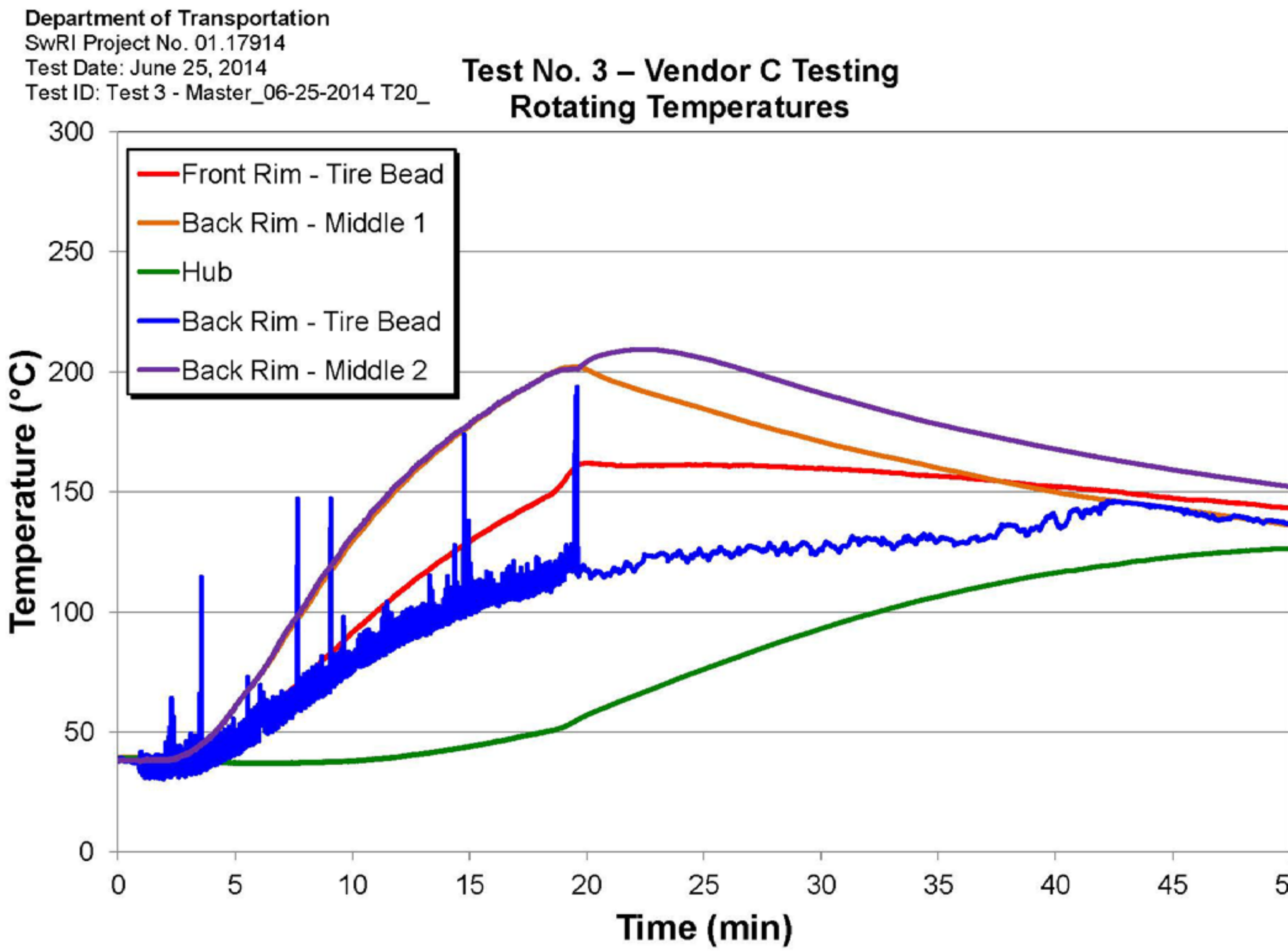


Department of Transportation
SwRI Project No. 01.17914
Test Date: June 25, 2014
Test ID: 14-176DOT000-3
Test No. 2 – Vendor C Testing
Stationary Temperatures
Temperature (°C)
Time (min)
0
100
200
300
400
500
600
700
800
0
30
60
90
120
Top of Caliper Housing
Torque Plate - Top
Torque Plate - Bottom
Spindle Weld Pad
1 in. Below Wheel Well
ABS Sensor Location
Brake Pad


Department of Transportation
SwRI Project No. 01.17914
Test Date: June 25, 2014
Test ID: Test 2 - Node35852
Test No. 2 – Vendor C Testing
Rotating Temperatures
Back Rim - Middle 1
Hub
Back Rim - Tire Bead
Back Rim - Middle 2
Temperature (°C)
Time (min)
0
20
40
60
80
100
120
140
160
180
200
0
10
20
30
40
50
60
70
80
90


Department of Transportation
SwRI Project No. 01.17914
Test Date: June 25, 2014
Wheel Well Vendor C
Test 3 Summary Chart
Maximum Stationary Temperature
Maximum Rotating Temperature
Sensor 1 Temperature
Sensor 2 Temperature
Nominal Tire Ignition Temperature
Sensor Alarm Threshold
Sensor 1 Activation Point
Sensor 2 Activation Point
Sensor 1 activated at 18:17 (94 ºC) and
Sensor 2 activated at 11:12 (85 ºC)
Temperature (ºC)
0
100
200
300
400
500
600
Time (min)
0
5
10
15
20
25
30
35


Department of Transportation
SwRI Project No. 01.17914
Test Date: June 25, 2014
Test ID: 14-176DOT000-4
Test No. 3 – Vendor C Testing
Al Wheel, Abbreviated Burnishing, Higher Brake Pad Temp
Torque
Power
Tire Speed
Energy
Torque (N-m)
Tire Speed (mph), Power (kW), Energy (MJ)
Time (min)
0
500
1000
1500
2000
2500
3000
0
50
100
150
200
250
300
0
5
10
15
20



Department of Transportation
SwRI Project No. 01.17914
Test Date: June 25, 2014
Test ID: Test 3 - Master_06-25-2014 T20_
Test No. 3 – Vendor C Testing
Rotating Temperatures
Front Rim - Tire Bead
Back Rim - Middle 1
Hub
Back Rim - Tire Bead
Back Rim - Middle 2
Temperature (°C)
Time (min)
0
50
100
150
200
250
300
5
10
15
20
25
30
35
40
45

APPENDIX M
WHEEL WELL EARLY WARNING SYSTEM DRAFT TEST PROCEDURE
(CONSISTING OF 7 PAGES)

Wheel Well Warning System Draft Test Procedure

Purpose:

The purpose of this test procedure is to qualify systems/sensors and algorithms which can detect a hot wheel before a tire fire occurs. The goal is that, upon detection, the motorcoach driver will be warned and if action is taken quickly to stop the vehicle, the source of heating can be eliminated and an ensuing tire fire can be avoided.

Critical Temperature Conditions:

Tires will not typically ignite until they reach a temperature of approximately 400 ºC (References 1 and 2). This is well above the temperatures that tires, brakes, bearings, and wheel assemblies normally encounter under normal (and even emergency braking) conditions. In some circumstances, lube oil (or bearing grease) or brake pad resin may be the first item ignited. Their Hot Surface Ignition (HSI) temperatures are in the range of 382 ºC and above. (Reference 3).

Basis of the Test:

This test procedure is based on a single tag axle that is supported at one end with a bearing structure and driven by an electric motor connected to the wheel lug nut assembly. The wheel is heated by partially engaging the disk brakes on the tag axle, causing heat to be transferred through the rotor and wheel assembly and into the tire.

Test Specimens:

There are several sensors that could be used to detect a hot wheel well in advance of tire ignition:

a. Sensor mounted on stationary components of the axle/wheel assembly:
   i. Thermocouples attached to axle, spindle, or stationary part of brake assembly
   ii. Thermocouples attached at or near the ABS sensor.
   iii. ABS sensor. Sensor failure or loss of signal may indicate a hot wheel.

b. Sensor mounted on rotating part of wheel/tire:
   i. Tire Pressure Monitoring Systems (TPMS). Several of these commercial devices measure temperature as well as pressure. Some are mounted on the valve stem, some on the wheel hub, and some on the tire itself.
   ii. A dedicated thermocouple mounted on a metallic part of the rotating wheel components.
c. Specimens are to be provided by the manufacturer of the device and installed per manufacturer's instructions.

Test Fixture:

Figure 1 provides a representation of the test fixture and Figure 2 provides a photograph of the actual assembly. Full drawings can be referenced in Appendix I.

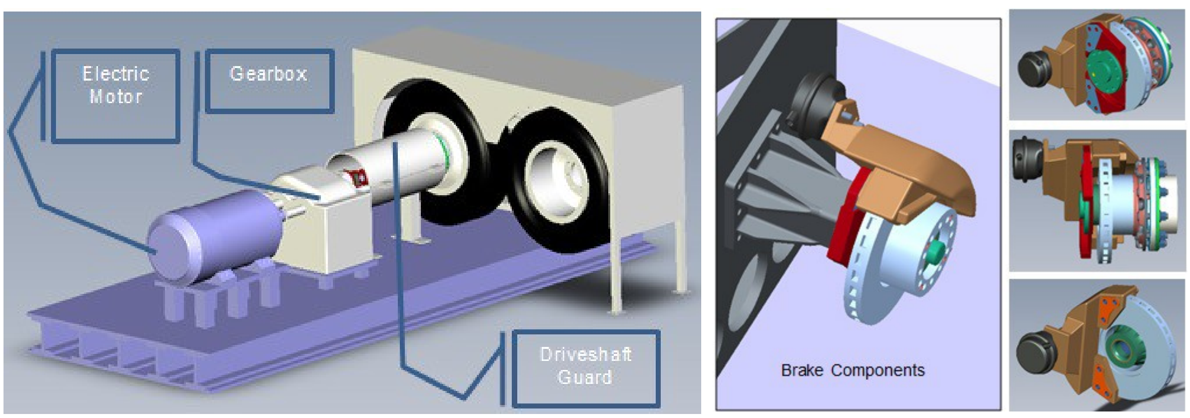


Figure 1. Motorcoach Wheel Well Test Fixture Final Design.

Figure 2. Wheel Well Mockup Test Fixture (Overall Plan View).

Figure 3. Wheel Well Mockup Test Fixture (Ground Level View).

The test will utilize an aluminum wheel (Size: 22.5 × 8.25) and new or used tire (Size: 315/8OR22.5). The tire will be pressurized with air to 30 psig.

Test Fixture Instrumentation:

Several measurements are required to be recorded during each test. They are summarized as follows.

- Tire Speed
  - Burnishing is performed at 40 mph
  - Tests are conducted at 60 mph
- Brake pressure
  - The disk brake air or Nitrogen pressure must be monitored during testing to apply the correct torque through the system.
  - During the development of the procedure, this required brake pressure was typically between 20-25 psig.
- Torque
  - The torque is not required to be directly measured during every test, but it is required that it be calculated if not directly measured.
  - During the development of the procedure, this was accomplished by mapping the current draw from the electric motor with the torque and after initial calibration; the torque meter was removed and replaced with a safety shear coupling.
- Temperatures (all Type K thermocouples)
  - Brake Pad Temperature: a thermocouple is inserted in the nominal center of the brake pad material (see Figure 4 below) and this is used to control the burnishing and device tests.
  - Stationary Temperatures: it is required that thermocouples be attached to the top of the caliper housing, the top of the torque plate and the bottom of the torque plate. These are used to assess the maximum safe levels of heating before the test is terminated, assuming the device under test has not activated by this point.

- Rotating Temperatures: it is recommended to measure the front and rear wheel/rim temperature in three locations each. Each side (front and rear) of the rim should be measured in two locations close to the tire bead and one location close the middle of the rim.

Figure 4. Brake Pad Thermocouple Location and Construction.

Brake Pad Burnishing:

This is an approval test procedure for evaluating air brake systems on a dynamometer, FMVSS 121D, *Laboratory Test Procedure for Air Brake Systems – Dynamometer, TP-121D-01.*

There is a burnishing procedure in Section 12 of this document. An excerpt of this procedure is as follows:

Place the brake assembly on an inertia dynamometer and adjust the brake as recommended by the brake manufacturer. Make 200 stops from 40 mph at a deceleration of 10 ft/s/s, with an initial brake temperature on each stop of not less than 315ºF and not more than 385ºF. Make 200 additional stops from 40 mph at a deceleration of 10 ft/s/s, with an initial brake temperature on each stop of not less than 450ºF and not more than 550ºF.

During the development of this procedure it was shown that an abbreviated burnishing cycle of 20 stops, instead of 200 was adequate for performance of the sensor evaluation test without observing brake glazing.

A new set of brake pads will be used for each test and they will be burnished following the procedure below.

- Set the tire speed to 40 mph.
- Conduct the first set of 20 stops between a brake pad temperature of 315-385ºF.
    - In order to meet the deceleration requirements on this test fixture, as opposed to a dynamometer, the torque is adjusted to approximately 1500 N-m and applied to the brake pads for approximately 9 seconds during each heating cycle.
- Allow the brake pad temperature to cool to below 100 ºF.
- Conduct the second set of 20 stops between a brake pad temperature of 450-550 ºF.
    - In order to meet the deceleration requirements on this test fixture, as opposed to a dynamometer, the torque is adjusted to approximately 1500 N-m and applied to the brake pads for approximately 9 seconds during each heating cycle.
- Allow the assembly to cool to less than 100 ºF before the start of the device evaluation test.

Test Procedure and Criteria:

- The early warning system will be installed per manufacturer specifications.

- Set the tire speed to 60 mph.
- Engage the brakes such that 1500-2000 N-m of torque is generated, which will apply heat into the system until the brake pad temperature reaches 750 °C. Relieve brake pressure upon a brake temperature of
  750 ºC.
- Subsequent heating cycles from 650 – 750 °C will be administered until sensor activation or until the maximum stationary temperature reaches
  400 °C.
- If the sensor does not activate prior the maximum stationary temperature reaching 400 °C, the test will be aborted and the sensor considered to have failed this evaluation.
- If the sensor activates, one additional heating cycle will be performed, the wheel stopped, and the final observations made of additional heating and final sensor temperature.
- During the final cool down period, the fixture will be monitored and during this time, if the maximum stationary temperature exceeds 400 °C, the sensor will be considered to have failed this evaluation. If the stationary temperature remains below 400 °C during the cool down period, the sensor will be considered to have passed this evaluation.

References:

1. NTSB – Greyhound tests. “Motorcoach Tire Fire Test Report,” Joe Panagliotou, NTSB, Accident Number HWY-06-1-H022.
2. “Motorcoach Flammability Project: Final Report; NIST Technical Note 1705, July
   2011.
3. HSI temp for lube oil and grease. See NFPA 921, “Guide for Fire and Explosion Investigations,” page 235. Gear oil is listed as >382 ºC using the ASTM flask method.

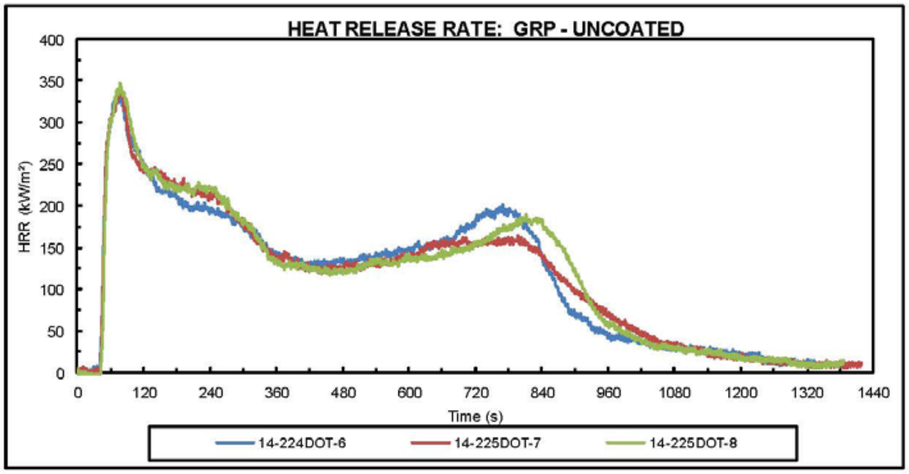
APPENDIX N
FIRE HARDENING CONE CALORIMETER TEST DATA
(CONSISTING OF 24 PAGES)

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	GRP - Uncoated
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²
		Duct Flow:	24 l/s
Orientation:	Horizontal	*Sample Area:*	0.00884 m²
Frame:	Yes	*Distance:*	25 mm
Spark Igniter:	Yes	*Operator:*	Abe Mata

Test ID	Test Date	t_{ig} (s)	Test Duration (s)	C-Factor (SI Units)	HRR_{peak} (kW/m²)	THR (MJ/m²)	HRR_{60s} (kW/m²)	HRR_{180s} (kW/m²)	HRR_{300s} (kW/m²)	$HRR_{30s,max}$ (kW/m²)
14-224DOT-6	08/12/14	40	1227	0.0435	338	158.5	263	236	214	319
14-225DOT-7	08/13/14	41	1320	0.0428	340	160.1	267	244	222	321
14-225DOT-8	08/13/14	42	1280	0.0428	346	161.7	273	246	225	328
Average		41	1276	---	342	160.1	268	242	221	323

Initial Mass (g)	Mass at Ignition (g)	Final Mass (g)	Mass Loss (g/m²)	MLR (g/m²-s)	10-90 MLR (g/m²-s)	EHC (MJ/kg)	$S_{A,1}$ (m²/m²)	$S_{A,2}$ (m²/m²)	S_A (m²/m²)	SEA (m²/kg)
97.2	97.2	32.9	7276	5.9	7.9	21.8	1	6088	6089	837
97.4	97.0	30.8	7534	5.7	7.8	21.3	5	6429	6435	853
98.2	97.8	31.5	7543	5.9	7.9	21.4	4	6849	6853	908
97.6	97.3	31.7	7451	5.8	7.9	21.5	4	6455	6459	866

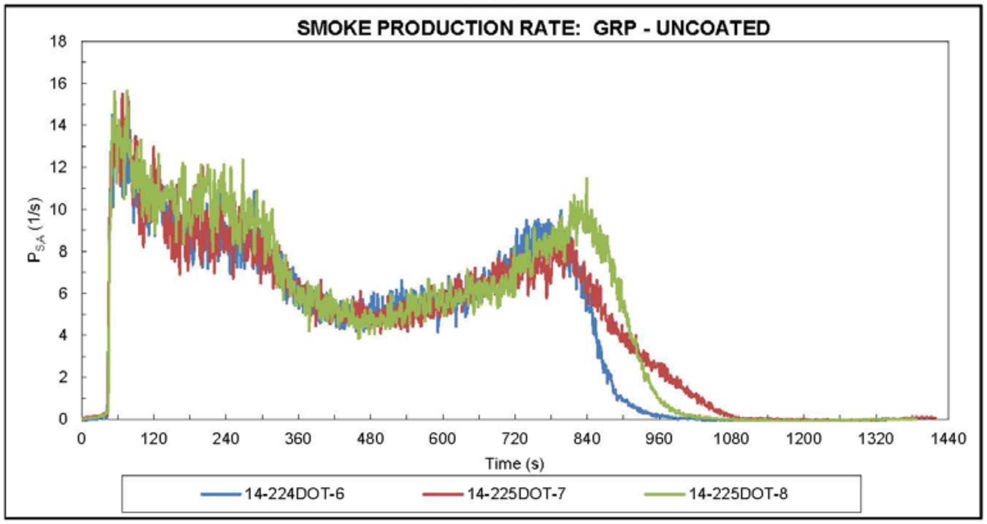


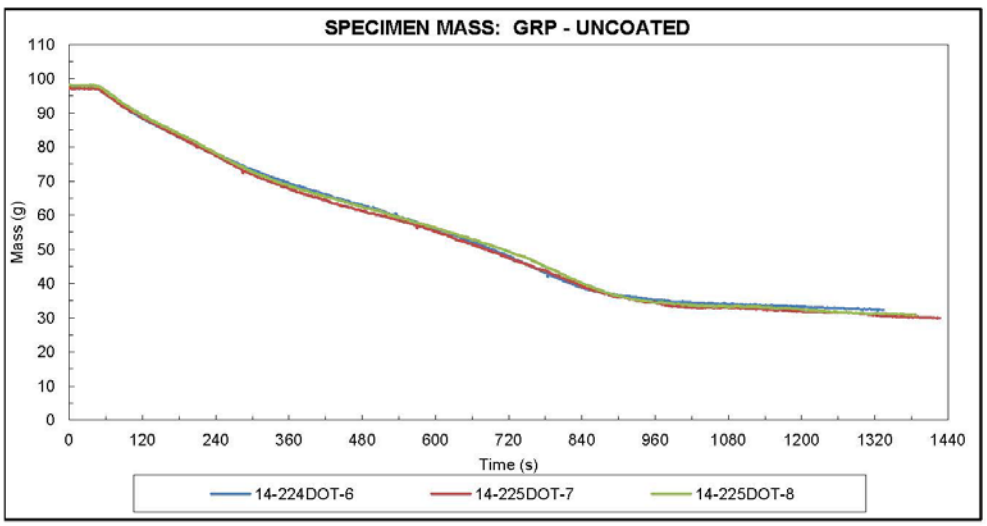
CONE CALORIMETER TEST REPORT

Client: DOT/NHTSA *Material ID:* GRP - Uncoated

SwRI Project No: 01.17914 *Heat Flux:* 50 kW/m²

(Page 2)



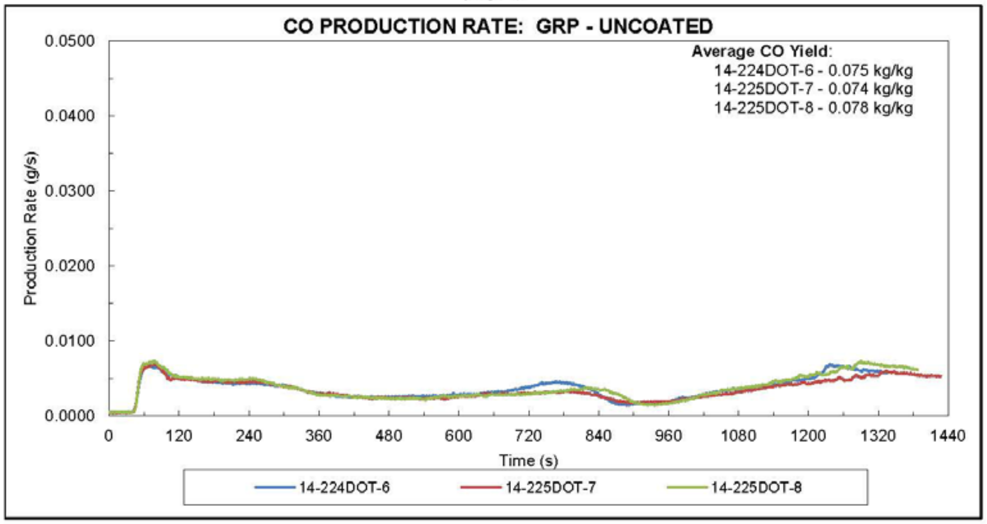


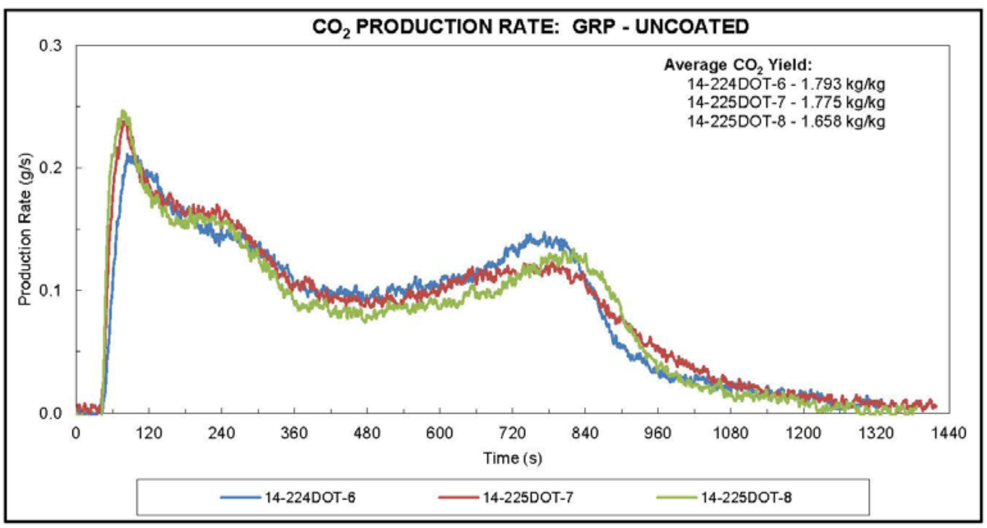
Notes & Observations:

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	GRP - Uncoated
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²

(Page 3)





Notes & Observations:

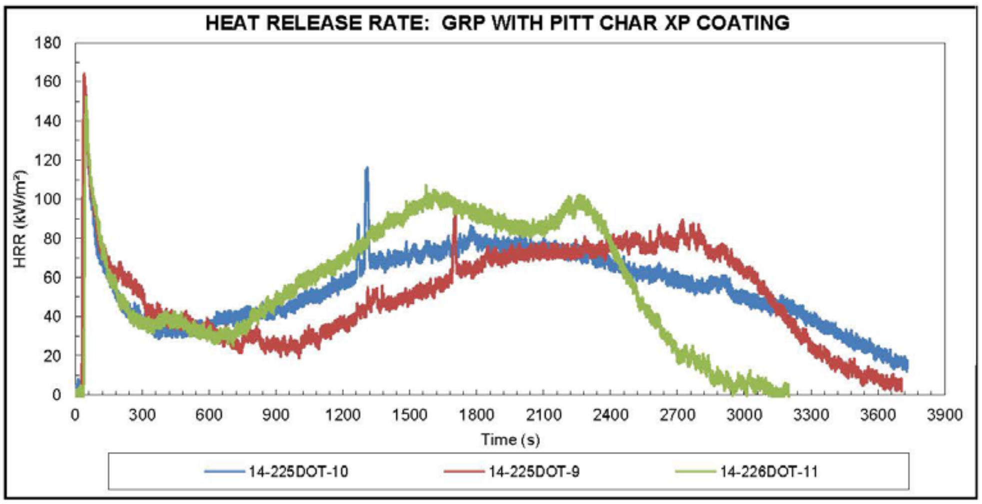
SOUTHWEST RESEARCH INSTITUTE

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	GRP with Pitt Char Coating
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²
		Duct Flow:	24 l/s
Orientation:	Horizontal	*Sample Area:*	0.00884 m²
Frame:	Yes	*Distance:*	25 mm
Spark Igniter:	Yes	*Operator:*	Abe Mata

Test ID	Test Date	t_{ig} (s)	Test Duration (s)	C-Factor (SI Units)	HRR_{peak} (kW/m²)	THR (MJ/m²)	HRR_{60s} (kW/m²)	HRR_{180s} (kW/m²)	HRR_{300s} (kW/m²)	$HRR_{30s,max}$ (kW/m²)
14-225DOT-10	08/13/14	32	3600	0.0428	153	198.7	101	74	60	126
14-225DOT-9	08/13/14	25	3600	0.0428	164	186.8	112	84	72	139
14-226DOT-11	08/14/14	35	3214	0.0416	152	181.8	107	77	62	127
Average		31	3471	---	156	189.1	107	78	65	131

Initial Mass (g)	Mass at Ignition (g)	Final Mass (g)	Mass Loss (g/m²)	MLR (g/m²-s)	10-90 MLR (g/m²-s)	EHC (MJ/kg)	$S_{A,1}$ (m²/m²)	$S_{A,2}$ (m²/m²)	S_A (m²/m²)	SEA (m²/kg)
121.5	121.4	46.2	8515	2.4	2.5	23.3	28	4224	4252	496
130.9	130.5	51.2	9017	2.5	2.6	20.7	19	3620	3638	401
122.6	122.4	47.1	8522	2.7	4.2	21.3	33	5416	5449	636
125.0	124.8	48.2	8685	2.5	3.1	21.8	27	4420	4447	511

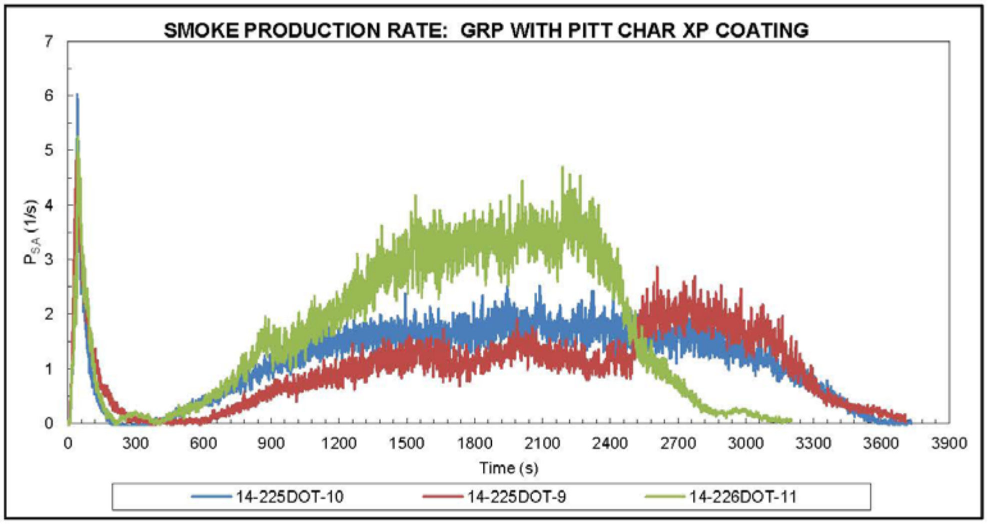


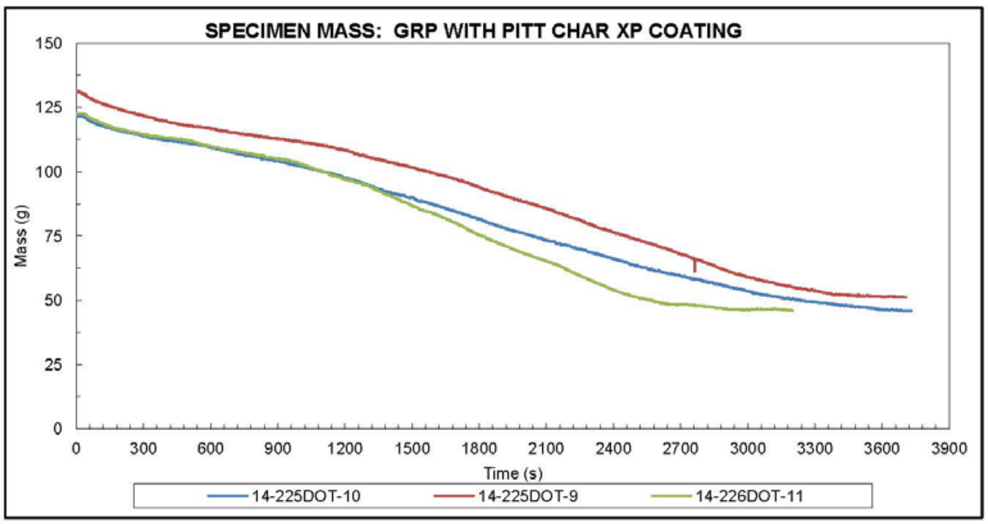
SOUTHWEST RESEARCH INSTITUTE

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	GRP with Pitt Char Coating
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²

(Page 2)





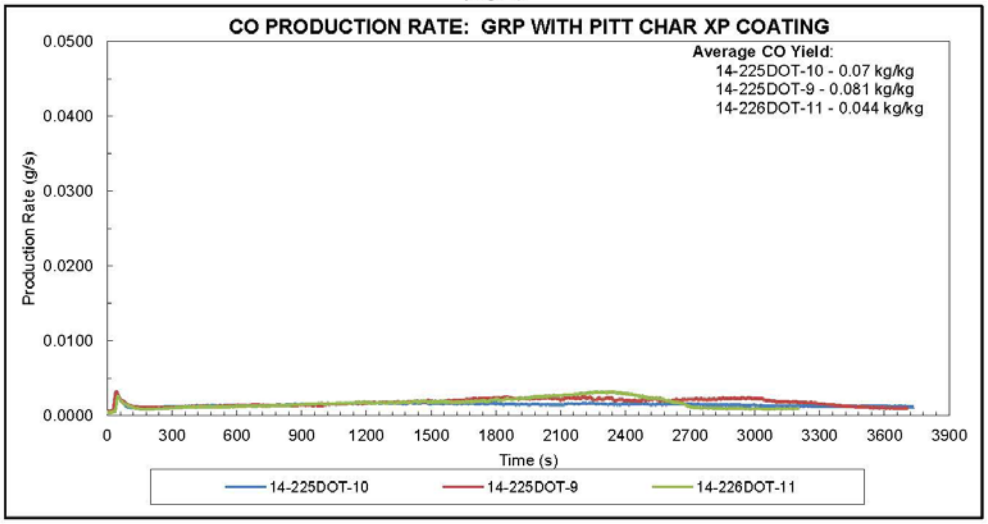
Notes & Observations:

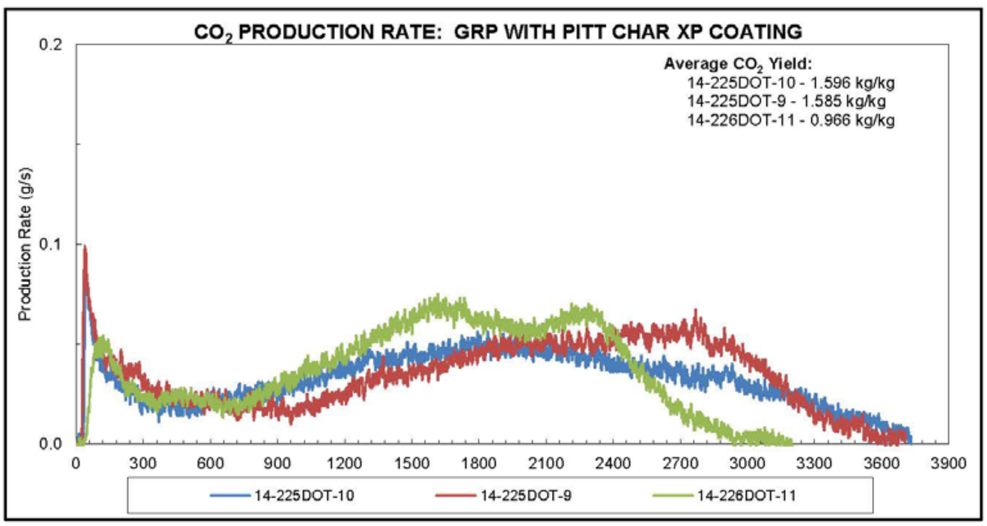
SOUTHWEST RESEARCH INSTITUTE

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	GRP with Pitt Char Coating
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²

(Page 3)





Notes & Observations:

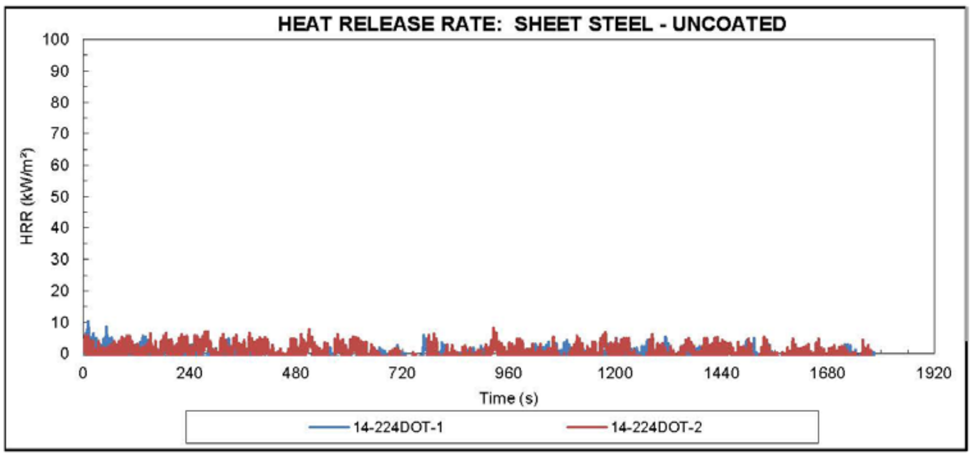
CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Sheet Steel - Uncoated
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²
		Duct Flow:	24 l/s
Orientation:	Horizontal	*Sample Area:*	0.00884 m²
Frame:	Yes	*Distance:*	25 mm
Spark Igniter:	Yes	*Operator:*	Abe Mata

Test ID	Test Date	t_{ig} (s)	Test Duration (s)	C-Factor (SI Units)	HRR_{peak} (kW/m²)	THR (MJ/m²)	HRR_{60s} (kW/m²)	HRR_{180s} (kW/m²)	HRR_{300s} (kW/m²)	$HRR_{30s, max}$ (kW/m²)
14-224DOT-1	08/12/14	NI	1787	0.0435	10	0.3	3	0	-1	0
14-224DOT-2	08/12/14	NI	1787	0.0435	8	0.9	0	0	1	2
Average		NI	NI	---	9	0.6	1	0	0	1

NI = No Ignition

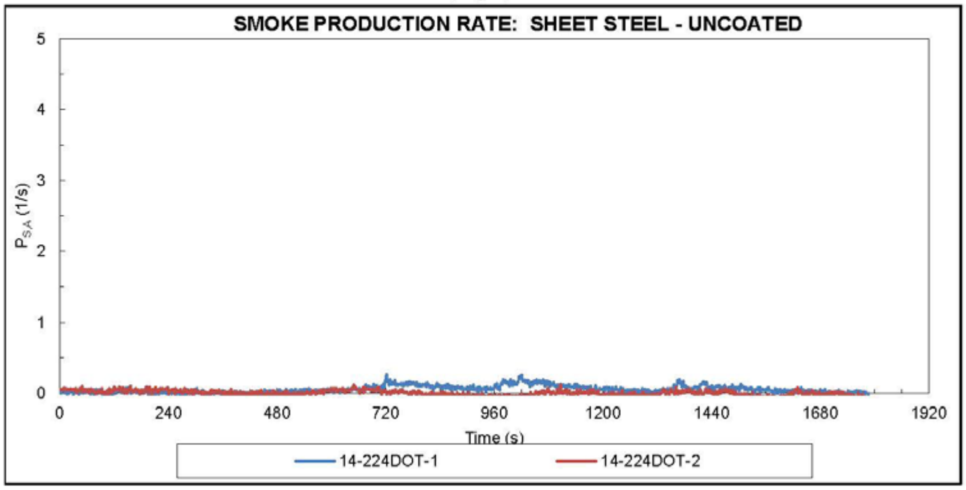
Initial Mass (g)	Mass at Ignition (g)	Final Mass (g)	Mass Loss (g/m²)	MLR (g/m²-s)	10-90 MLR (g/m²-s)	EHC (MJ/kg)	$S_{A,1}$ (m²/m²)	$S_{A,2}$ (m²/m²)	S_A (m²/m²)	SEA (m²/kg)
98.2	NI	98.0	23	0.2	0.2	0.9	97	N/A	97	247
98.6	NI	98.0	67	0.0	0.0	12.8	26	N/A	26	398
98.4	NI	98.0	45	0.1	0.1	6.8	62	N/A	62	323

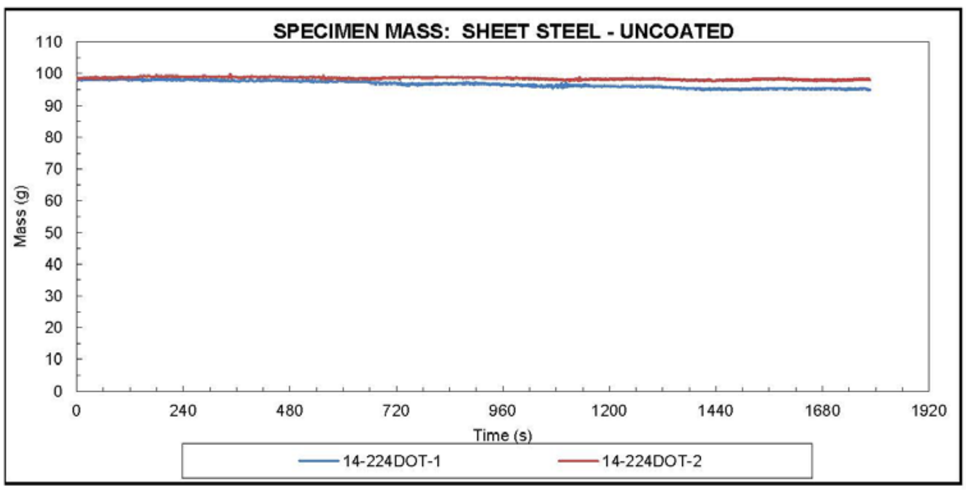


CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Sheet Steel - Uncoated
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²

(Page 2)



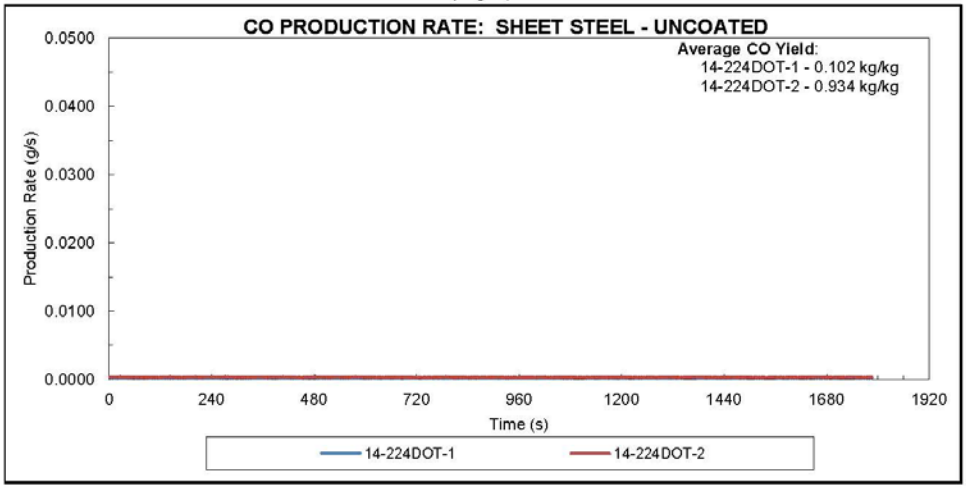


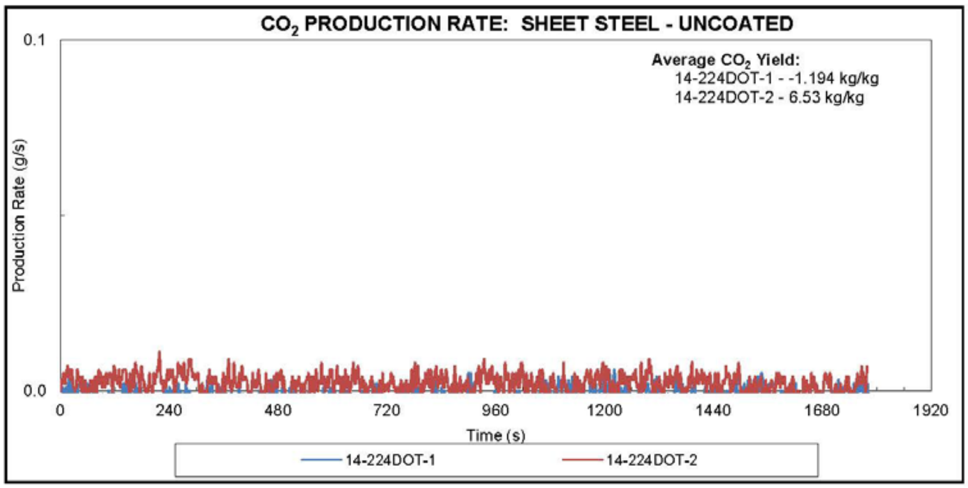
Notes & Observations:

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Sheet Steel - Uncoated
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²

(Page 3)





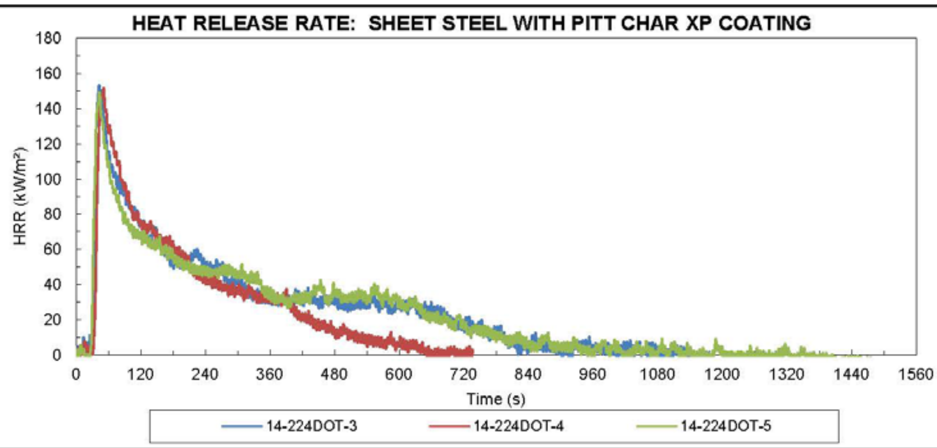
Notes & Observations:

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Sheet Steel - Coated
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²
		Duct Flow:	24 l/s
Orientation:	Horizontal	*Sample Area:*	0.00884 m²
Frame:	Yes	*Distance:*	25 mm
Spark Igniter:	Yes	*Operator:*	Abe Mata

Test ID	Test Date	t_{ig} (s)	Test Duration (s)	C-Factor (SI Units)	HRR_{peak} (kW/m²)	THR (MJ/m²)	HRR_{60s} (kW/m²)	HRR_{180s} (kW/m²)	HRR_{300s} (kW/m²)	$HRR_{30s, max}$ (kW/m²)
14-224DOT-3	08/12/14	29	1069	0.0435	153	33.3	110	81	67	131
14-224DOT-4	08/12/14	32	630	0.0435	152	24.5	111	82	65	134
14-224DOT-5	08/12/14	25	1380	0.0435	149	33.6	98	75	64	124
Average		29	1026	---	151	30.5	106	79	65	130

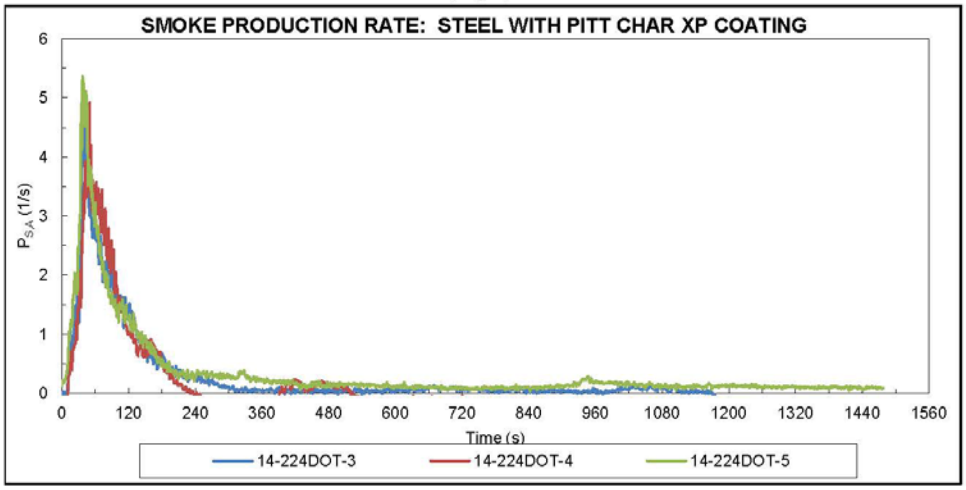
Initial Mass (g)	Mass at Ignition (g)	Final Mass (g)	Mass Loss (g/m²)	MLR (g/m²-s)	10-90 MLR (g/m²-s)	EHC (MJ/kg)	$S_{A,1}$ (m²/m²)	$S_{A,2}$ (m²/m²)	S_A (m²/m²)	SEA (m²/kg)
128.6	128.0	112.3	1846	1.7	2.1	18.0	20	333	353	181
118.5	118.2	108.3	1150	1.9	2.7	21.3	17	296	313	257
132.2	131.4	114.5	2001	1.4	1.8	16.8	22	470	492	235
126.4	125.9	111.7	1666	1.7	2.2	18.7	20	366	386	224

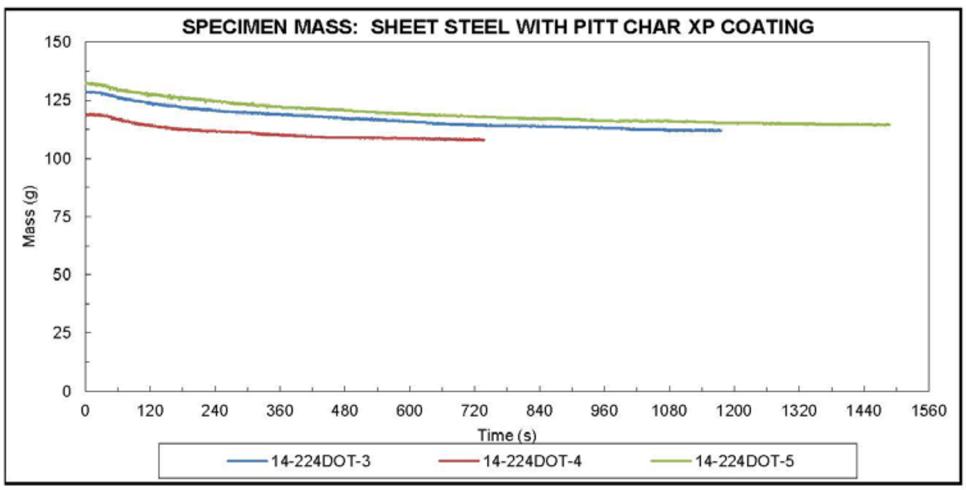


CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Sheet Steel - Coated
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²

(Page 2)



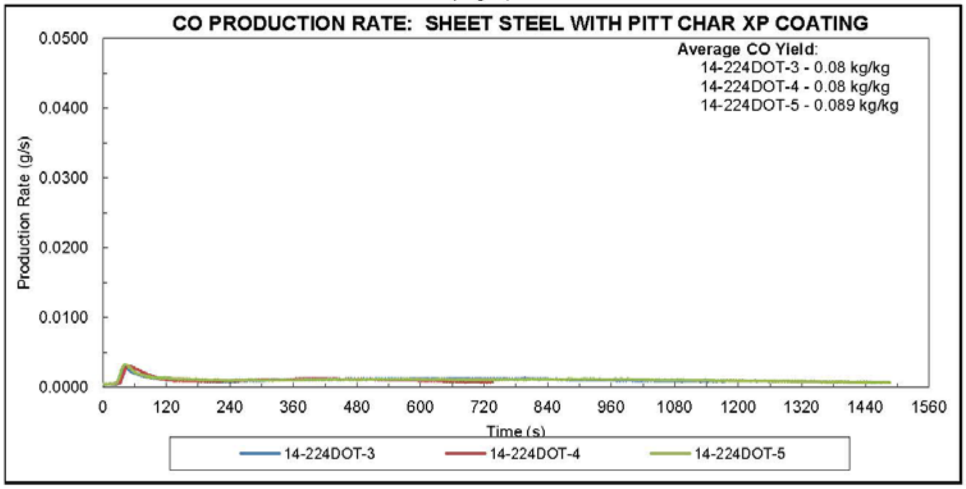


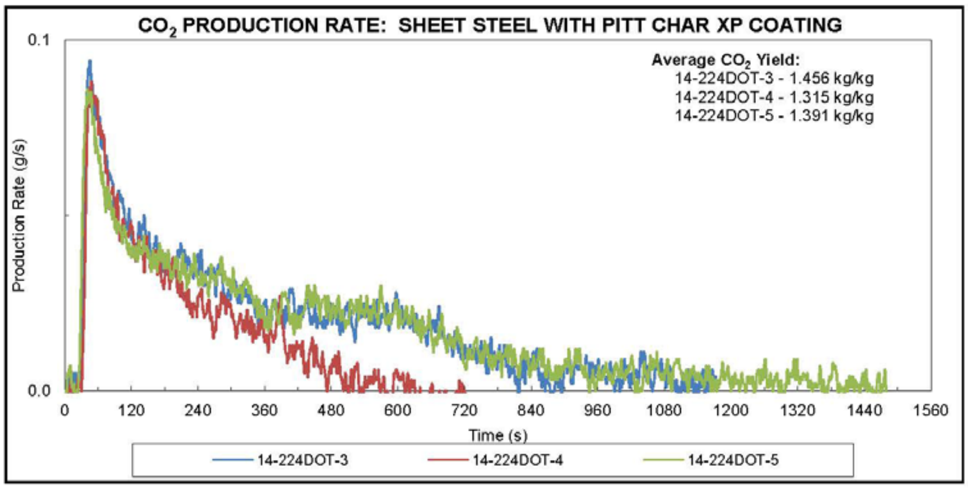
Notes & Observations:

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Sheet Steel - Coated
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²

(Page 3)





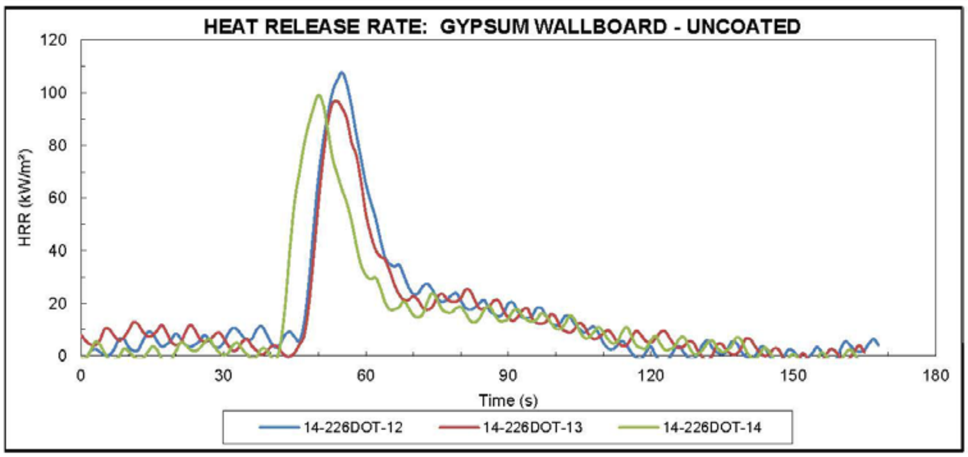
Notes & Observations:

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Gypsum Wallboard - Uncoated
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²
		Duct Flow:	24 l/s
Orientation:	Horizontal	*Sample Area:*	0.00884 m²
Frame:	Yes	*Distance:*	25 mm
Spark Igniter:	Yes	*Operator:*	Abe Mata

Test ID	Test Date	t_{ig} (s)	Test Duration (s)	C-Factor (SI Units)	HRR_{peak} (kW/m²)	THR (MJ/m²)	HRR_{60s} (kW/m²)	HRR_{180s} (kW/m²)	HRR_{300s} (kW/m²)	$HRR_{30s, max}$ (kW/m²)
14-226DOT-12	08/14/14	44	62	0.0416	108	1.4				64
14-226DOT-13	08/14/14	45	66	0.0416	97	1.4				54
14-226DOT-14	08/14/14	40	63	0.0416	99	1.3				52
Average		43	64	---	101	1.4	N/A	N/A	N/A	57

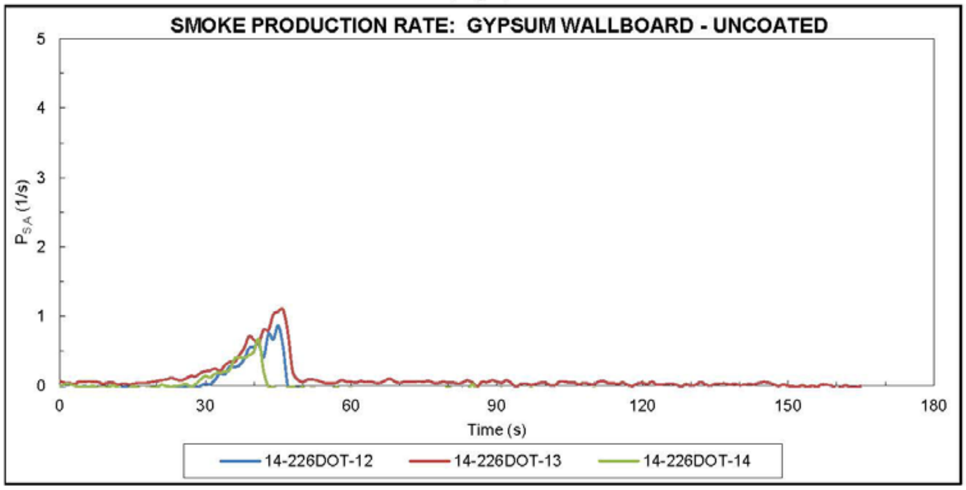
Initial Mass (g)	Mass at Ignition (g)	Final Mass (g)	Mass Loss (g/m²)	MLR (g/m²-s)	10-90 MLR (g/m²-s)	EHC (MJ/kg)	$S_{A,1}$ (m²/m²)	$S_{A,2}$ (m²/m²)	S_A (m²/m²)	SEA (m²/kg)
117.4	116.5	115.4	227	3.9	3.9	6.2	5	2	7	8
114.7	113.7	112.3	266	4.1	3.5	5.4	10	4	13	14
112.4	112.1	110.4	227	3.2	5.9	5.7	3	1	4	5
114.8	114.1	112.7	240	3.7	4.4	5.7	6	2	8	9

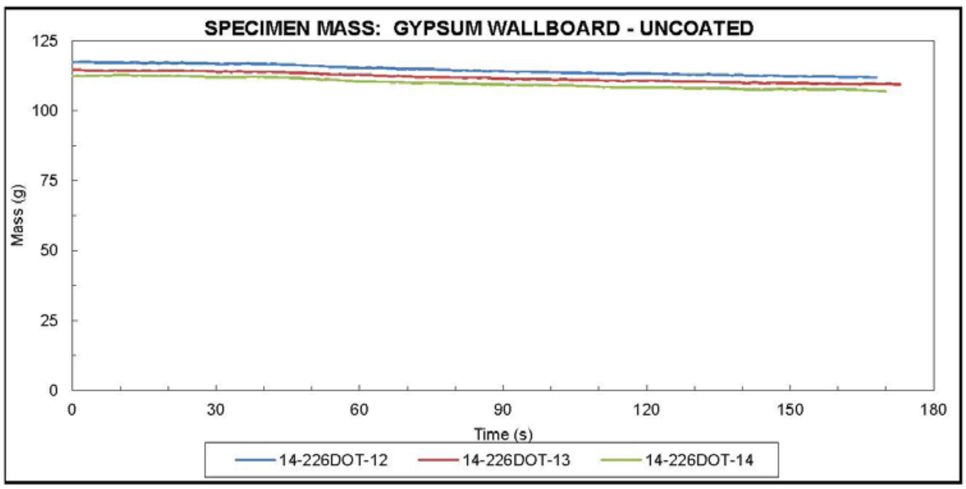


CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Gypsum Wallboard - Uncoated
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²

(Page 2)



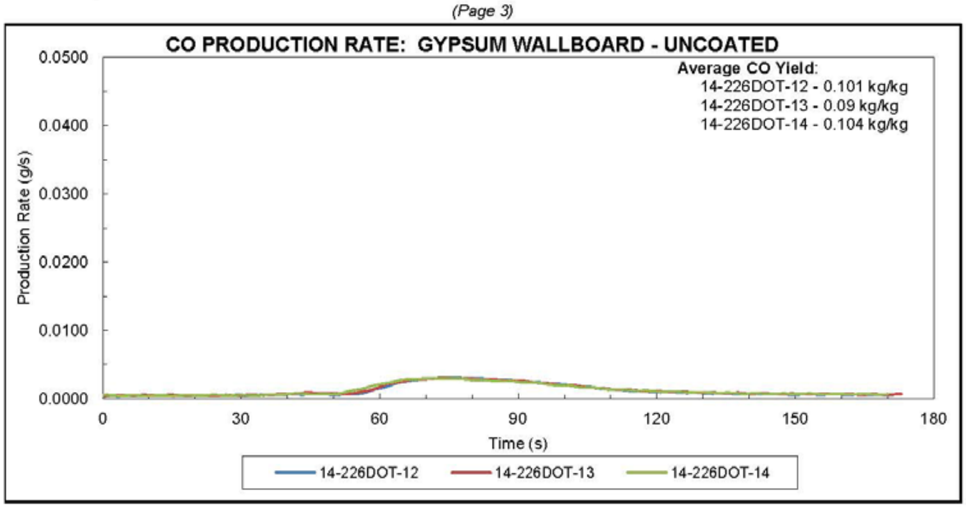


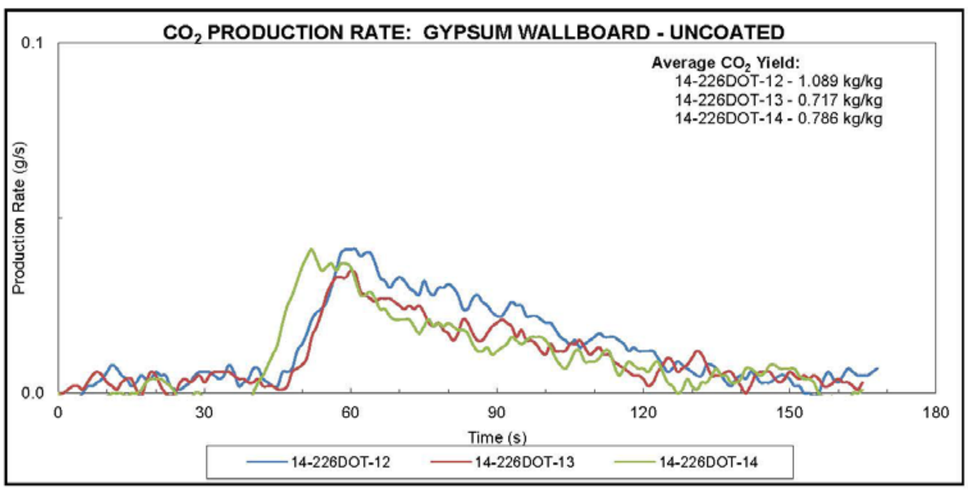
Notes & Observations:

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Gypsum Wallboard - Uncoated
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²

(Page 3)





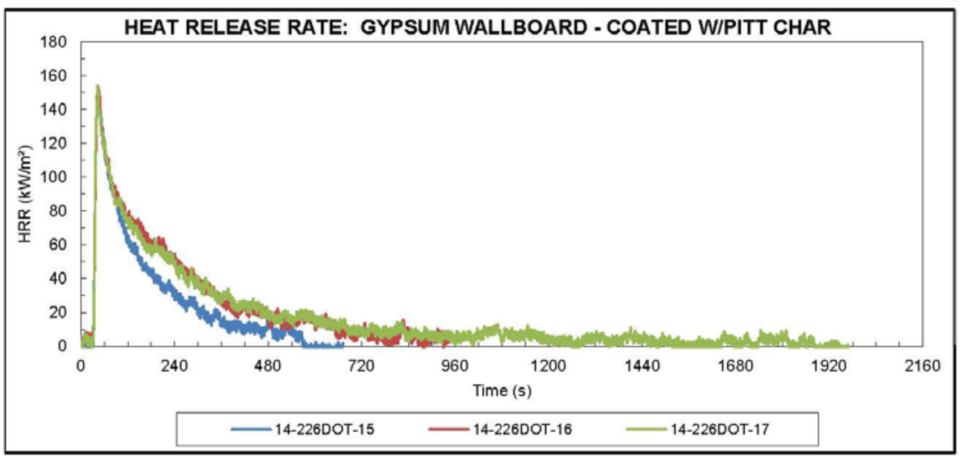
Notes & Observations:

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Gypsum Wallboard - Coated
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²
		Duct Flow:	24 l/s
Orientation:	Horizontal	*Sample Area:*	0.00884 m²
Frame:	Yes	*Distance:*	25 mm
Spark Igniter:	Yes	*Operator:*	Abe Mata

Test ID	Test Date	t_{ig} (s)	Test Duration (s)	C-Factor (SI Units)	HRR_{peak} (kW/m²)	THR (MJ/m²)	HRR_{60s} (kW/m²)	HRR_{180s} (kW/m²)	HRR_{300s} (kW/m²)	$HRR_{30s, max}$ (kW/m²)
14-226DOT-15	08/14/14	29	565	0.0416	151	18.5	104	71	53	129
14-226DOT-16	08/14/14	31	847	0.0416	153	27.6	108	83	67	129
14-226DOT-17	08/14/14	30	1872	0.0416	155	31.9	105	80	65	128
Average		30	1095	---	153	26.0	106	78	62	129

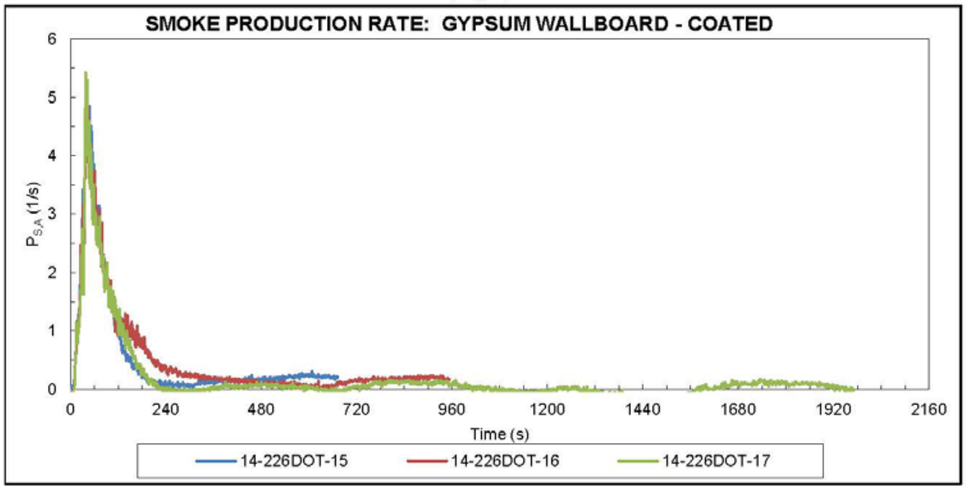
Initial Mass (g)	Mass at Ignition (g)	Final Mass (g)	Mass Loss (g/m²)	MLR (g/m²-s)	10-90 MLR (g/m²-s)	EHC (MJ/kg)	$S_{A,1}$ (m²/m²)	$S_{A,2}$ (m²/m²)	S_A (m²/m²)	SEA (m²/kg)
147.7	147.4	132.7	1695	3.1	3.1	10.9	24	326	350	192
149.8	149.0	129.8	2262	2.7	2.7	12.2	29	410	438	181
160.2	159.9	123.2	4182	2.2	2.3	7.6	23	352	375	84
152.6	152.1	128.6	2713	2.7	2.7	10.2	25	362	388	152

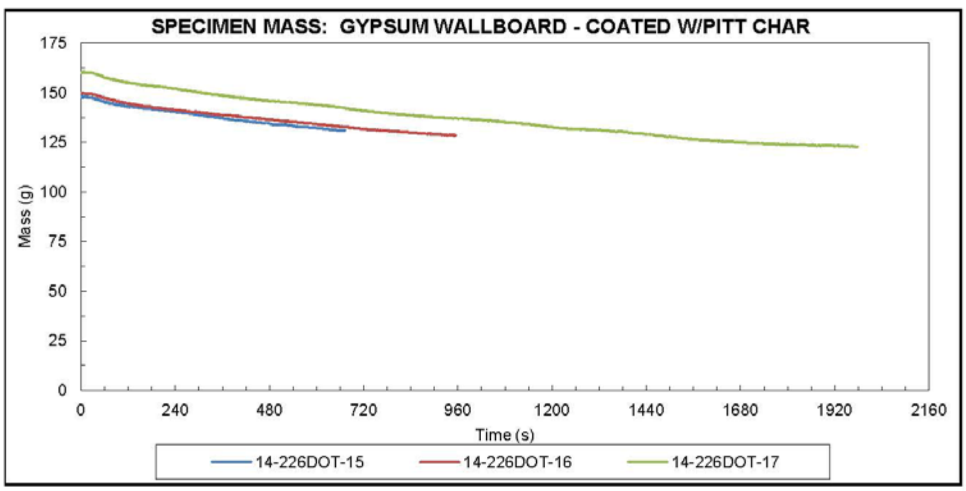


CONE CALORIMETER TEST REPORT

Client: DOT/NHTSA
SwRI Project No: 01.17914
Material ID: Gypsum Wallboard - Coated
Heat Flux: 50 kW/m²

(Page 2)



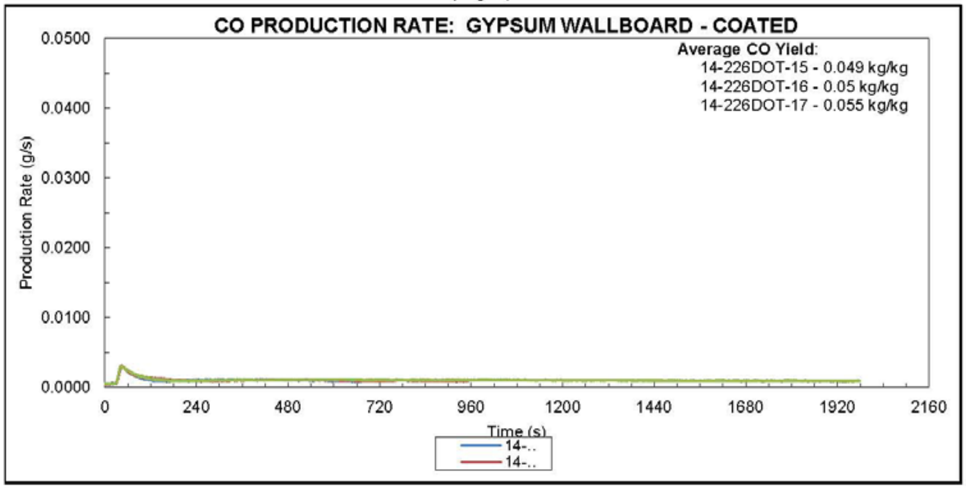


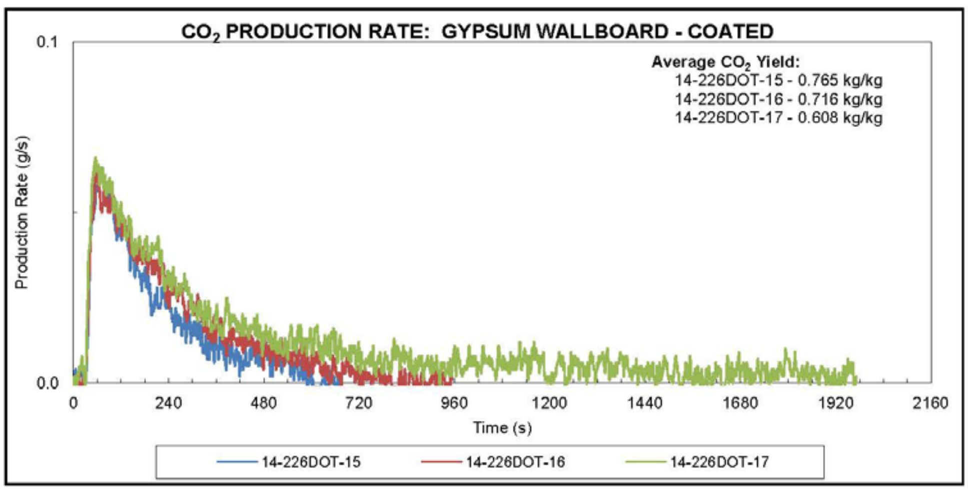
Notes & Observations:

CONE CALORIMETER TEST REPORT

Client: DOT/NHTSA
SwRI Project No: 01.17914
Material ID: Gypsum Wallboard - Coated
Heat Flux: 50 kW/m²

(Page 3)





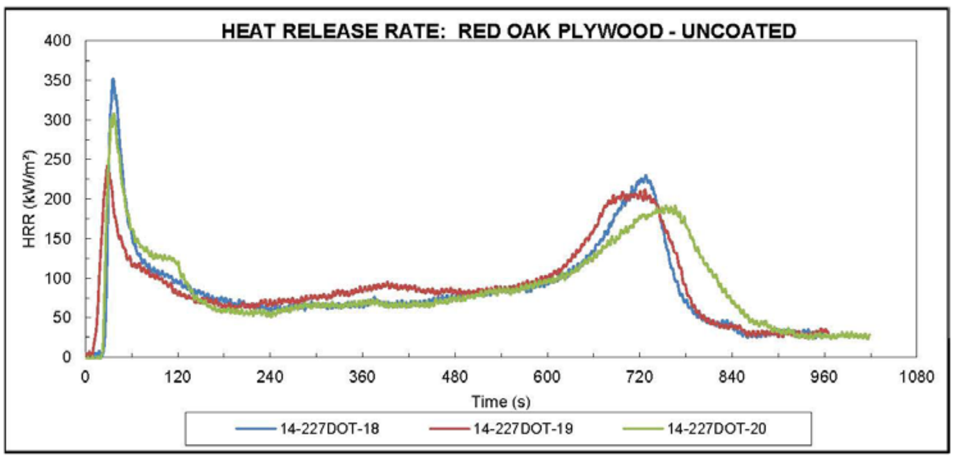
Notes & Observations:

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Red Oak Plywood - Uncoated
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²
		Duct Flow:	24 l/s
Orientation:	Horizontal	*Sample Area:*	0.00884 m²
Frame:	Yes	*Distance:*	25 mm
Spark Igniter:	Yes	*Operator:*	Abe Mata

Test ID	Test Date	t_{ig} (s)	Test Duration (s)	C-Factor (SI Units)	HRR_{peak} (kW/m²)	THR (MJ/m²)	HRR_{60s} (kW/m²)	HRR_{180s} (kW/m²)	HRR_{300s} (kW/m²)	$HRR_{30s, max}$ (kW/m²)
14-227DOT-18	08/15/14	23	854	0.0416	352	80.2	186	119	97	258
14-227DOT-19	08/15/14	9	858	0.0416	241	84.4	141	102	89	204
14-227DOT-20	08/15/14	20	920	0.0416	308	86.5	183	121	97	242
Average		17	877	---	300	83.7	170	114	94	234

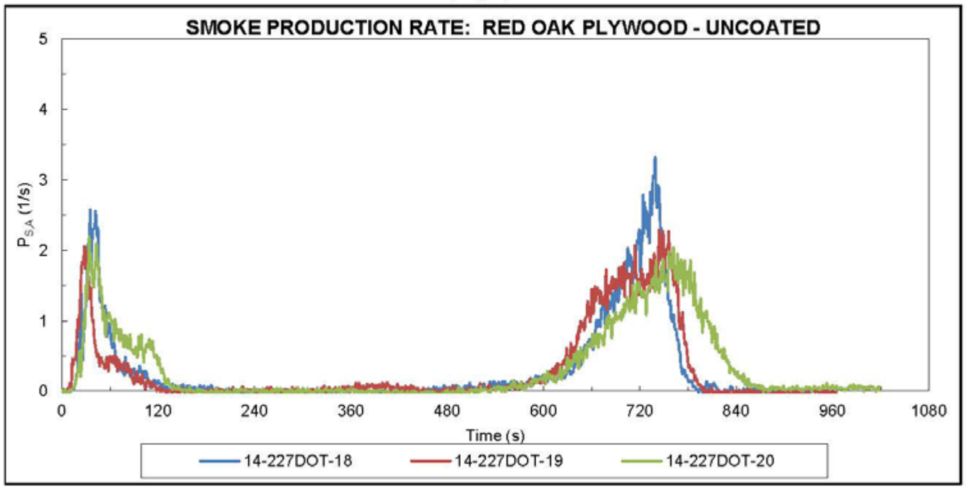
Initial Mass (g)	Mass at Ignition (g)	Final Mass (g)	Mass Loss (g/m²)	MLR (g/m²-s)	10-90 MLR (g/m²-s)	EHC (MJ/kg)	$S_{A,1}$ (m²/m²)	$S_{A,2}$ (m²/m²)	S_A (m²/m²)	SEA (m²/kg)
78.4	77.8	16.3	7027	8.3	8.3	11.4	3	297	300	42
82.1	82.0	17.9	7260	8.4	8.7	11.6	0	294	295	41
81.9	81.4	16.8	7369	8.0	8.3	11.7	1	340	341	46
80.8	80.4	17.0	7219	8.2	8.4	11.6	1	310	312	43

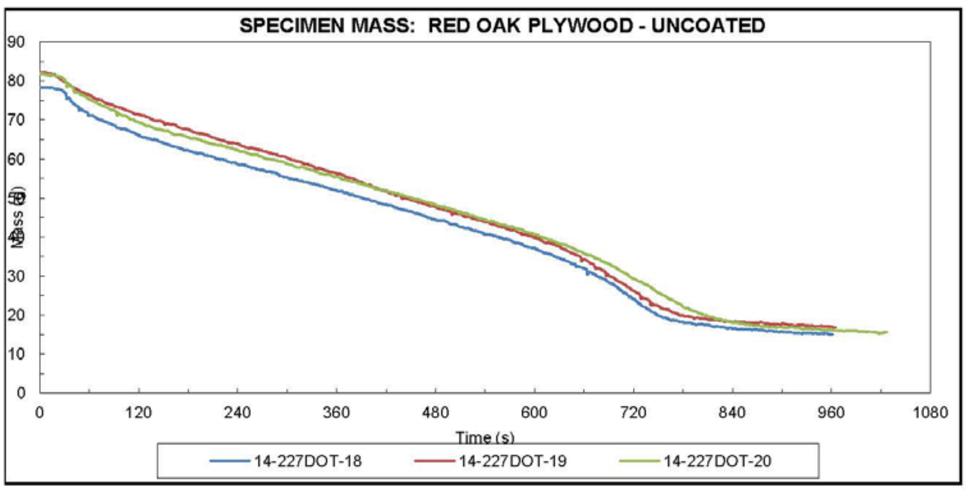


CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Red Oak Plywood - Uncoated
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²

(Page 2)



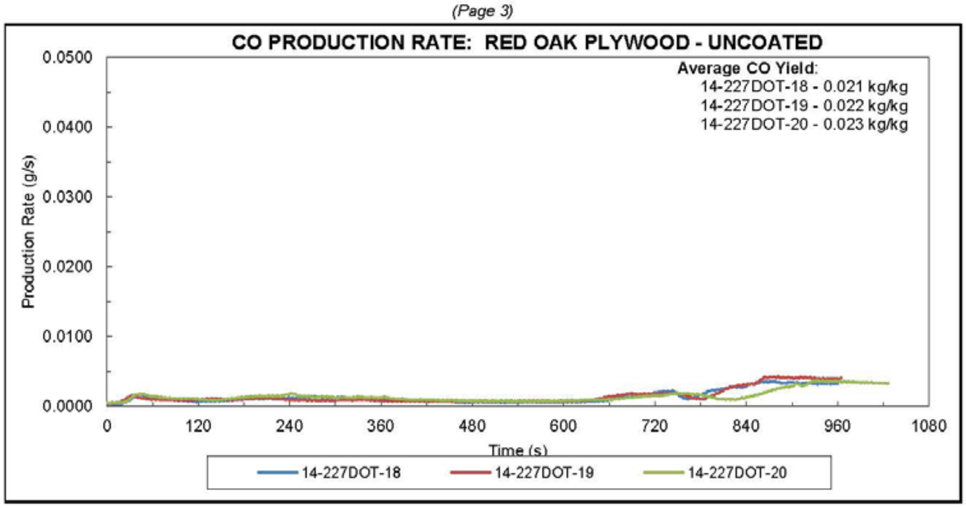


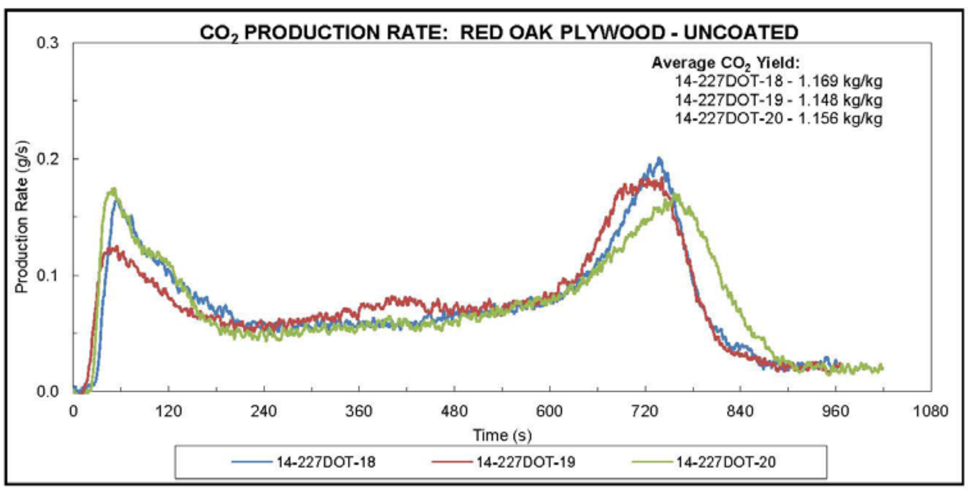
Notes & Observations:

CONE CALORIMETER TEST REPORT

Client: DOT/NHTSA
SwRI Project No: 01.17914
Material ID: Red Oak Plywood - Uncoated
Heat Flux: 50 kW/m²

(Page 3)





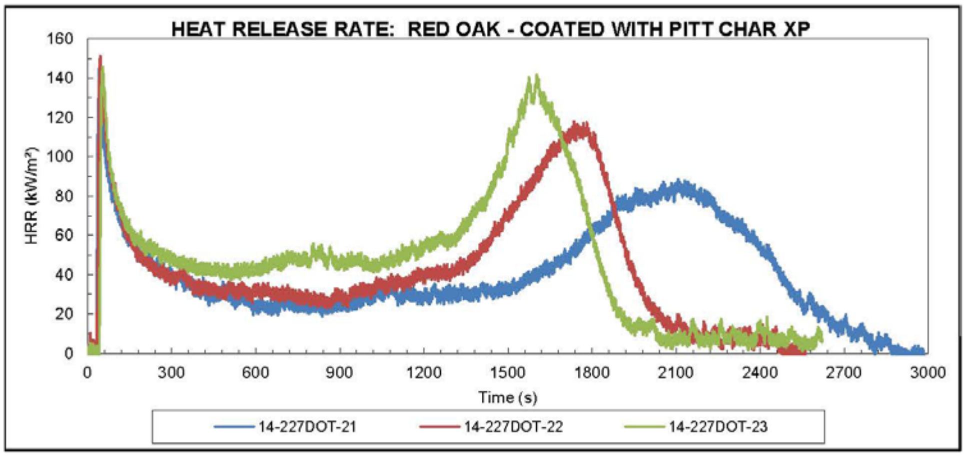
Notes & Observations:

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Red Oak Plywood - Coated
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²
		Duct Flow:	24 l/s
Orientation:	Horizontal	*Sample Area:*	0.00884 m²
Frame:	Yes	*Distance:*	25 mm
Spark Igniter:	Yes	*Operator:*	Abe Mata

Test ID	Test Date	t_{ig} (s)	Test Duration (s)	C-Factor (SI Units)	HRR_{peak} (kW/m²)	THR (MJ/m²)	HRR_{60s} (kW/m²)	HRR_{180s} (kW/m²)	HRR_{300s} (kW/m²)	$HRR_{30s, max}$ (kW/m²)
14-227DOT-21	08/15/14	29	2878	0.0416	146	118.6	97	72	60	120
14-227DOT-22	08/15/14	30	2455	0.0416	151	107.2	102	74	61	127
14-227DOT-23	08/15/14	40	2515	0.0416	146	121.9	100	75	65	134
Average		33	2616	---	148	115.9	99	74	62	127

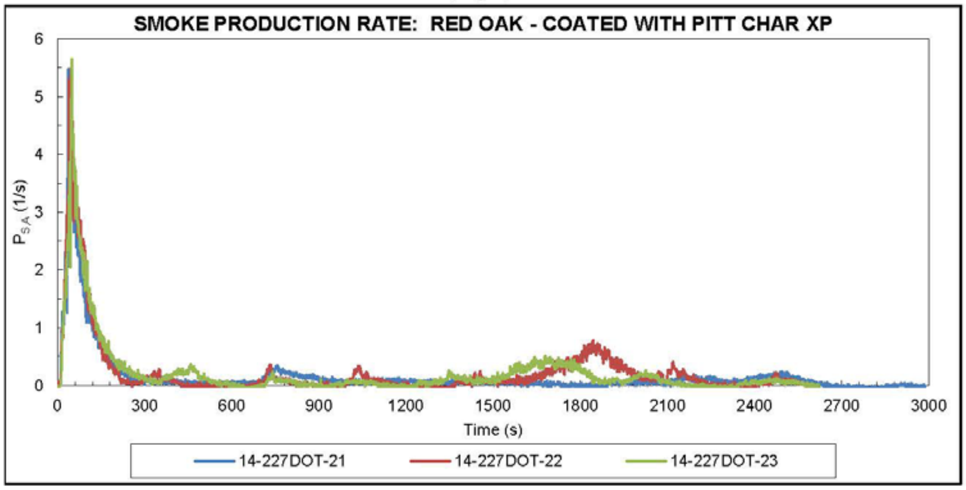
Initial Mass (g)	Mass at Ignition (g)	Final Mass (g)	Mass Loss (g/m²)	MLR (g/m²-s)	10-90 MLR (g/m²-s)	EHC (MJ/kg)	$S_{A,1}$ (m²/m²)	$S_{A,2}$ (m²/m²)	S_A (m²/m²)	SEA (m²/kg)
128.9	128.2	43.6	9652	3.3	3.7	12.3	24	459	484	48
112.9	128.6	50.1	7108	3.6	5.2	15.1	25	556	582	78
121.5	120.8	37.2	9541	3.8	5.1	12.8	47	518	565	54
121.1	125.8	43.6	8767	3.6	4.7	13.4	32	511	544	60

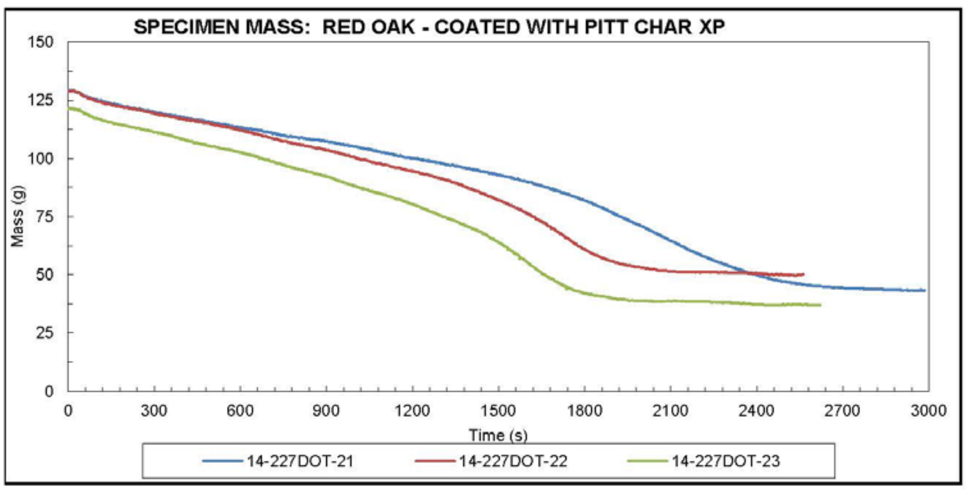


CONE CALORIMETER TEST REPORT

Client: DOT/NHTSA
SwRI Project No: 01.17914
Material ID: Red Oak Plywood - Coated
Heat Flux: 50 kW/m²

(Page 2)



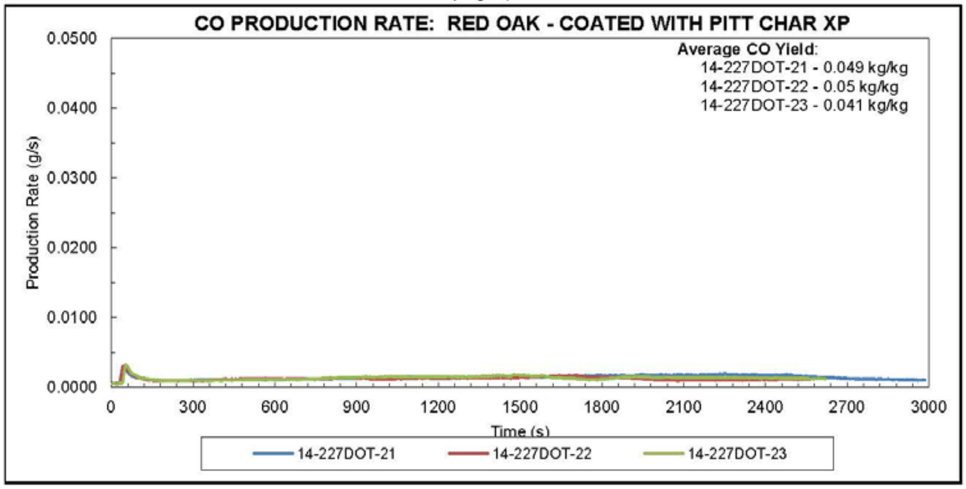


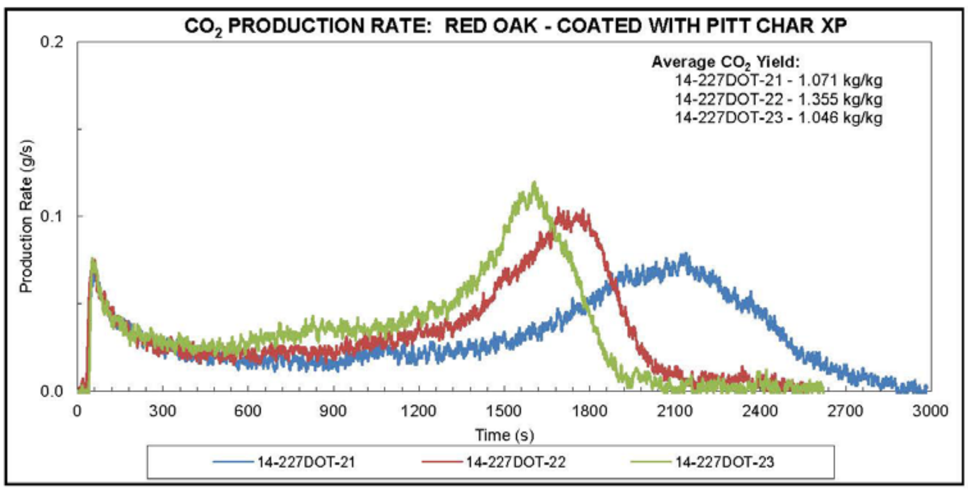
Notes & Observations:

CONE CALORIMETER TEST REPORT

Client:	DOT/NHTSA	*Material ID:*	Red Oak Plywood - Coated
SwRI Project No:	01.17914	*Heat Flux:*	50 kW/m²

(Page 3)





Notes & Observations:

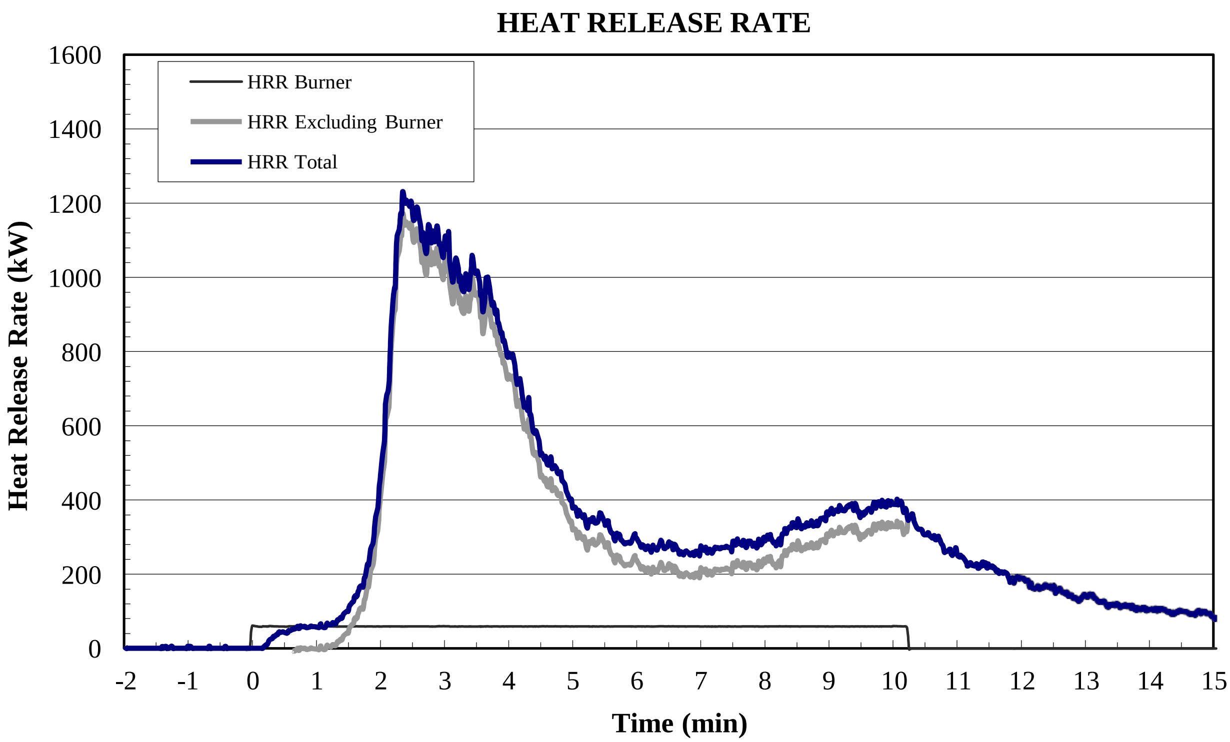
APPENDIX O
FIRE HARDENING PARALLEL PANEL TEST DATA
(CONSISTING OF 65 PAGES)

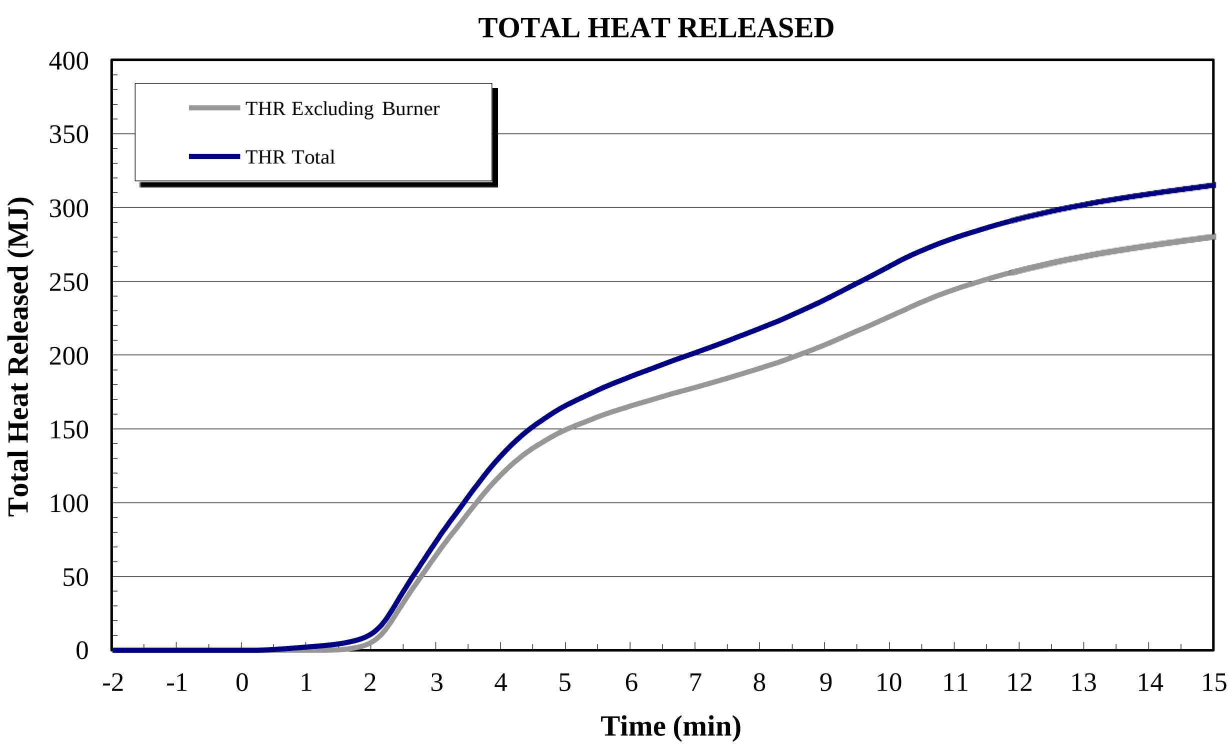
SUMMARY OF

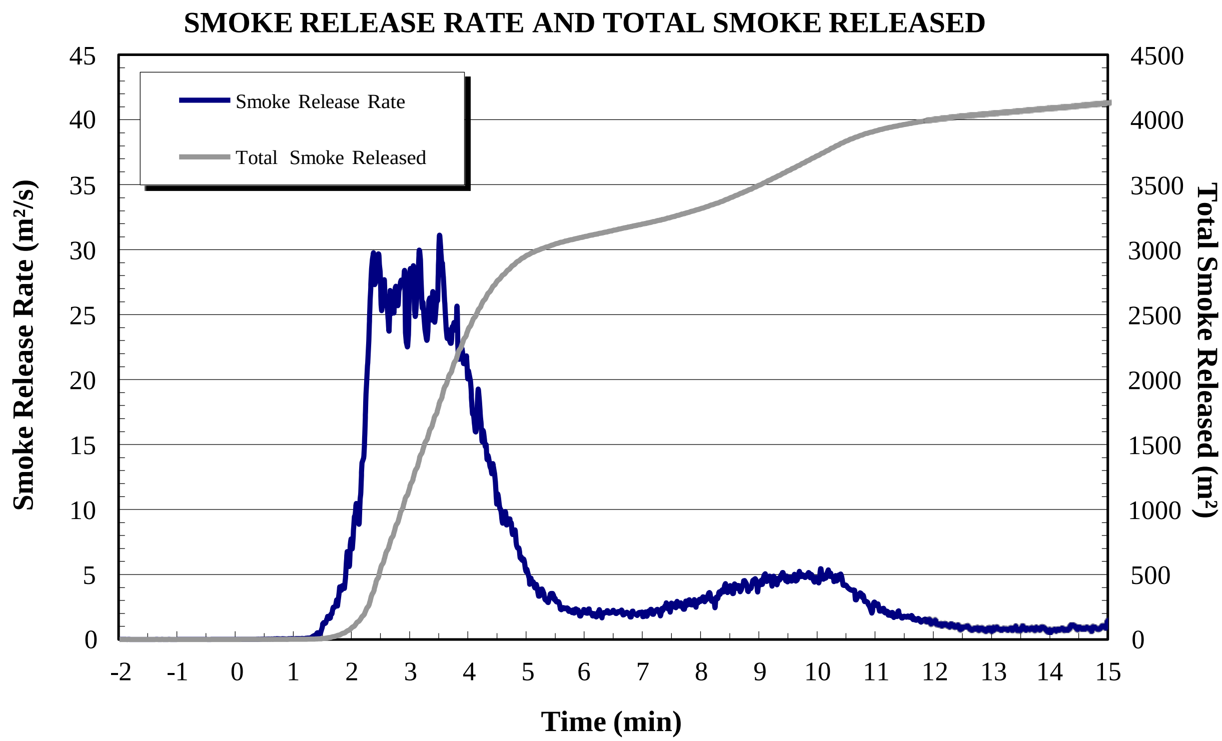
TEST RESULTS

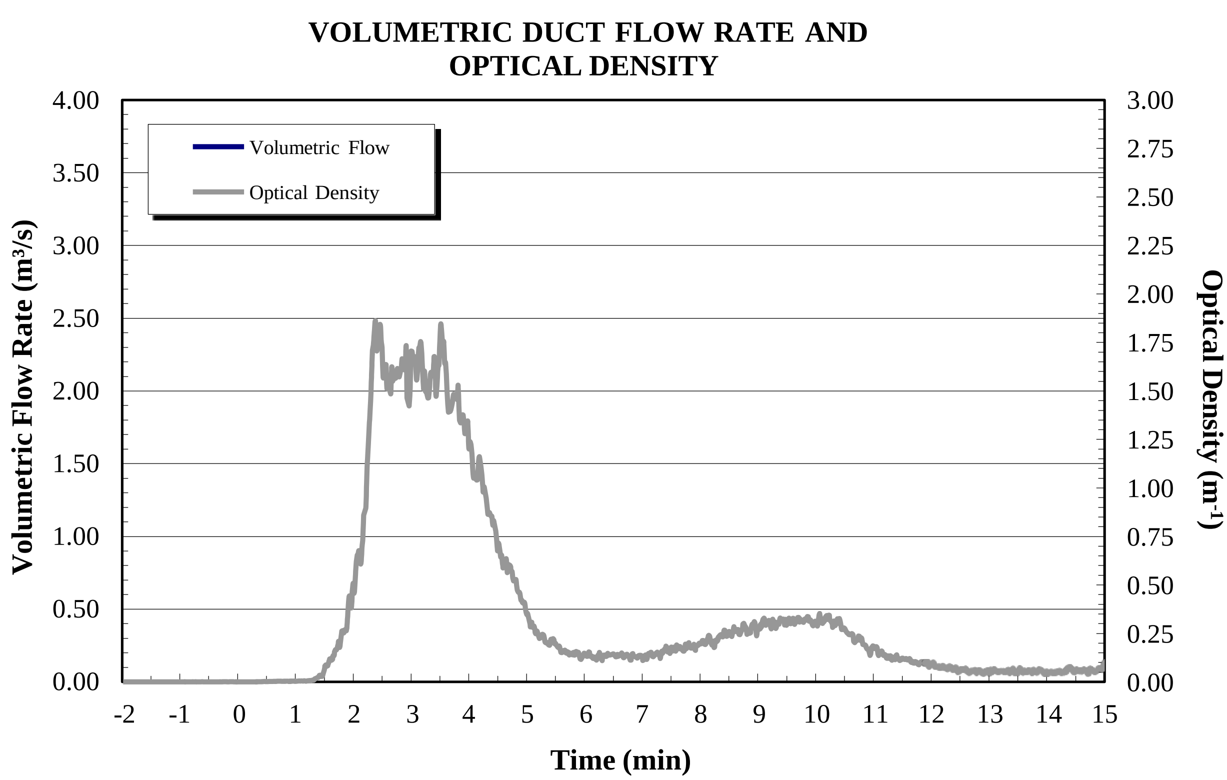
Material: ***GRP Uncoated - Run 1***

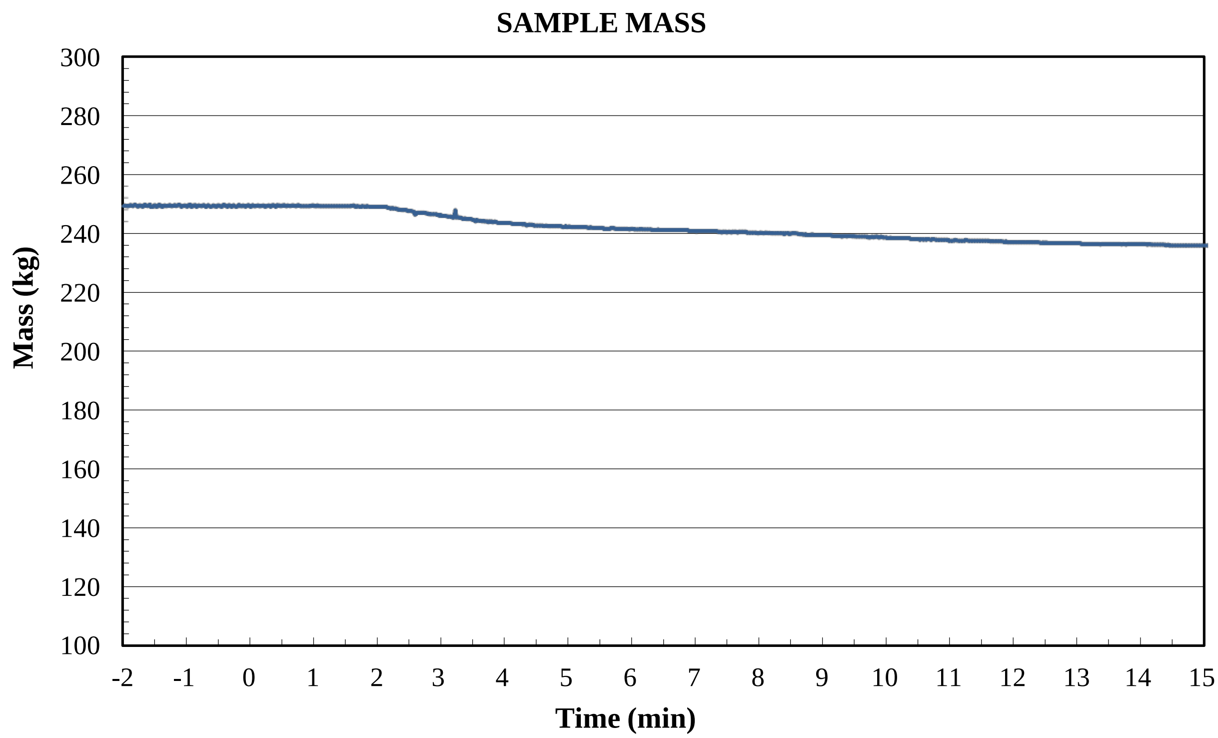
Maximum HRR_{total}	1233 kW	at	2 min 21 sec
Average HRR_{total}	530 kW		
Total Heat Released	318 MJ		
Maximum $HRR_{excl.\ burner}$	1174 kW	at	2 min 21 sec
Average $HRR_{excl.\ burner}$	472 kW		
Total Heat Released (Excluding Burner)	283 MJ		
Maximum $HRR_{10\ min}$	N/A*		
$HRR_{12\ min}$	N/A*		
Maximum Flame Height	> 2.4 m	at	7 min 0 sec
Heat Flux at 4 ft	92 kW/m²	at	2 min 40 sec
Maximum Smoke Generation $Rate_{0-10\ min}$	3.58 g/s	at	3 min 31 sec
Smoke Generation $Rate_{12min}$	N/A*		
Total Smoke Generated	528 g		
Maximum Smoke Release Rate	31.12 m²/s	at	2 min 40 sec
Average Smoke Release Rate	6.94 m²/s		
Total Smoke Released	4162 m²		
Maximum Optical Density	1.86 1/m	at	2 min 23 sec
Maximum Duct Flow Rate	6.93 m³/s		
Average Optical Density	0.321 1/m		
Average Volumetric Duct Flow Rate	6.60 m³/s		
Total Mass Loss	11.11 kg		
Smoke Yield	0.048		
Maximum Sample Backside Temperature	99°C	at	13 min 38 sec

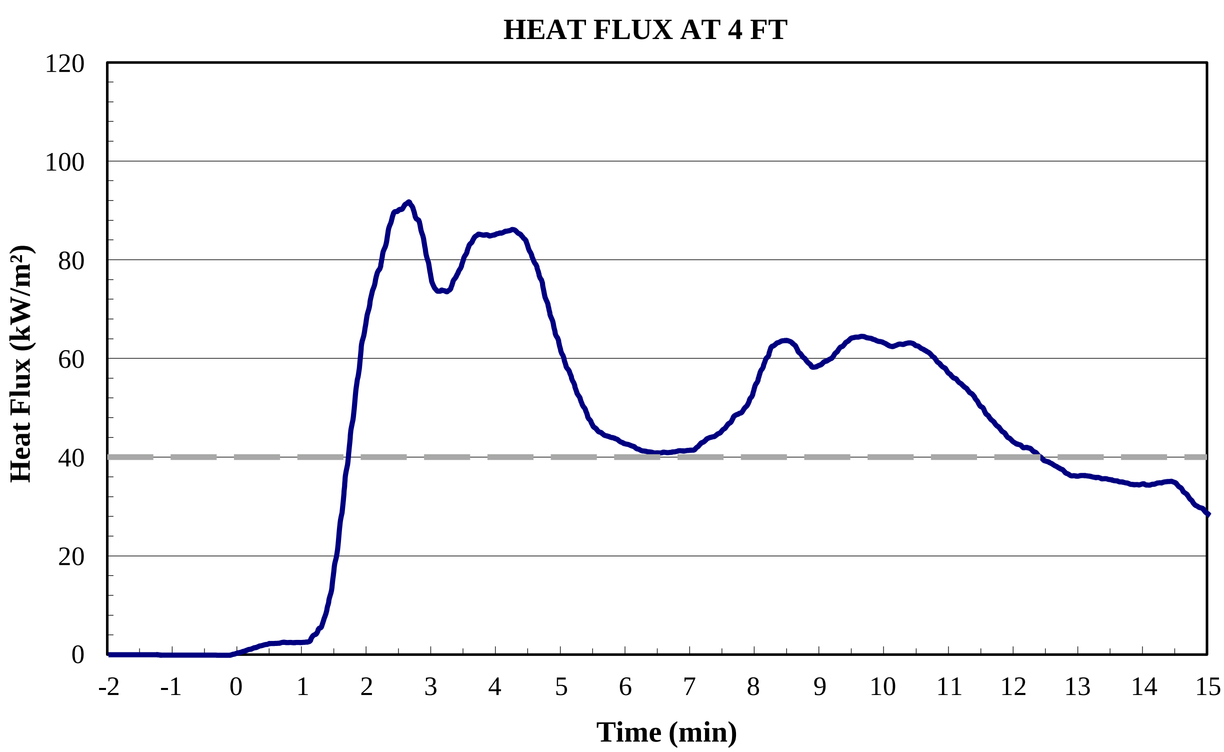

HEAT RELEASE RATE
HRR Burner
HRR Excluding Burner
HRR Total
Heat Release Rate (kW)
1600
1400
1200
1000
800
600
400
200
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Time (min)

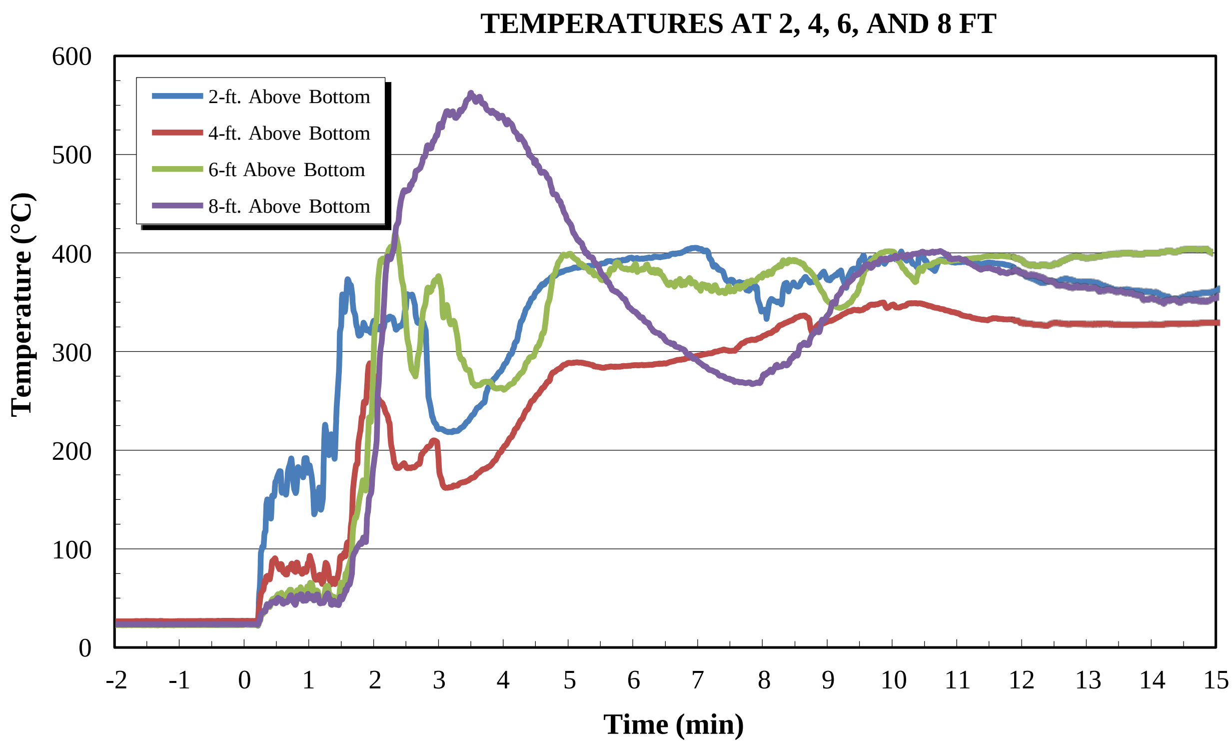

TOTAL HEAT RELEASED
THR Excluding Burner
THR Total
Total Heat Released (MJ)
400
350
300
250
200
150
100
50
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Time (min)


SMOKE RELEASE RATE AND TOTAL SMOKE RELEASED
Smoke Release Rate
Total Smoke Released
Smoke Release Rate (m²/s)
Total Smoke Released (m²)
Time (min)
45
40
35
30
25
20
15
10
5
0
4500
4000
3500
3000
2500
2000
1500
1000
500
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

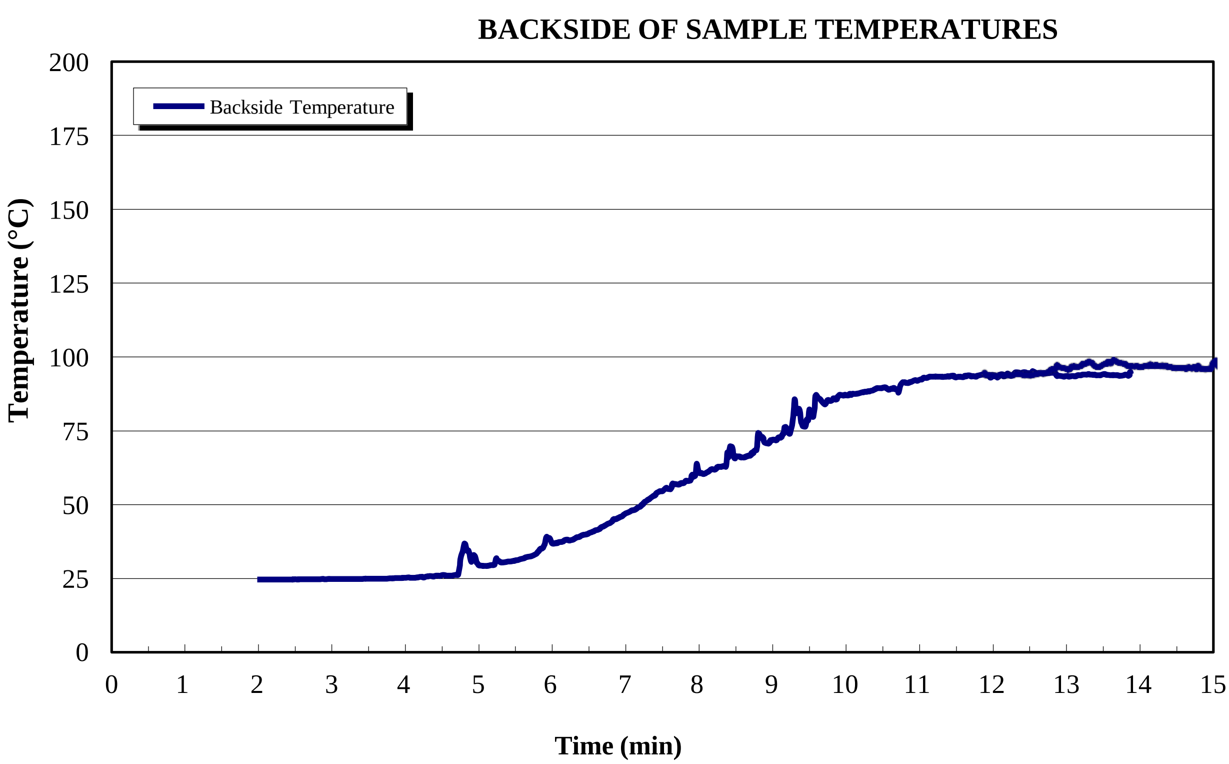

VOLUMETRIC DUCT FLOW RATE AND
OPTICAL DENSITY
Volumetric Flow
Optical Density
Volumetric Flow Rate (m³/s)
Optical Density (m-1)
Time (min)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15


SAMPLE MASS
Mass (kg)
300
280
260
240
220
200
180
160
140
120
100
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Time (min)


HEAT FLUX AT 4 FT
Heat Flux (kW/m²)
120
100
80
60
40
20
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Time (min)



TEMPERATURES AT 2, 4, 6, AND 8 FT
2-ft. Above Bottom
4-ft. Above Bottom
6-ft Above Bottom
8-ft. Above Bottom
Temperature (°C)
Time (min)



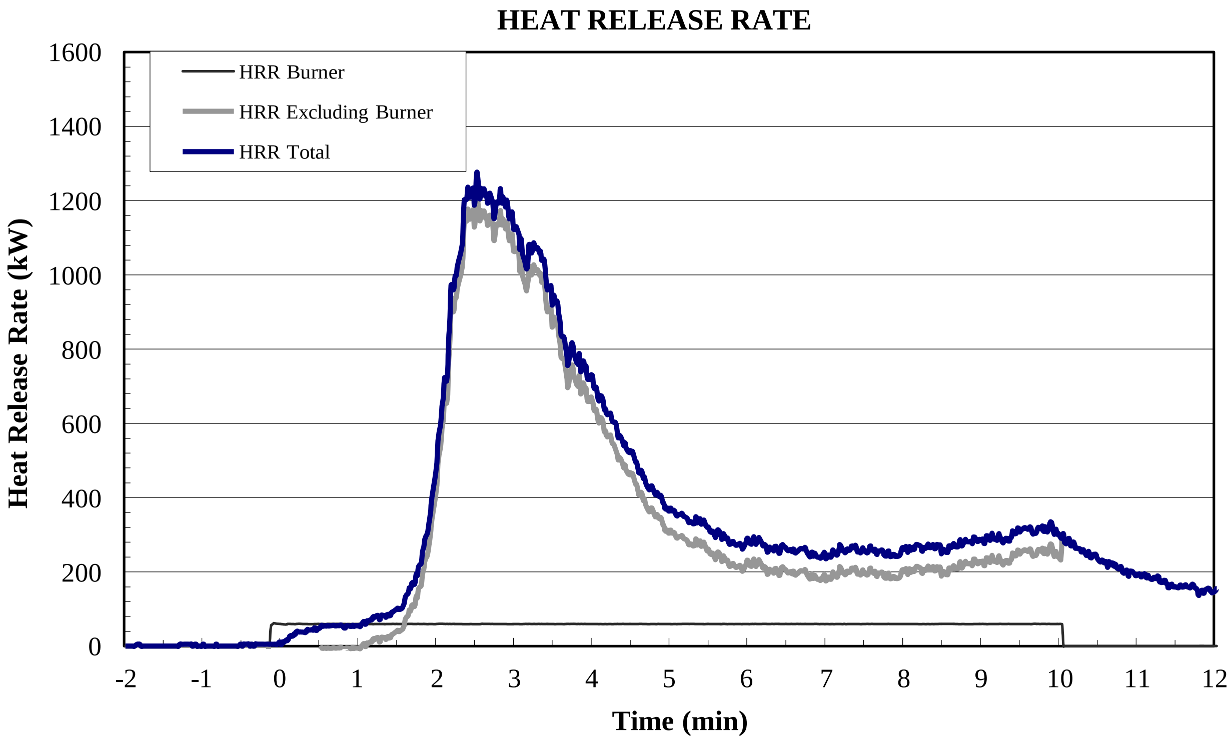
BACKSIDE OF SAMPLE TEMPERATURES
Backside Temperature
Temperature (°C)
Time (min)

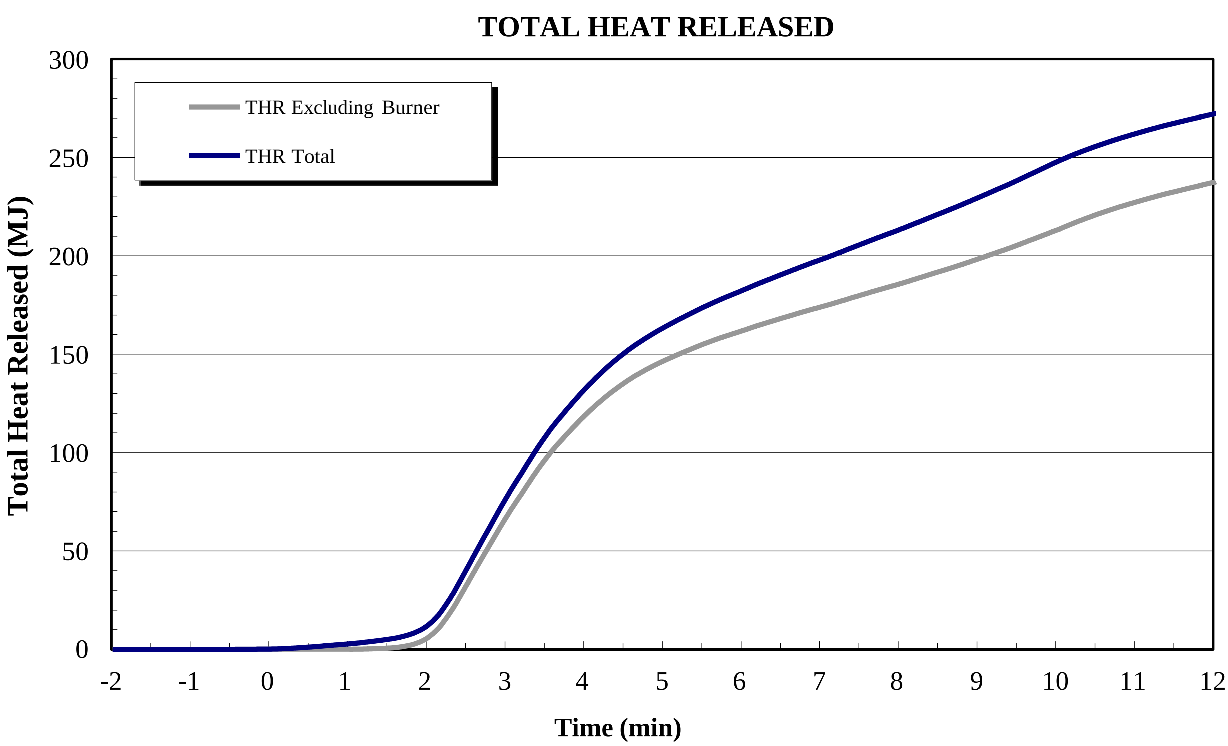
SUMMARY OF

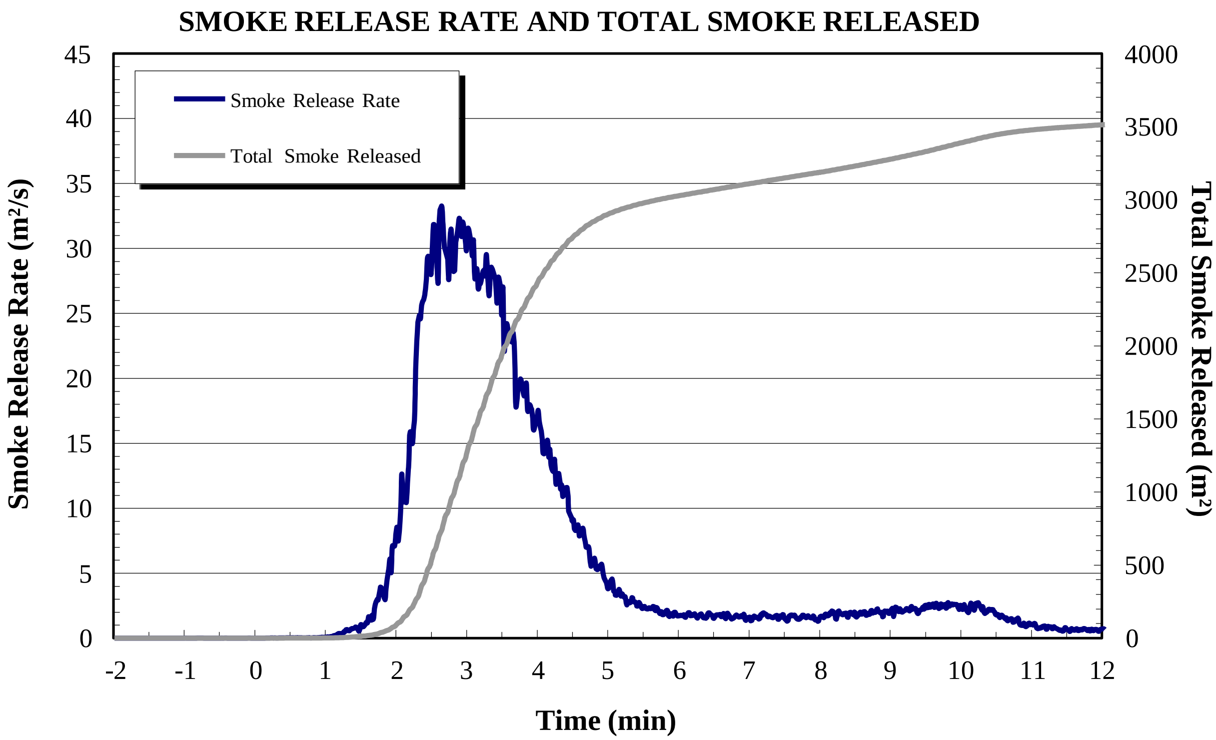
TEST RESULTS

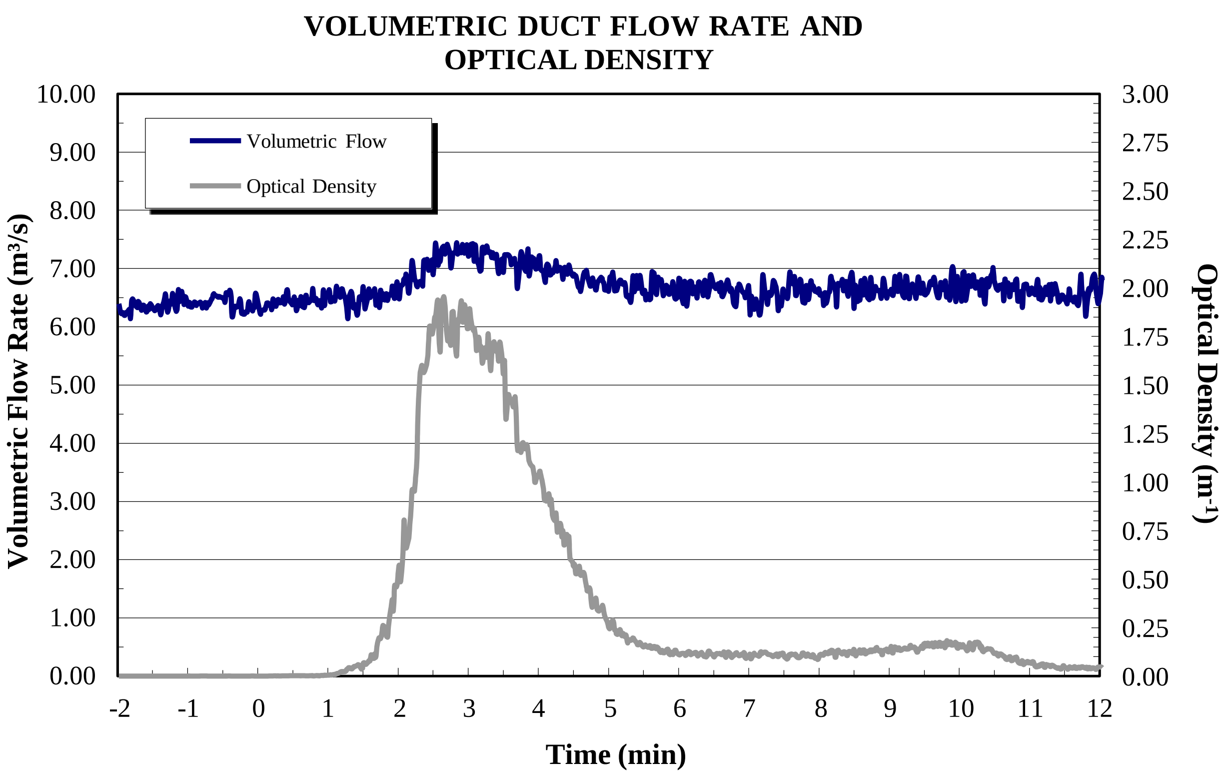
Material: ***GRP Uncoated - Run 2***

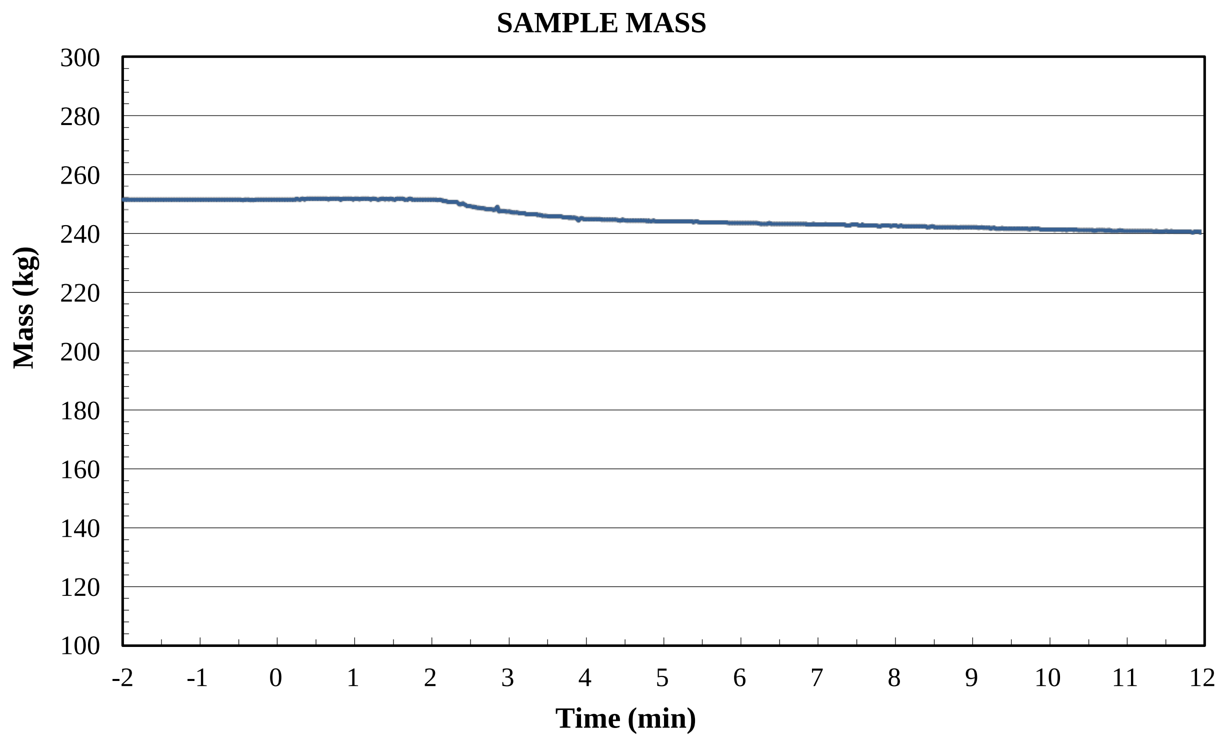
Maximum HRR_{total}	1277 kW	at	2 min 31 sec
Average HRR_{total}	456 kW		
Total Heat Released	274 MJ		
Maximum $HRR_{excl.\ burner}$	1218 kW	at	2 min 31 sec
Average $HRR_{excl.\ burner}$	398 kW		
Total Heat Released (Excluding Burner)	239 MJ		
Maximum $HRR_{10\ min}$	N/A*		
$HRR_{12\ min}$	N/A*		
Maximum Flame Height	> 2.4 m	at	7 min 0 sec
Heat Flux at 4 ft	130 kW/m²	at	2 min 46 sec
Maximum Smoke Generation $Rate_{0\text{-}10\ min}$	3.82 g/s	at	2 min 38 sec
Smoke Generation $Rate_{12min}$	N/A*		
Total Smoke Generated	484 g		
Maximum Smoke Release Rate	33.26 m²/s	at	2 min 46 sec
Average Smoke Release Rate	5.86 m²/s		
Total Smoke Released	3518 m²		
Maximum Optical Density	1.96 1/m	at	2 min 38 sec
Maximum Duct Flow Rate	7.38 m³/s		
Average Optical Density	0.334 1/m		
Average Volumetric Duct Flow Rate	6.67 m³/s		
Total Mass Loss	10.02 kg		
Smoke Yield	0.048		
Maximum Sample Backside Temperature	100°C	at	12 min 7 sec


HEAT RELEASE RATE
HRR Burner
HRR Excluding Burner
HRR Total
Heat Release Rate (kW)
1600
1400
1200
1000
800
600
400
200
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)

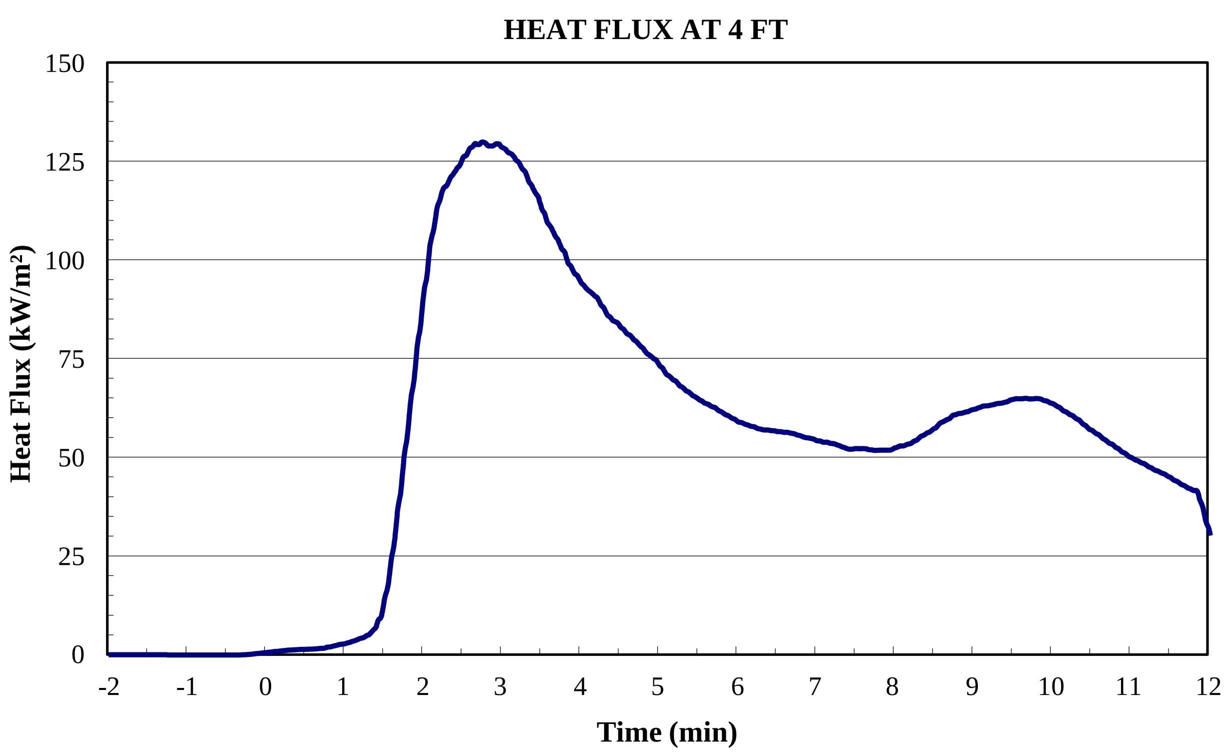

TOTAL HEAT RELEASED
THR Excluding Burner
THR Total
Total Heat Released (MJ)
300
250
200
150
100
50
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)


SMOKE RELEASE RATE AND TOTAL SMOKE RELEASED
Smoke Release Rate
Total Smoke Released
Smoke Release Rate (m²/s)
Total Smoke Released (m²)
Time (min)
45
40
35
30
25
20
15
10
5
0
4000
3500
3000
2500
2000
1500
1000
500
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12

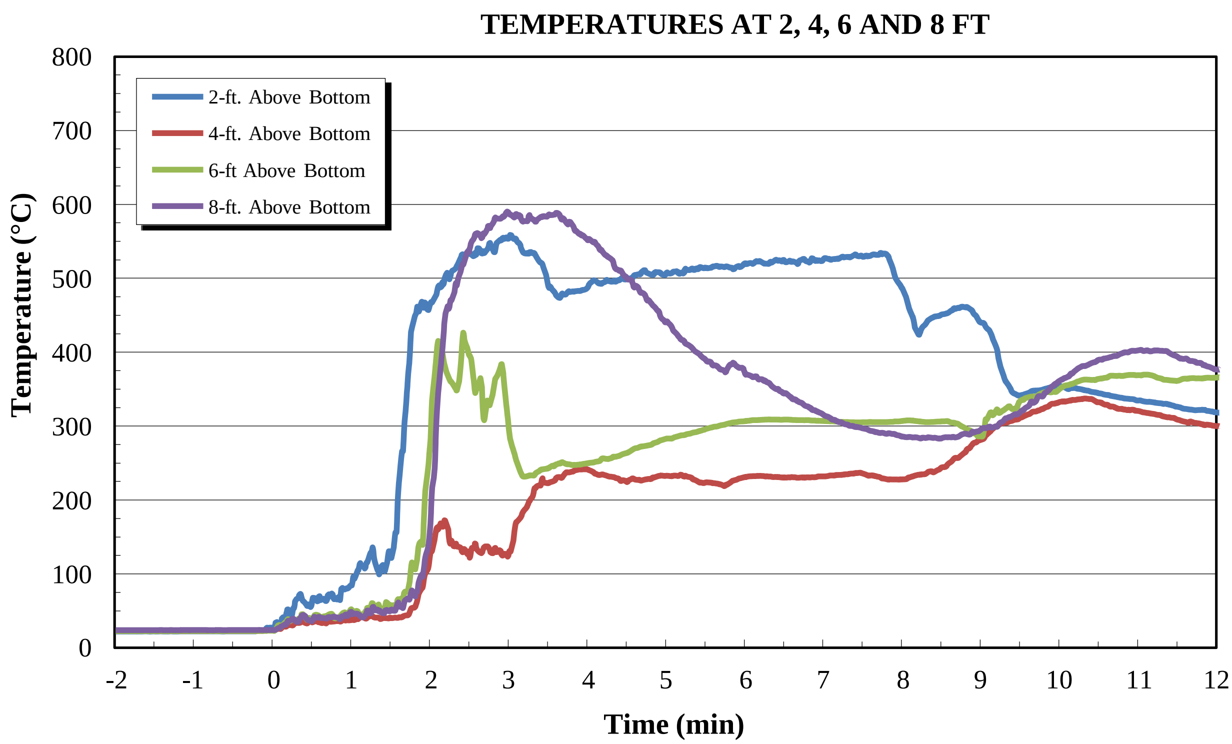

VOLUMETRIC DUCT FLOW RATE AND OPTICAL DENSITY
Volumetric Flow
Optical Density
Volumetric Flow Rate (m³/s)
Optical Density (m⁻¹)
Time (min)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12



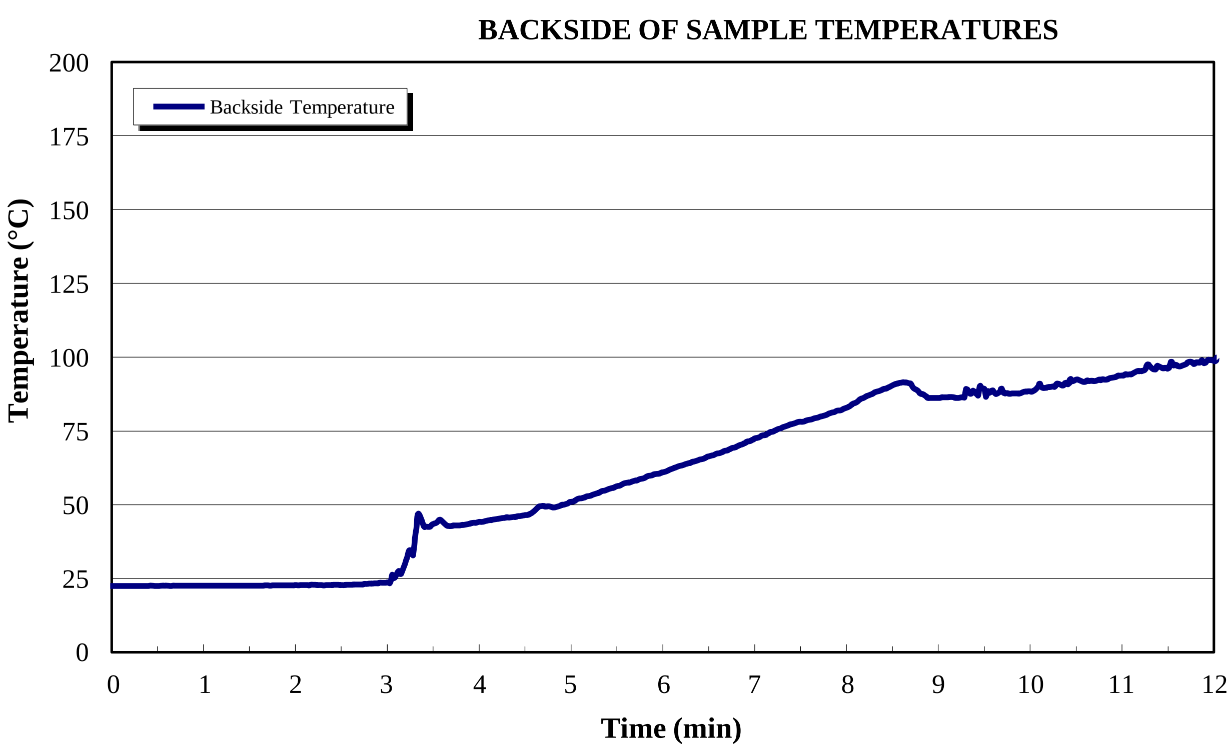
SAMPLE MASS
Mass (kg)
300
280
260
240
220
200
180
160
140
120
100
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)



HEAT FLUX AT 4 FT
Heat Flux (kW/m²)
150
125
100
75
50
25
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)



TEMPERATURES AT 2, 4, 6 AND 8 FT
2-ft. Above Bottom
4-ft. Above Bottom
6-ft Above Bottom
8-ft. Above Bottom
Temperature (°C)
Time (min)
800
700
600
500
400
300
200
100
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12



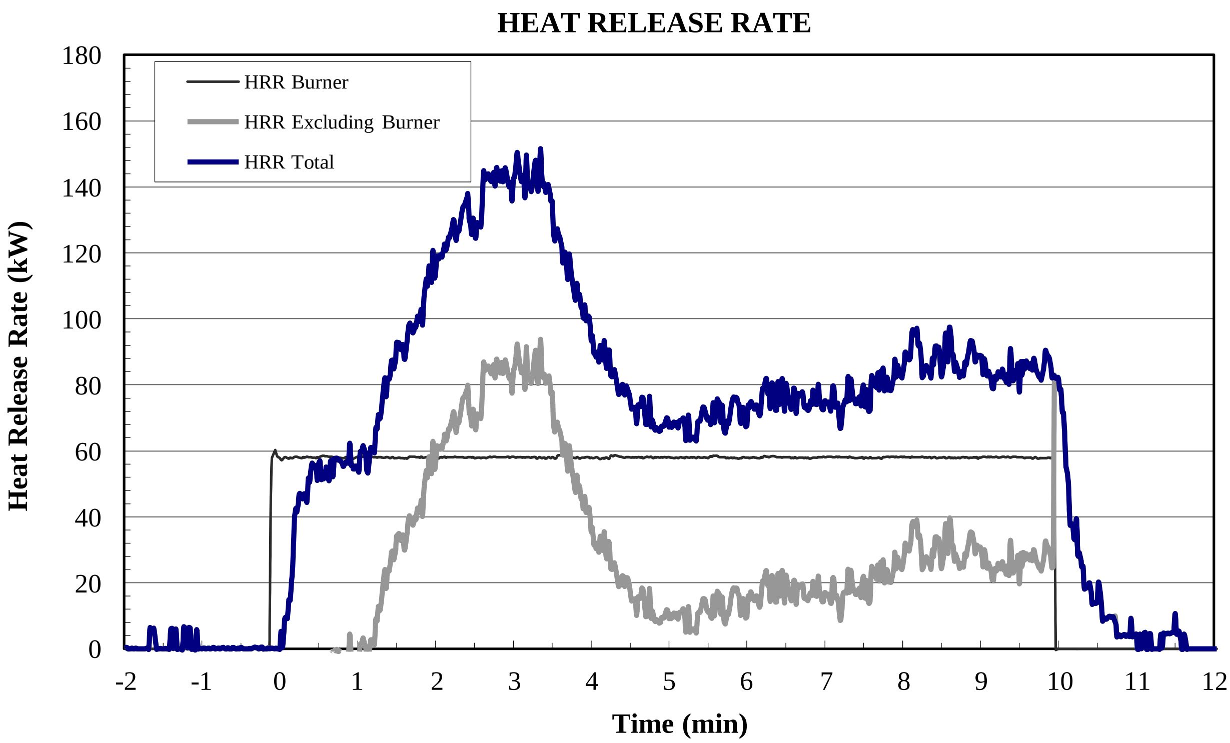
BACKSIDE OF SAMPLE TEMPERATURES
Backside Temperature
Temperature (°C)
Time (min)
200
175
150
125
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12

SUMMARY OF

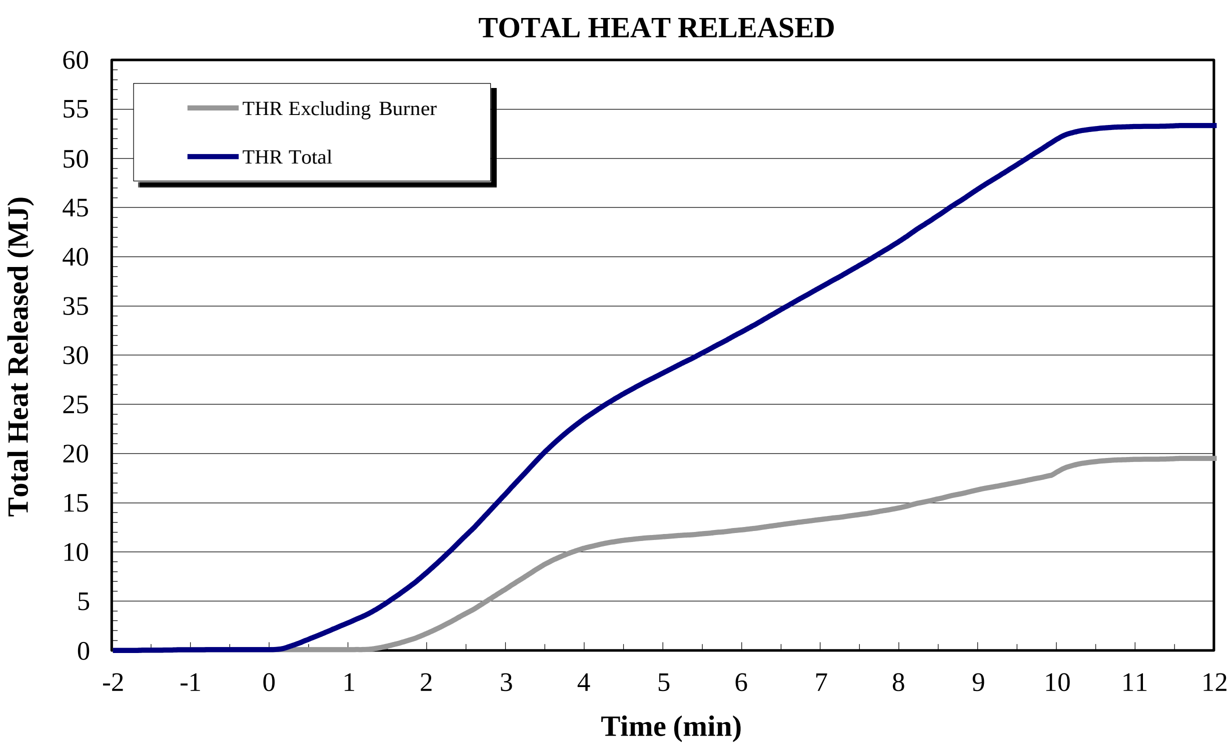
TEST RESULTS

Material: ***GRP - Coated - Run 1***

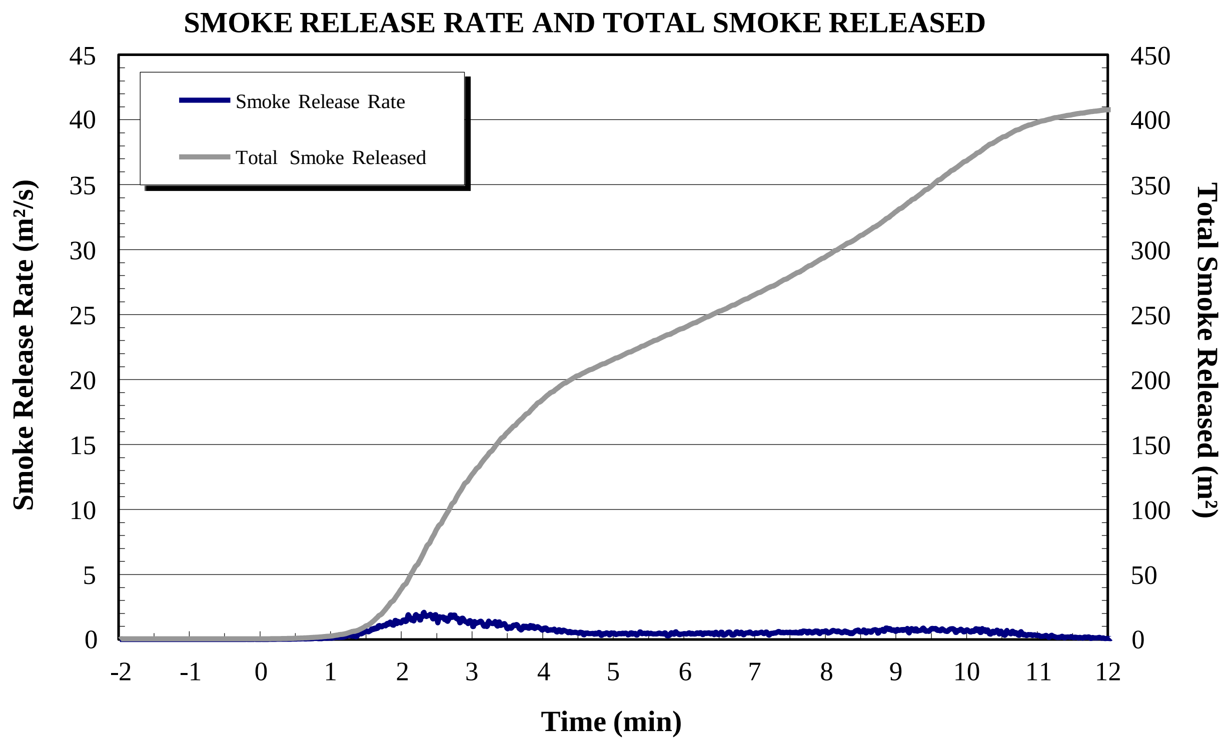
Maximum HRR_{total}	152 kW	at	3 min 21 sec
Average HRR_{total}	89 kW		
Total Heat Released	53 MJ		
Maximum $HRR_{excl.\ burner}$	94 kW	at	3 min 21 sec
Average $HRR_{excl.\ burner}$	33 kW		
Total Heat Released (Excluding Burner)	20 MJ		
Maximum $HRR_{10\ min}$	N/A*		
$HRR_{12\ min}$	N/A*		
Maximum Flame Height	> 2.4 m	at	7 min 0 sec
Heat Flux at 4 ft	45 kW/m²	at	2 min 48 sec
Maximum Smoke Generation $Rate_{0\text{-}10\ min}$	0.24 g/s	at	2 min 19 sec
Smoke Generation $Rate_{12min}$	N/A*		
Total Smoke Generated	39 g		
Maximum Smoke Release Rate	2.07 m²/s	at	2 min 48 sec
Average Smoke Release Rate	0.68 m²/s		
Total Smoke Released	408 m²		
Maximum Optical Density	0.15 1/m	at	2 min 19 sec
Maximum Duct Flow Rate	6.04 m³/s		
Average Optical Density	0.040 1/m		
Average Volumetric Duct Flow Rate	6.00 m³/s		
Total Mass Loss	2.01 kg		
Smoke Yield	0.019		
Maximum Sample Backside Temperature	68°C	at	11 min 59 sec

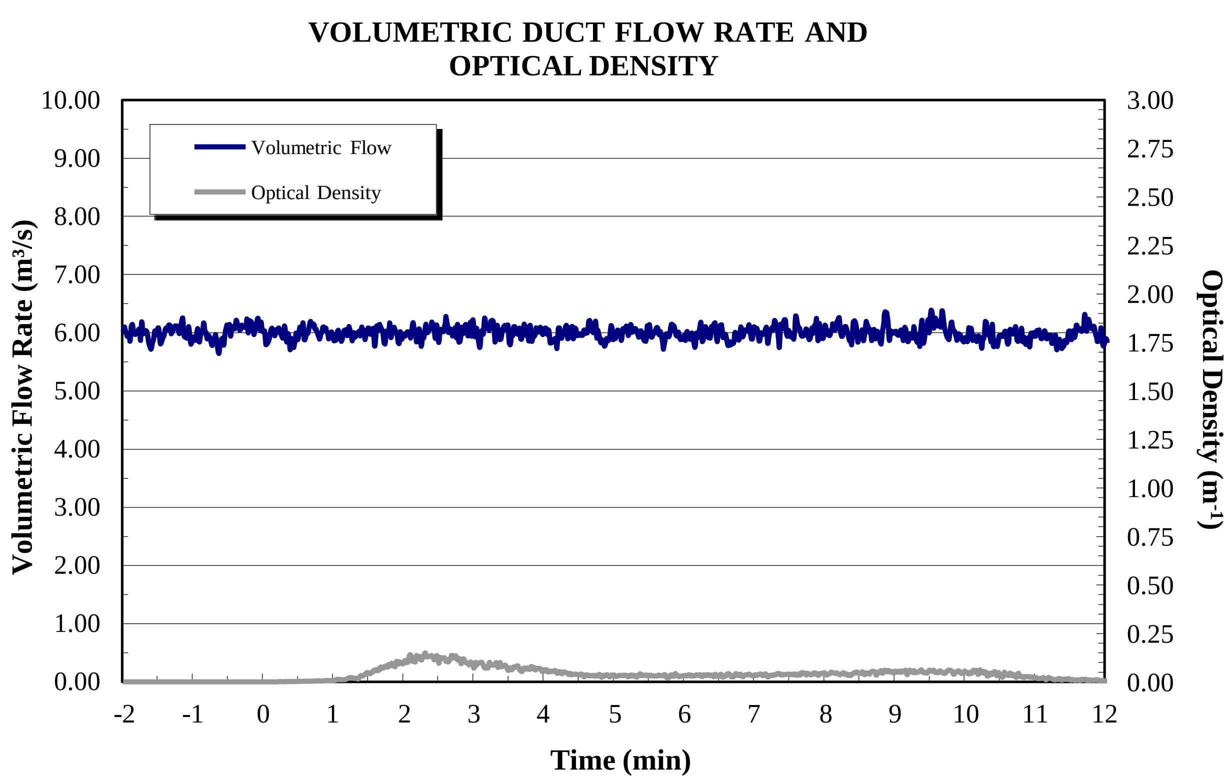


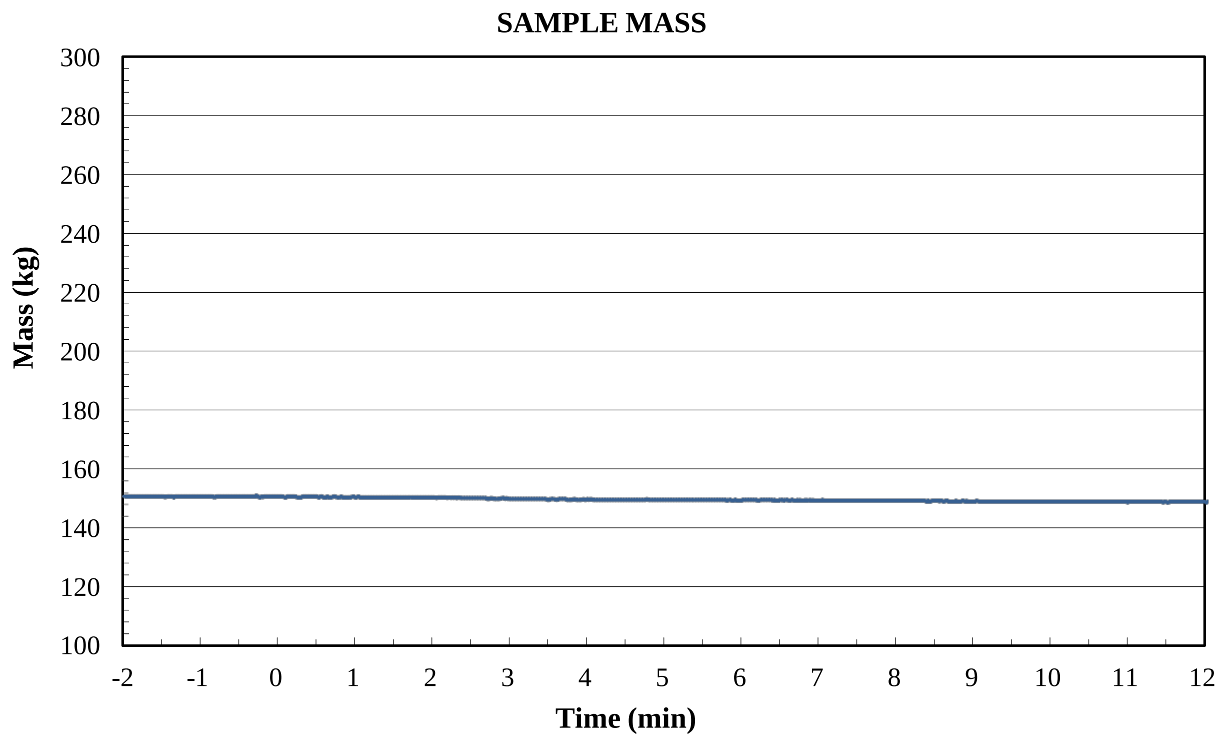
HEAT RELEASE RATE
HRR Burner
HRR Excluding Burner
HRR Total
Heat Release Rate (kW)
180
160
140
120
100
80
60
40
20
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)

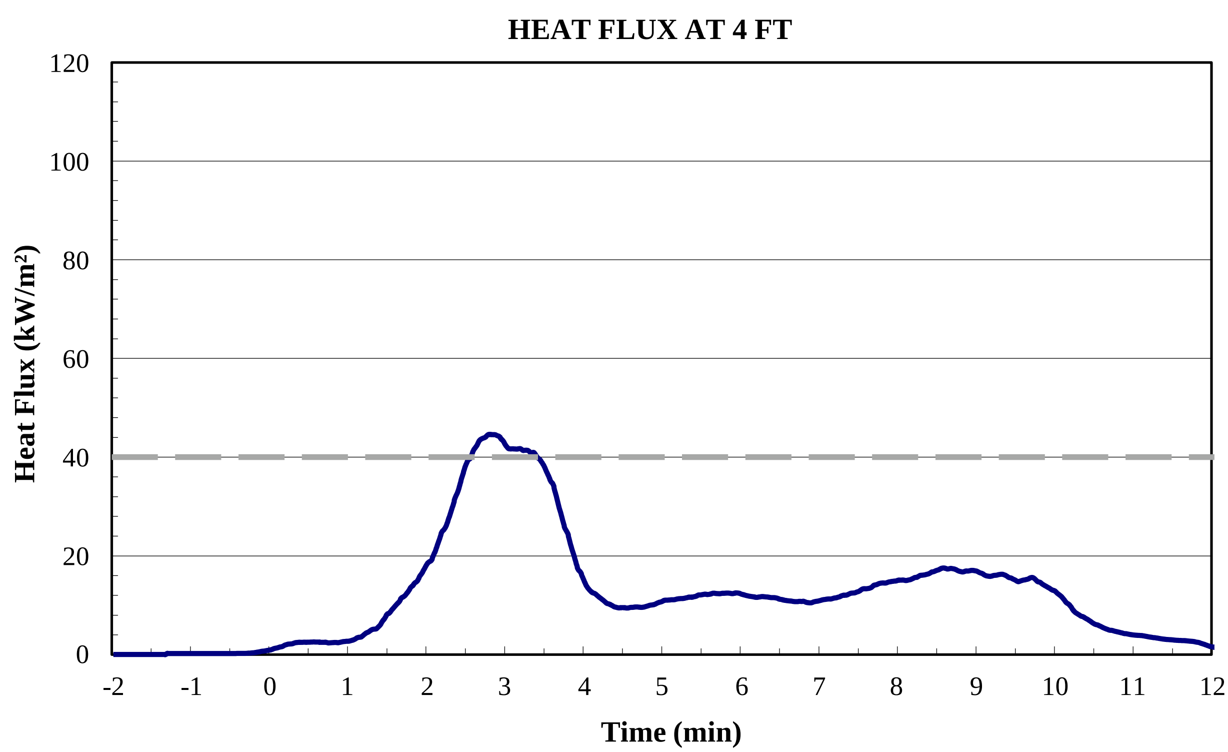


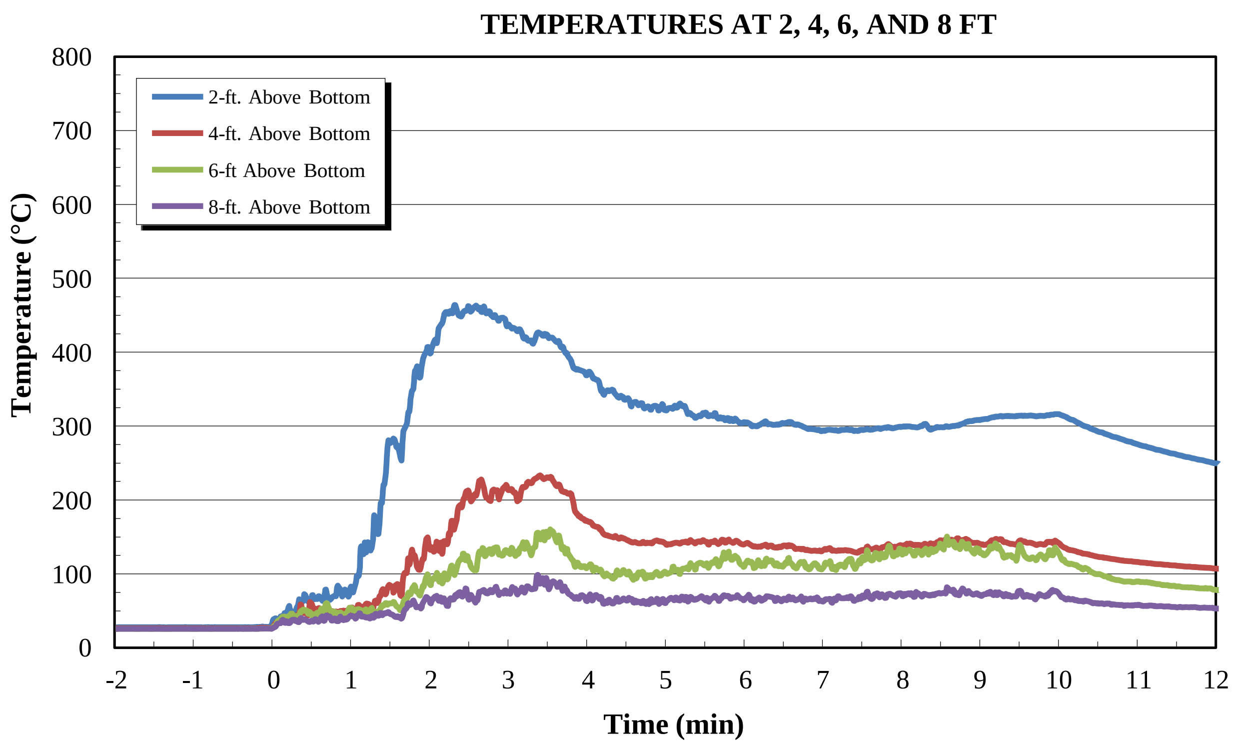
TOTAL HEAT RELEASED
THR Excluding Burner
THR Total
Total Heat Released (MJ)
60
55
50
45
40
35
30
25
20
15
10
5
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)


SMOKE RELEASE RATE AND TOTAL SMOKE RELEASED
Smoke Release Rate
Total Smoke Released
Smoke Release Rate (m²/s)
Total Smoke Released (m²)
Time (min)
45
40
35
30
25
20
15
10
5
0
450
400
350
300
250
200
150
100
50
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12

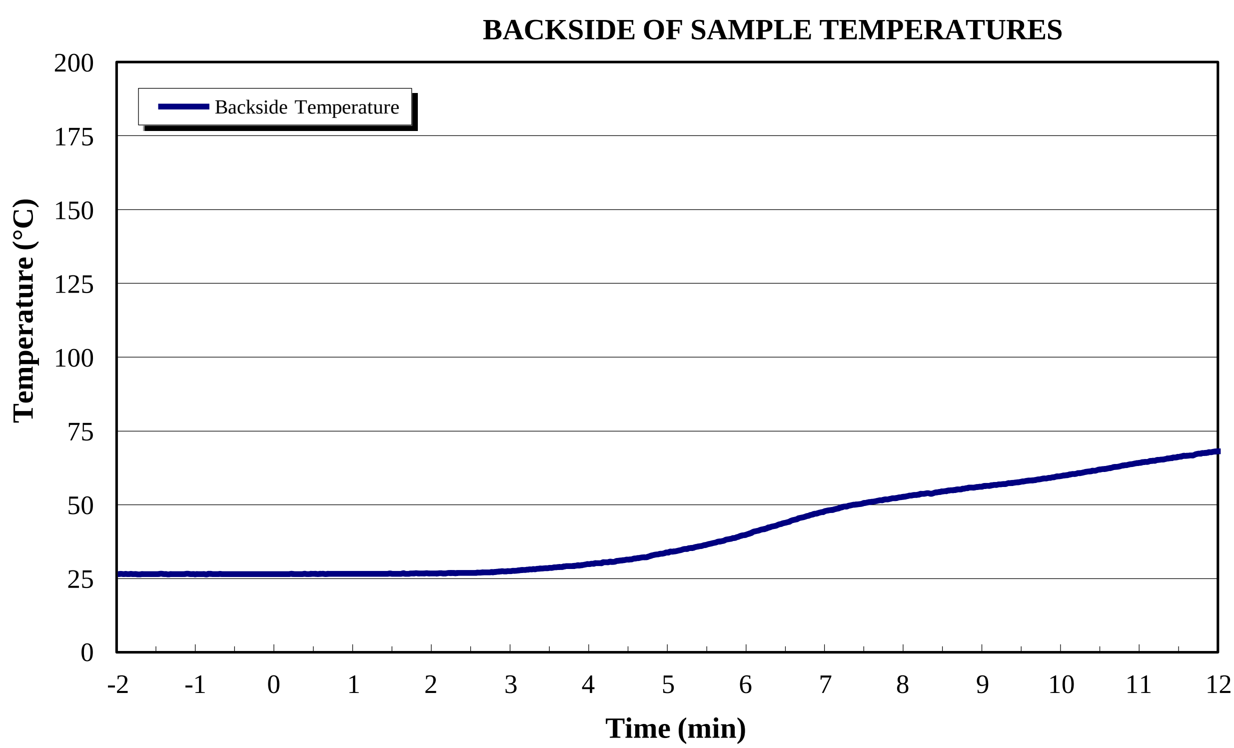

VOLUMETRIC DUCT FLOW RATE AND
OPTICAL DENSITY
Volumetric Flow
Optical Density
Volumetric Flow Rate (m³/s)
Optical Density (m⁻¹)
Time (min)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12


SAMPLE MASS
Mass (kg)
300
280
260
240
220
200
180
160
140
120
100
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)


HEAT FLUX AT 4 FT
Heat Flux (kW/m²)
120
100
80
60
40
20
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)



TEMPERATURES AT 2, 4, 6, AND 8 FT
2-ft. Above Bottom
4-ft. Above Bottom
6-ft Above Bottom
8-ft. Above Bottom
Temperature (°C)
800
700
600
500
400
300
200
100
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)



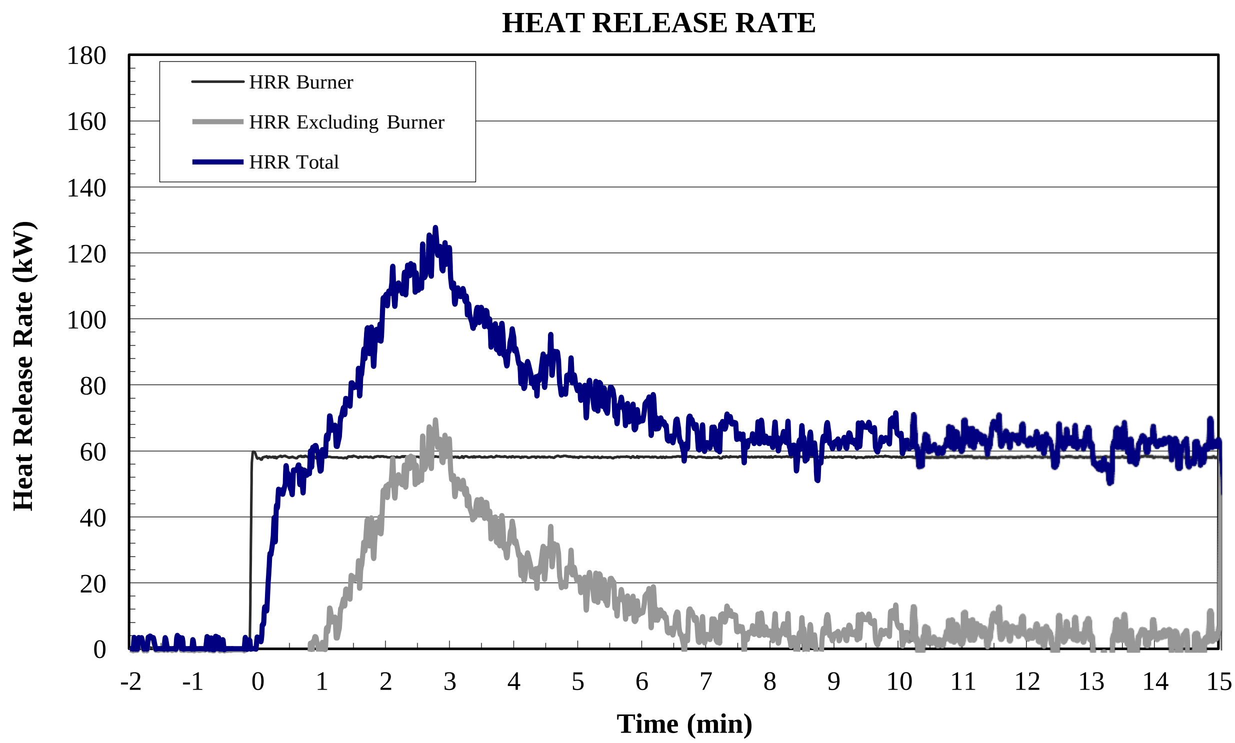
BACKSIDE OF SAMPLE TEMPERATURES
Backside Temperature
Temperature (°C)
200
175
150
125
100
75
50
25
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)

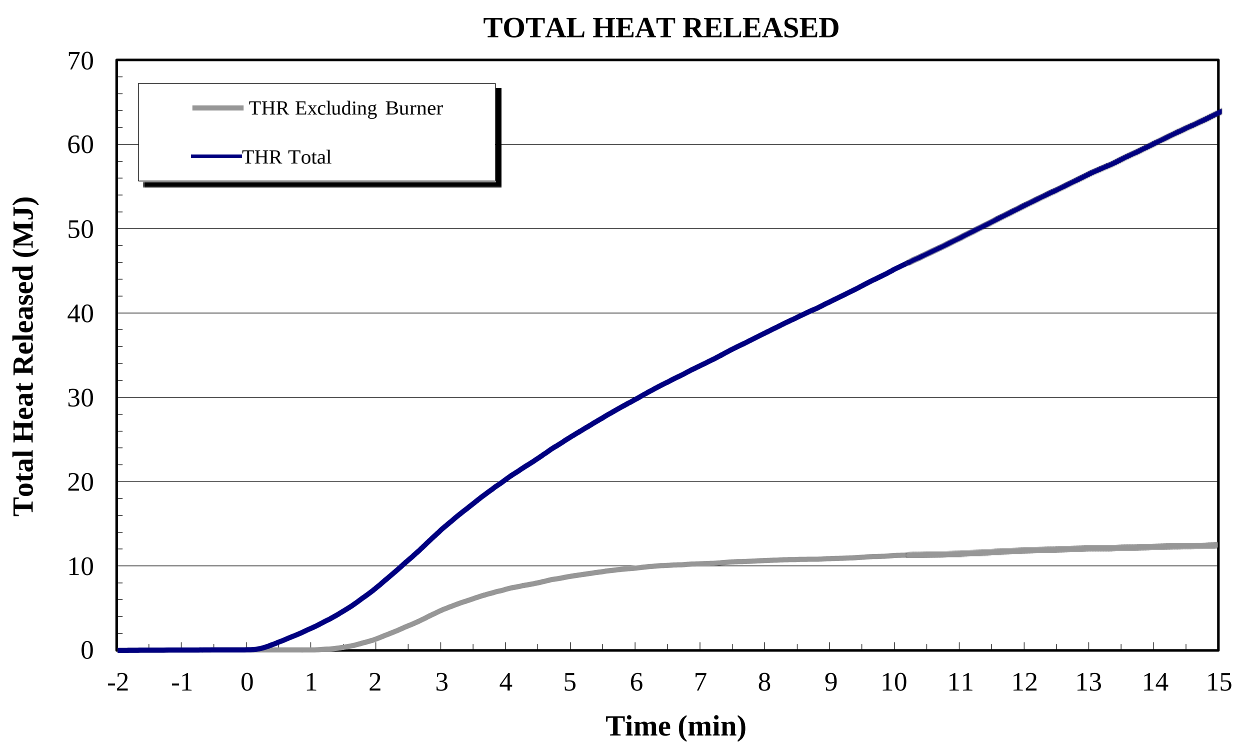
SUMMARY OF

TEST RESULTS

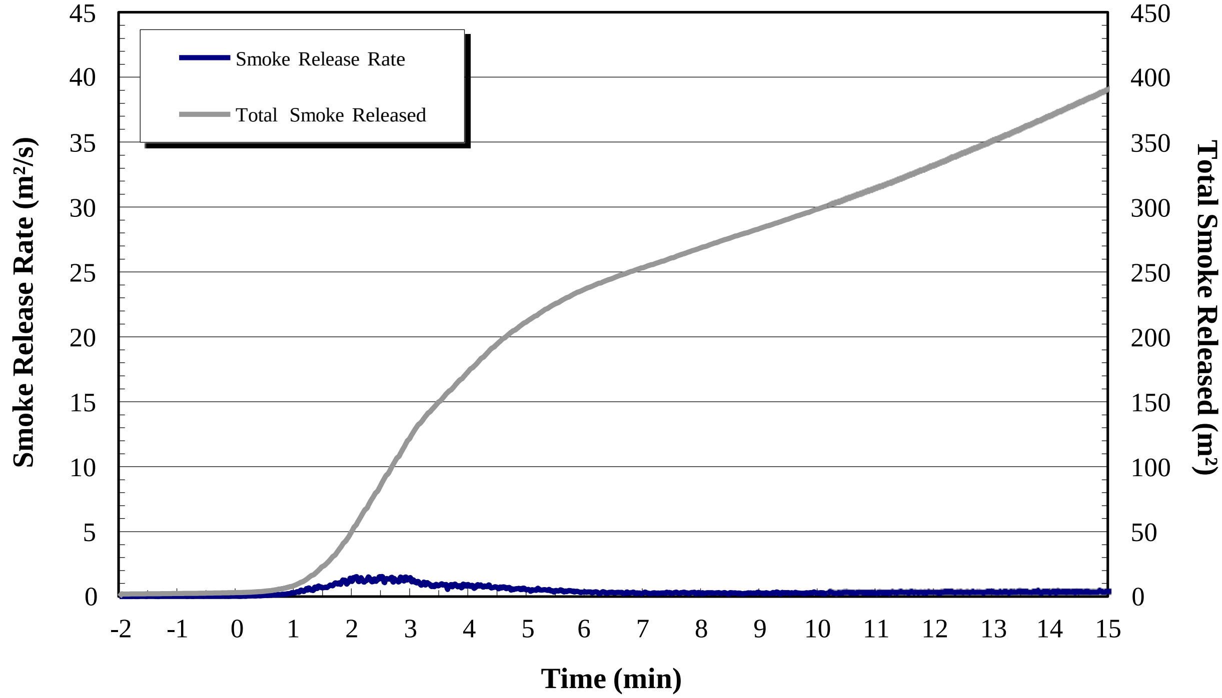
Material: ***GRP - Coated - Run 2***

Maximum HRR_{total}	128 kW	at	2 min 47 sec
Average HRR_{total}	97 kW		
Total Heat Released	58 MJ		
Maximum $HRR_{excl.\ burner}$	69 kW	at	2 min 47 sec
Average $HRR_{excl.\ burner}$	20 kW		
Total Heat Released (Excluding Burner)	12 MJ		
Maximum $HRR_{10\ min}$	N/A*		
$HRR_{12\ min}$	N/A*		
Maximum Flame Height	> 2.4 m	at	7 min 0 sec
Heat Flux at 4 ft	36 kW/m^2	at	2 min 46 sec
Maximum Smoke Generation $Rate_{0\text{-}10\ min}$	0.18 g/s	at	2 min 32 sec
Smoke Generation $Rate_{12min}$	N/A*		
Total Smoke Generated	34 g		
Maximum Smoke Release Rate	1.55 m^2/s	at	2 min 46 sec
Average Smoke Release Rate	0.60 m^2/s		
Total Smoke Released	360 m^2		
Maximum Optical Density	0.11 1/m	at	2 min 5 sec
Maximum Duct Flow Rate	5.95 m^3/s		
Average Optical Density	0.032 1/m		
Average Volumetric Duct Flow Rate	5.99 m^3/s		
Total Mass Loss	1.44 kg		
Smoke Yield	0.024		
Maximum Sample Backside Temperature	62°C	at	15 min 0 sec

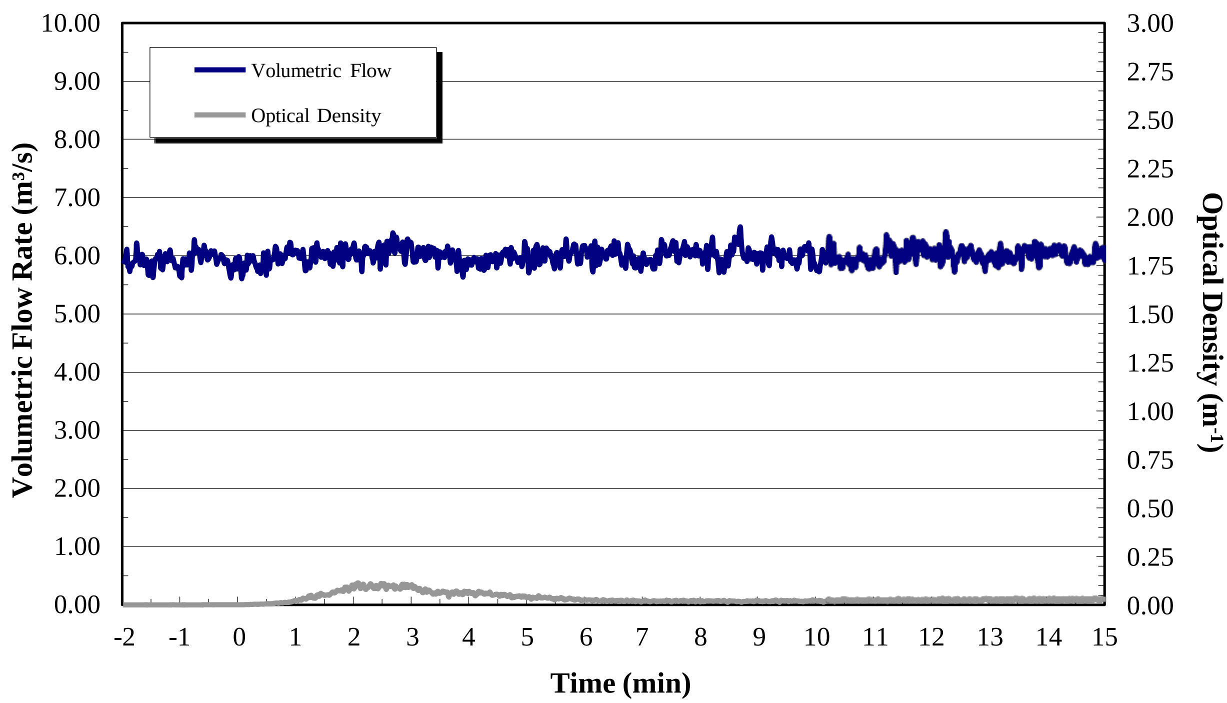

HEAT RELEASE RATE
HRR Burner
HRR Excluding Burner
HRR Total
Heat Release Rate (kW)
Time (min)
180
160
140
120
100
80
60
40
20
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

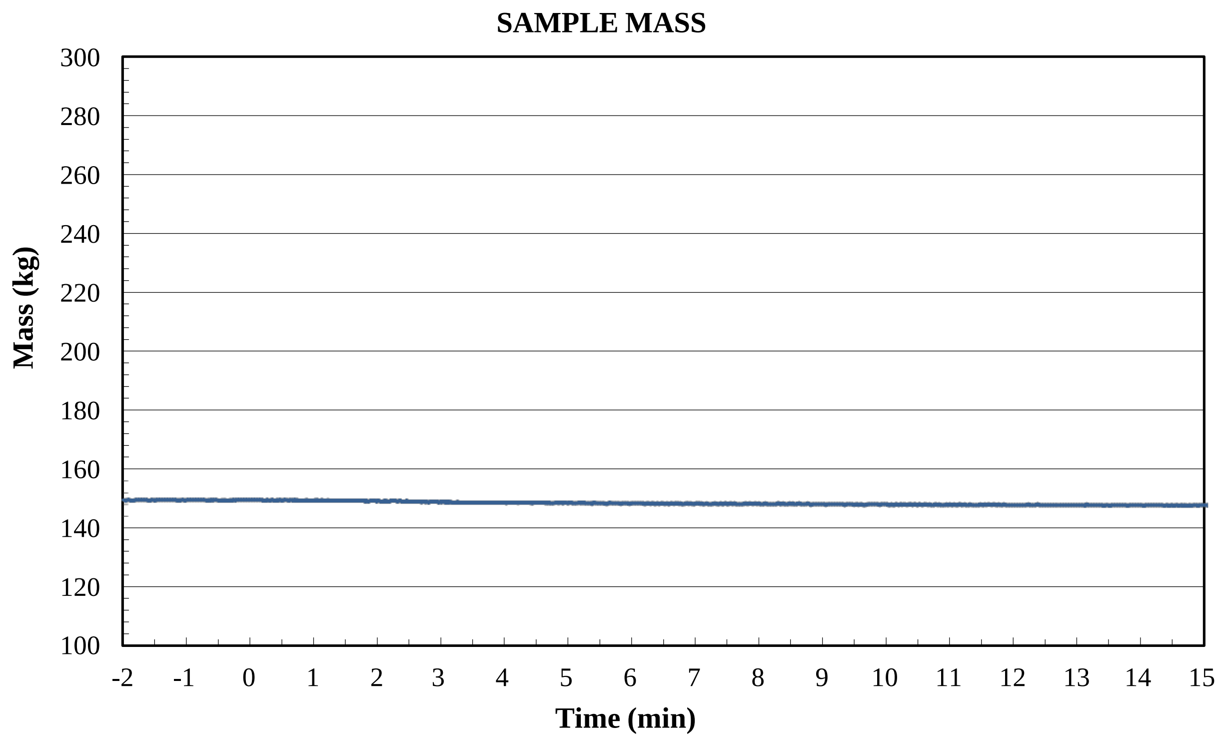

TOTAL HEAT RELEASED
THR Excluding Burner
THR Total
Total Heat Released (MJ)
Time (min)
70
60
50
40
30
20
10
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

SMOKE RELEASE RATE AND TOTAL SMOKE RELEASED

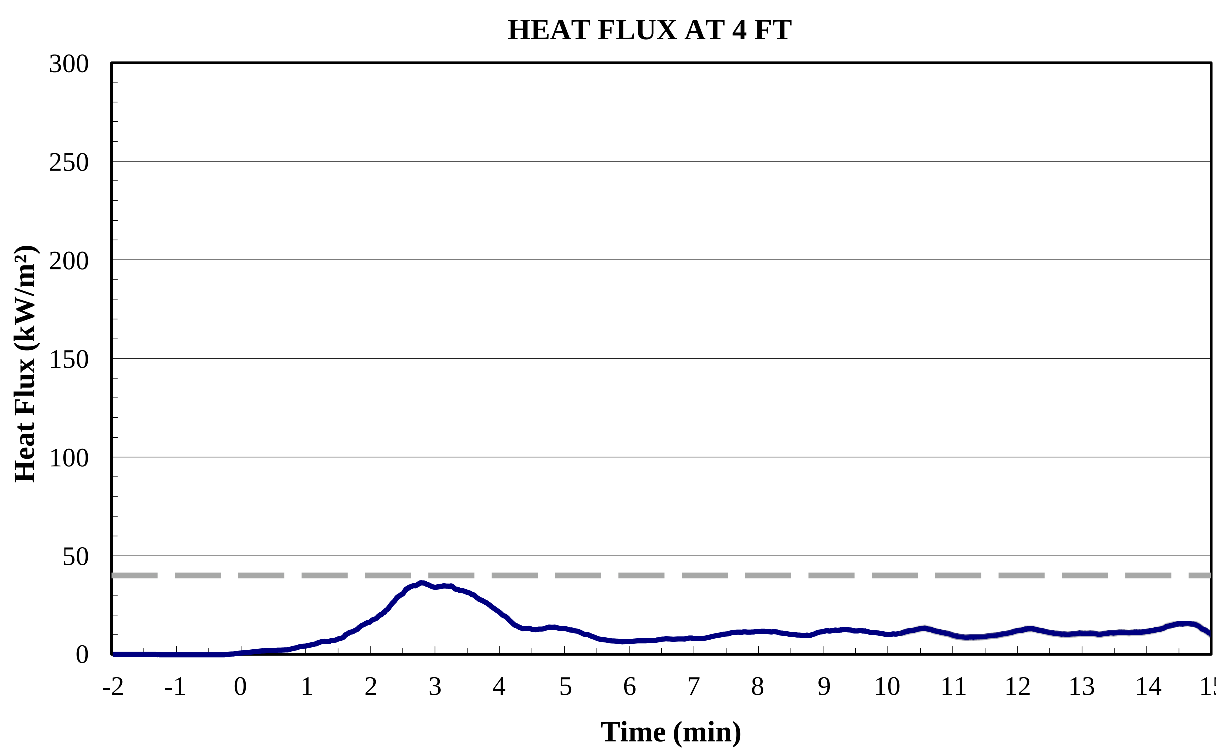


VOLUMETRIC DUCT FLOW RATE AND OPTICAL DENSITY

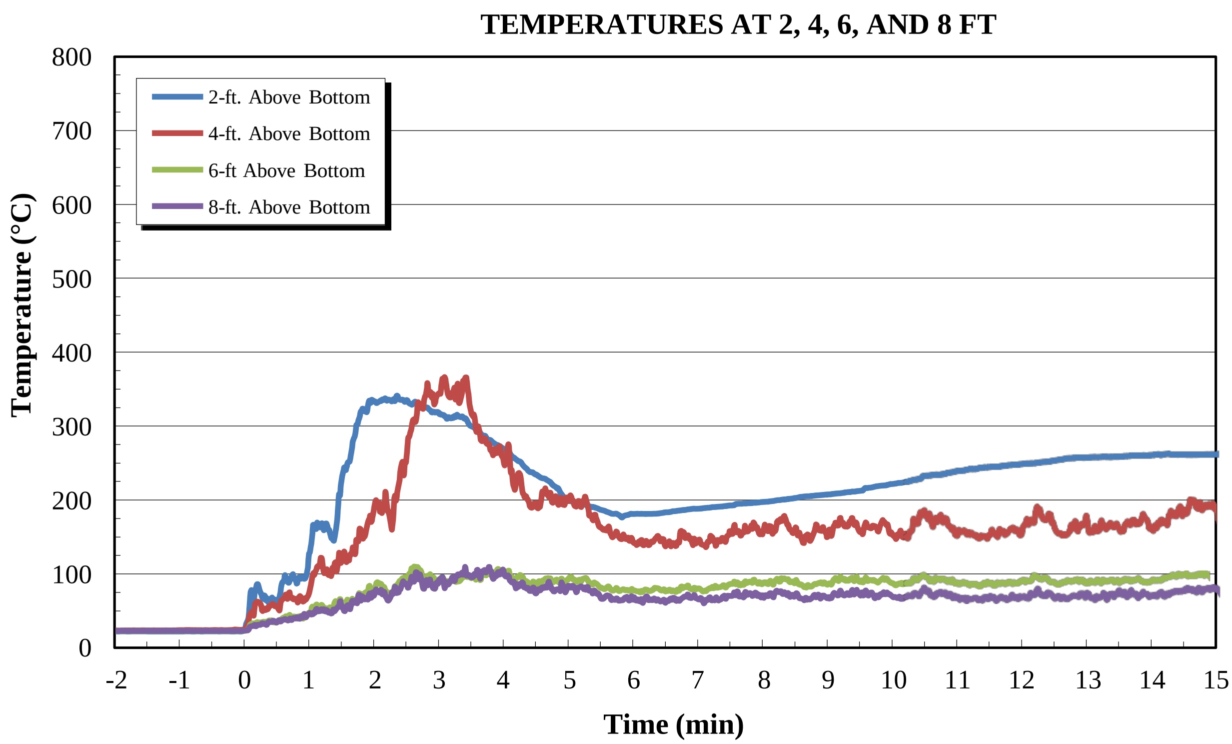


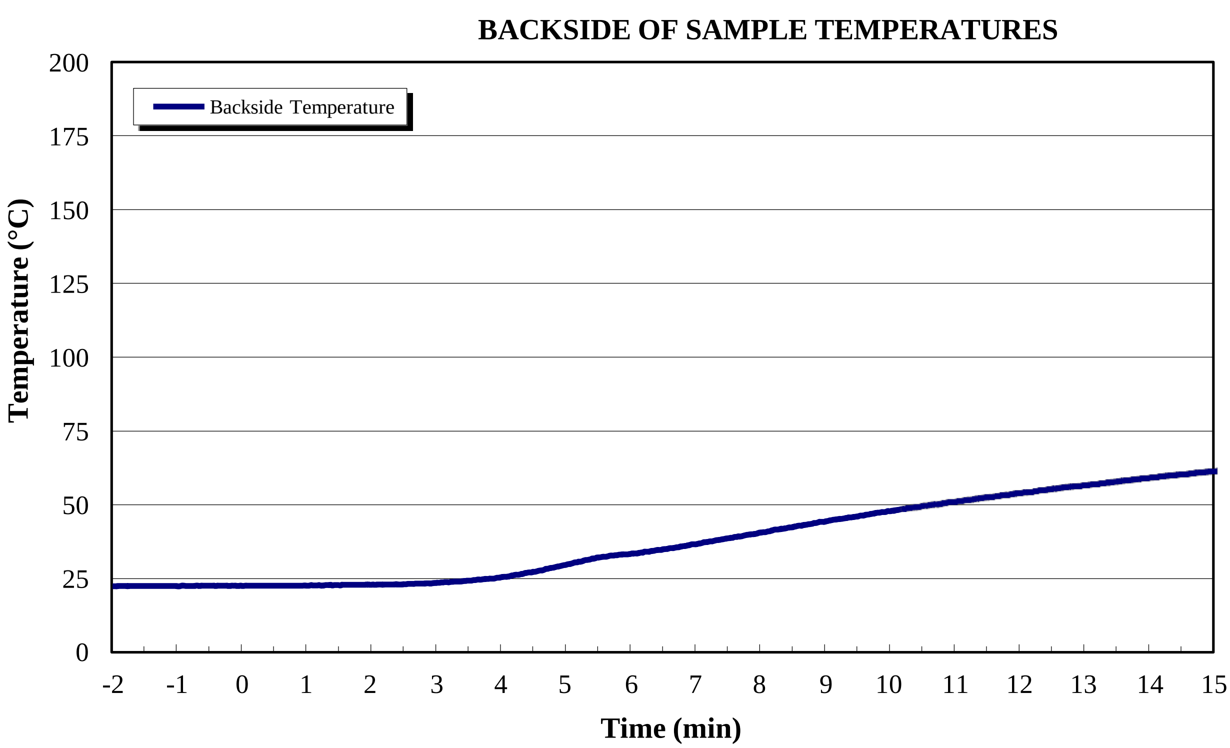


SAMPLE MASS
Mass (kg)
300
280
260
240
220
200
180
160
140
120
100
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Time (min)



HEAT FLUX AT 4 FT
Heat Flux (kW/m²)
300
250
200
150
100
50
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Time (min)


TEMPERATURES AT 2, 4, 6, AND 8 FT
2-ft. Above Bottom
4-ft. Above Bottom
6-ft Above Bottom
8-ft. Above Bottom
Temperature (°C)
Time (min)
0
100
200
300
400
500
600
700
800
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

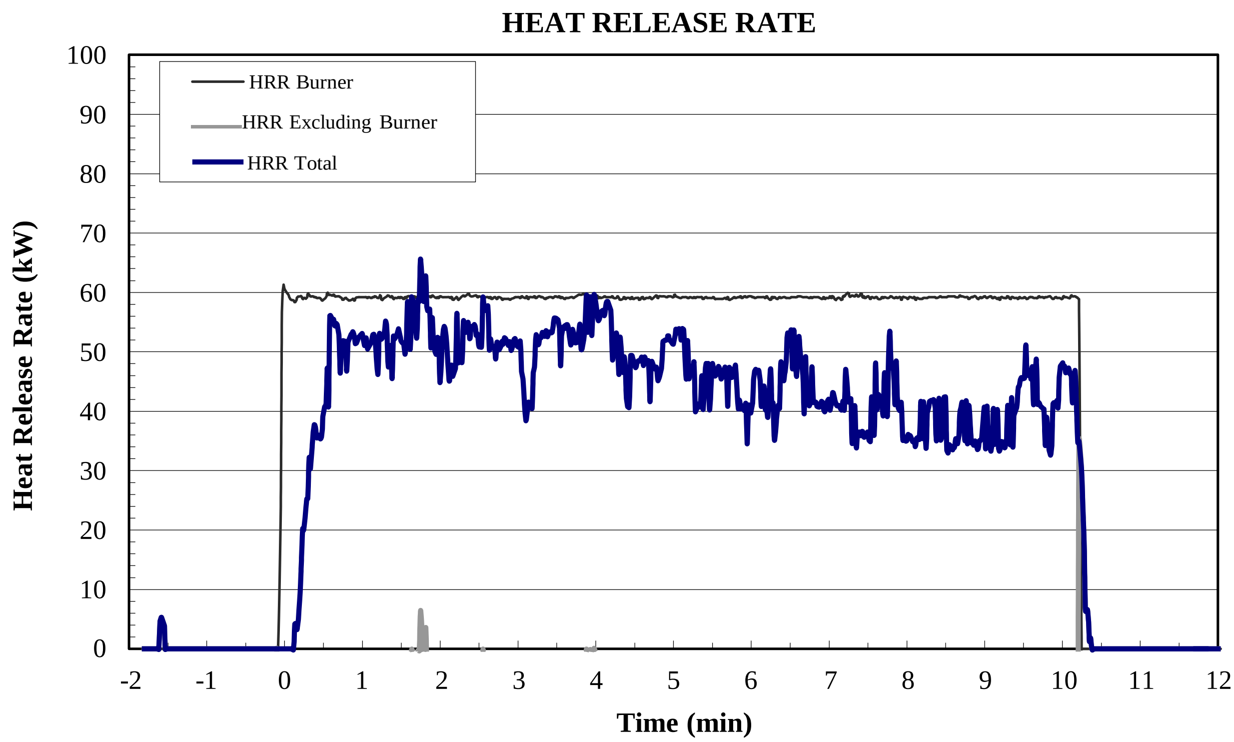

BACKSIDE OF SAMPLE TEMPERATURES
Backside Temperature
Temperature (°C)
Time (min)
0
25
50
75
100
125
150
175
200
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

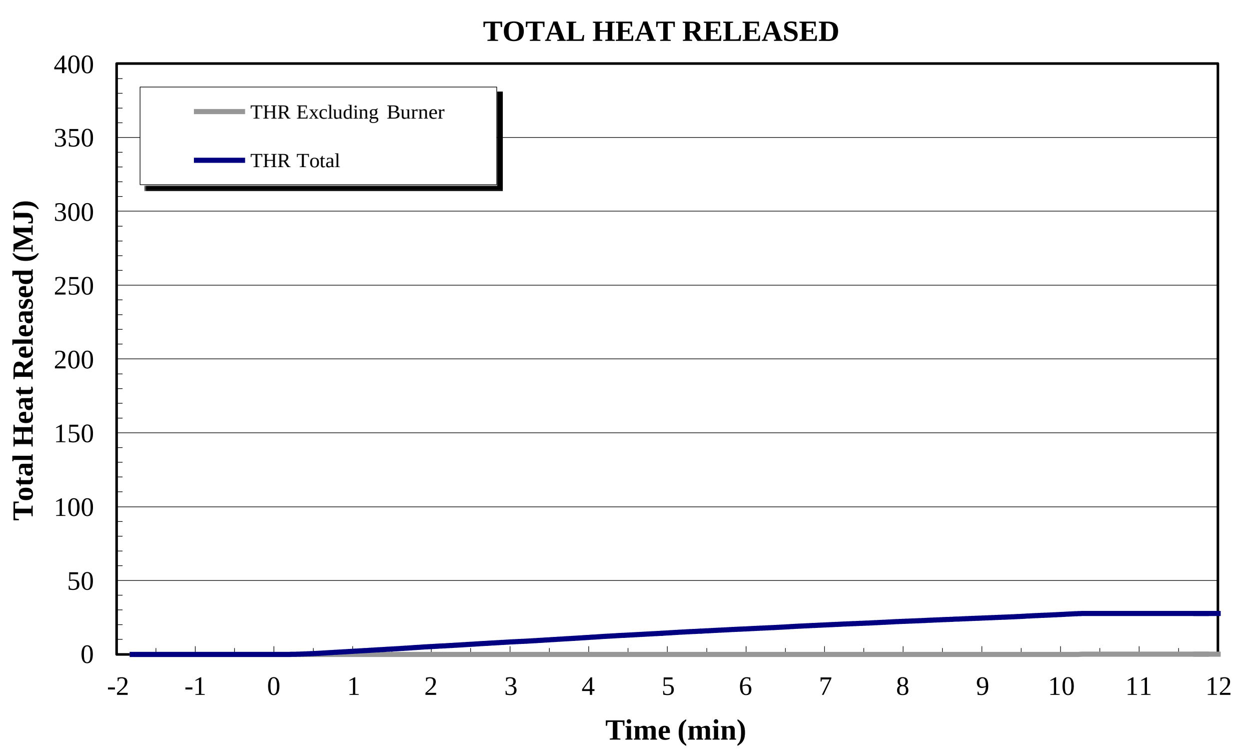
SUMMARY OF

TEST RESULTS

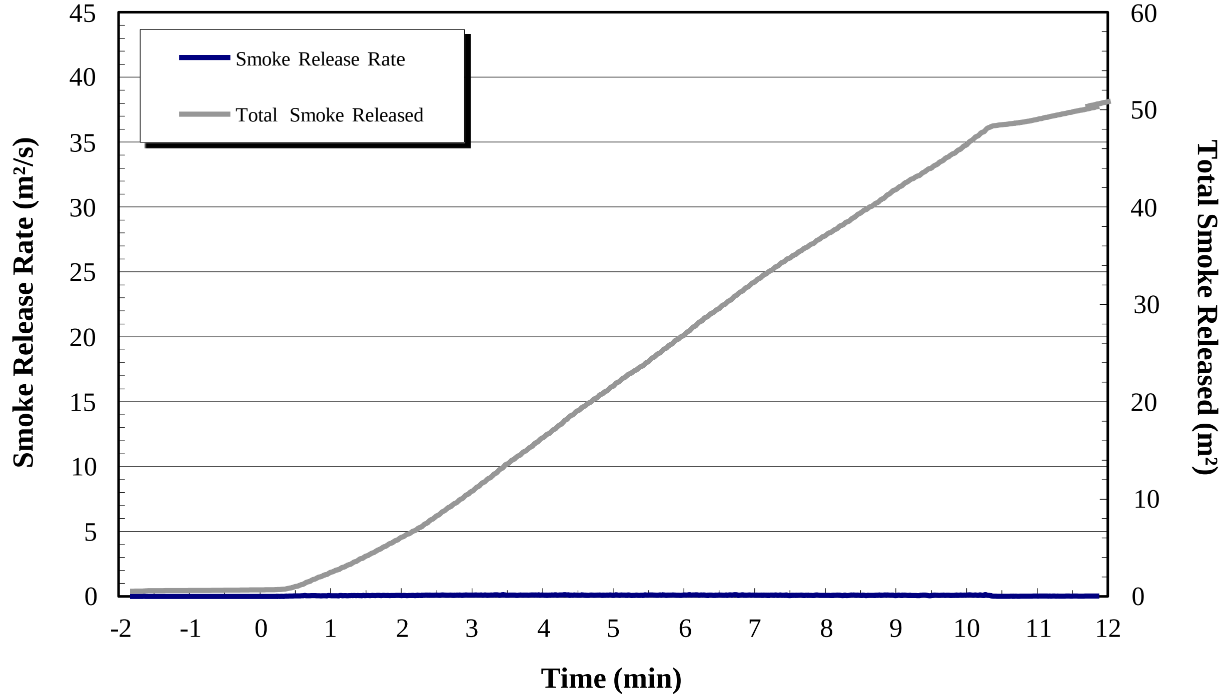
Material: ***Steel - Uncoated - Run 1***

Maximum HRR_{total}	66 kW	at	1 min 35 sec
Average HRR_{total}	46 kW		
Total Heat Released	28 MJ		
Maximum $HRR_{excl.\ burner}$	35 kW	at	10 min 3 sec
Average $HRR_{excl.\ burner}$	0 kW		
Total Heat Released (Excluding Burner)	0 MJ		
Maximum $HRR_{10\ min}$	N/A*		
$HRR_{12\ min}$	N/A*		
Maximum Flame Height	> 2.4 m	at	7 min 0 sec
Heat Flux at 4 ft	5 kW/m²	at	3 min 44 sec
Maximum Smoke Generation $Rate_{0\text{-}10\ min}$	0.02 g/s	at	5 min 55 sec
Smoke Generation $Rate_{12min}$	N/A*		
Total Smoke Generated	6 g		
Maximum Smoke Release Rate	0.15 m²/s	at	3 min 44 sec
Average Smoke Release Rate	0.08 m²/s		
Total Smoke Released	51 m²		
Maximum Optical Density	0.01 1/m	at	10 min 6 sec
Maximum Duct Flow Rate	6.37 m³/s		
Average Optical Density	0.005 1/m		
Average Volumetric Duct Flow Rate	6.45 m³/s		
Total Mass Loss	2.17 kg		
Smoke Yield	0.003		
Maximum Sample Backside Temperature	49°C	at	12 min 3 sec

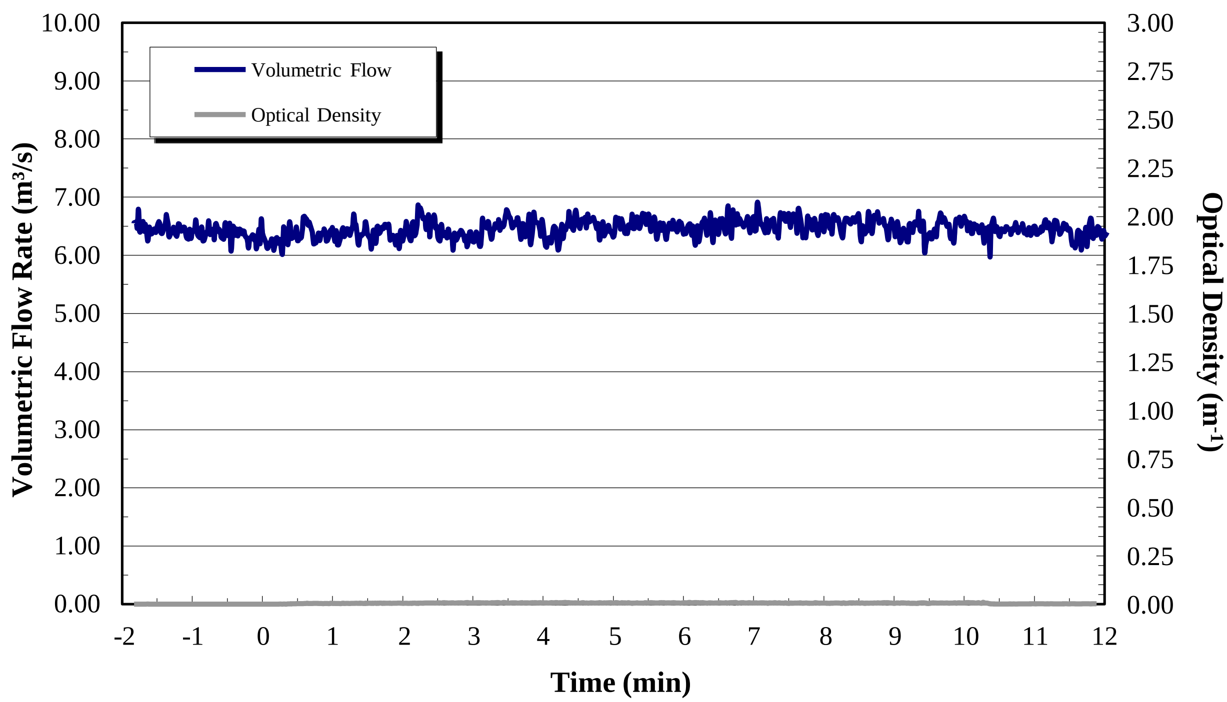

HEAT RELEASE RATE
HRR Burner
HRR Excluding Burner
HRR Total
Heat Release Rate (kW)
Time (min)
100
90
80
70
60
50
40
30
20
10
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12


TOTAL HEAT RELEASED
THR Excluding Burner
THR Total
Total Heat Released (MJ)
Time (min)
400
350
300
250
200
150
100
50
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12

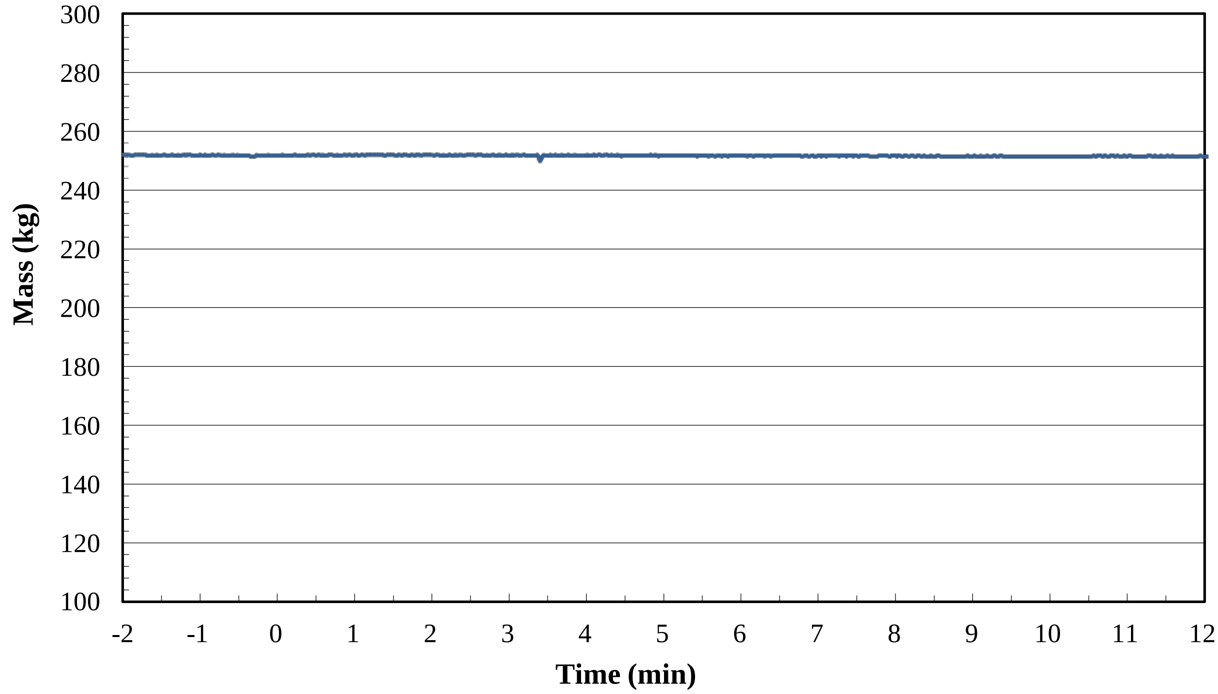
SMOKE RELEASE RATE AND TOTAL SMOKE RELEASED



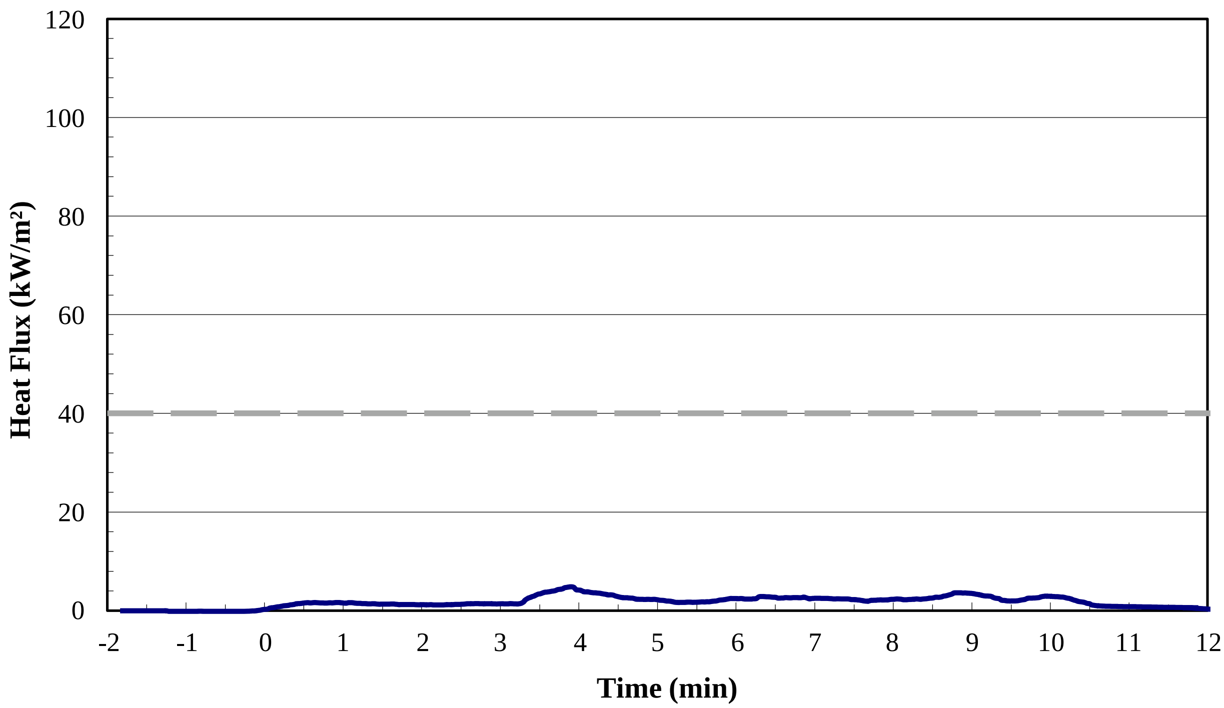
VOLUMETRIC DUCT FLOW RATE AND OPTICAL DENSITY

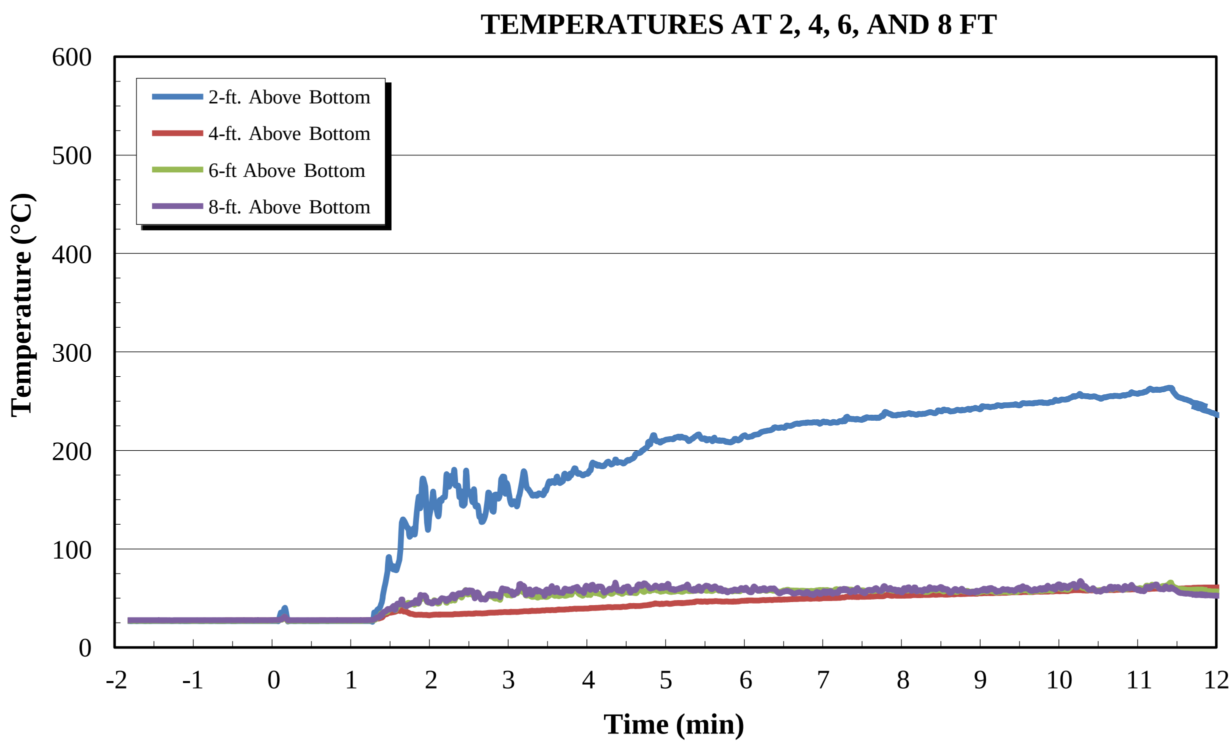


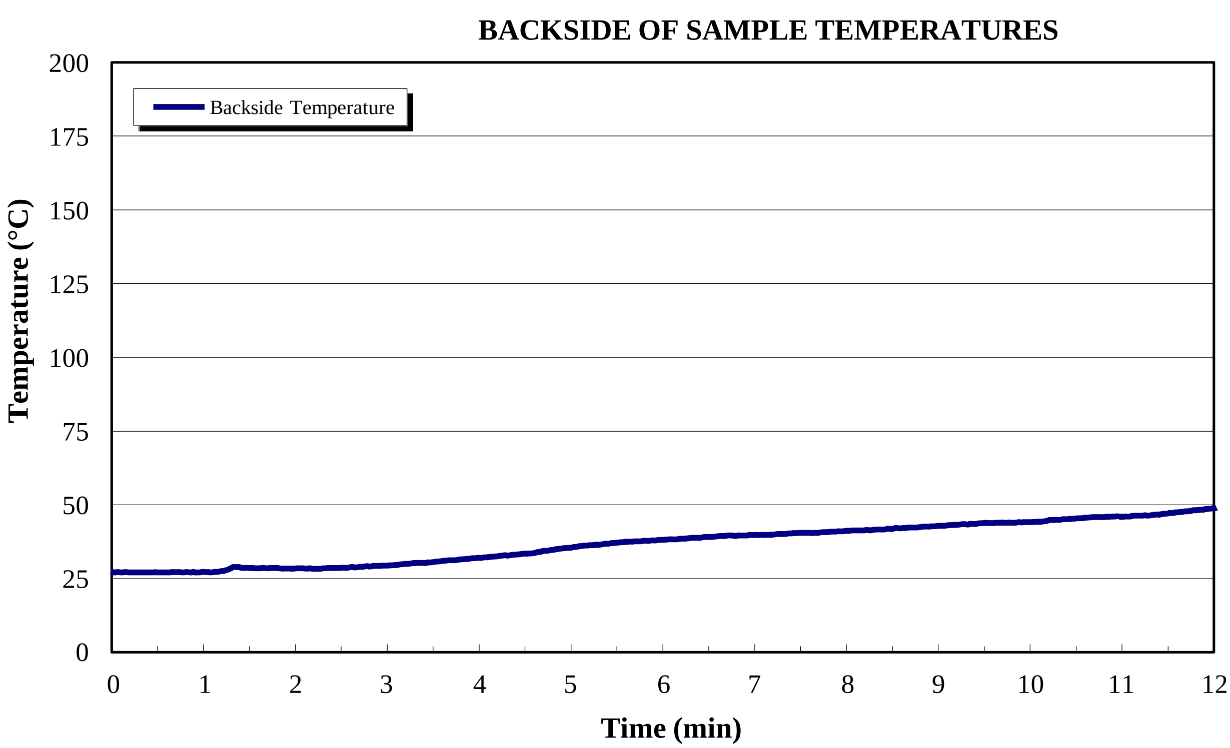
SAMPLE MASS



HEAT FLUX AT 4 FT




TEMPERATURES AT 2, 4, 6, AND 8 FT
2-ft. Above Bottom
4-ft. Above Bottom
6-ft Above Bottom
8-ft. Above Bottom
Temperature (°C)
600
500
400
300
200
100
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)

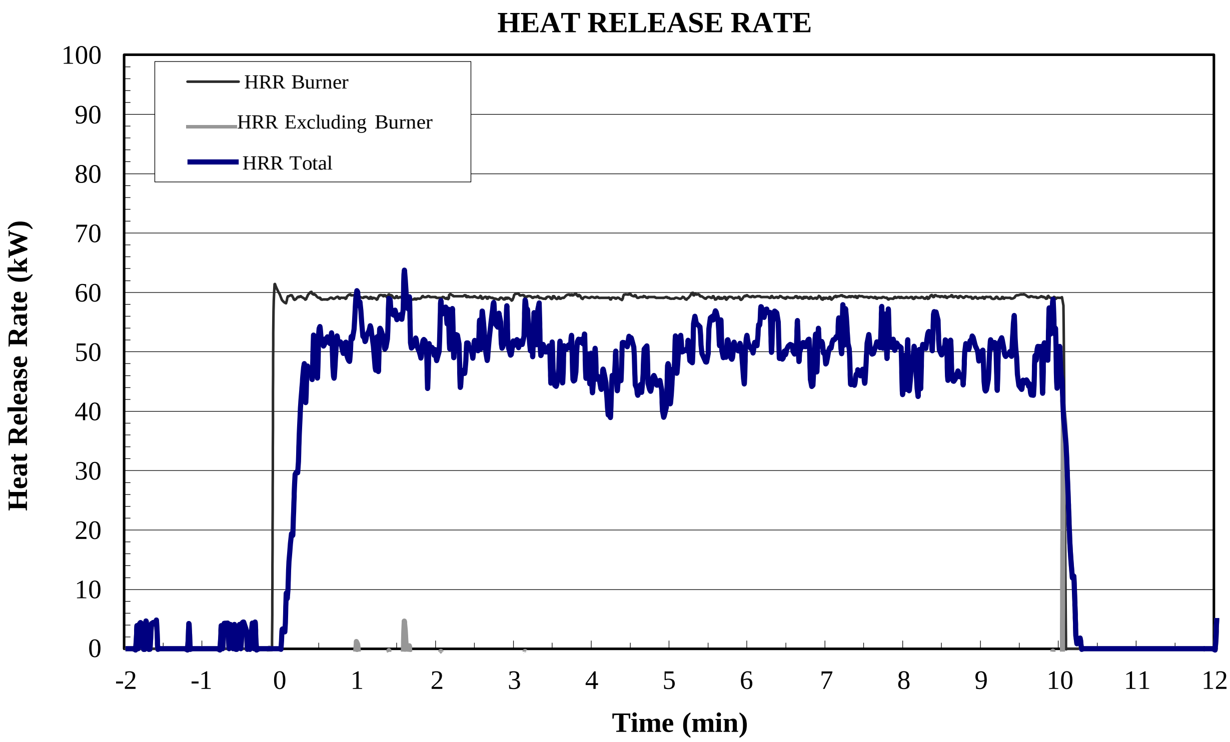

BACKSIDE OF SAMPLE TEMPERATURES
Backside Temperature
Temperature (°C)
200
175
150
125
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)

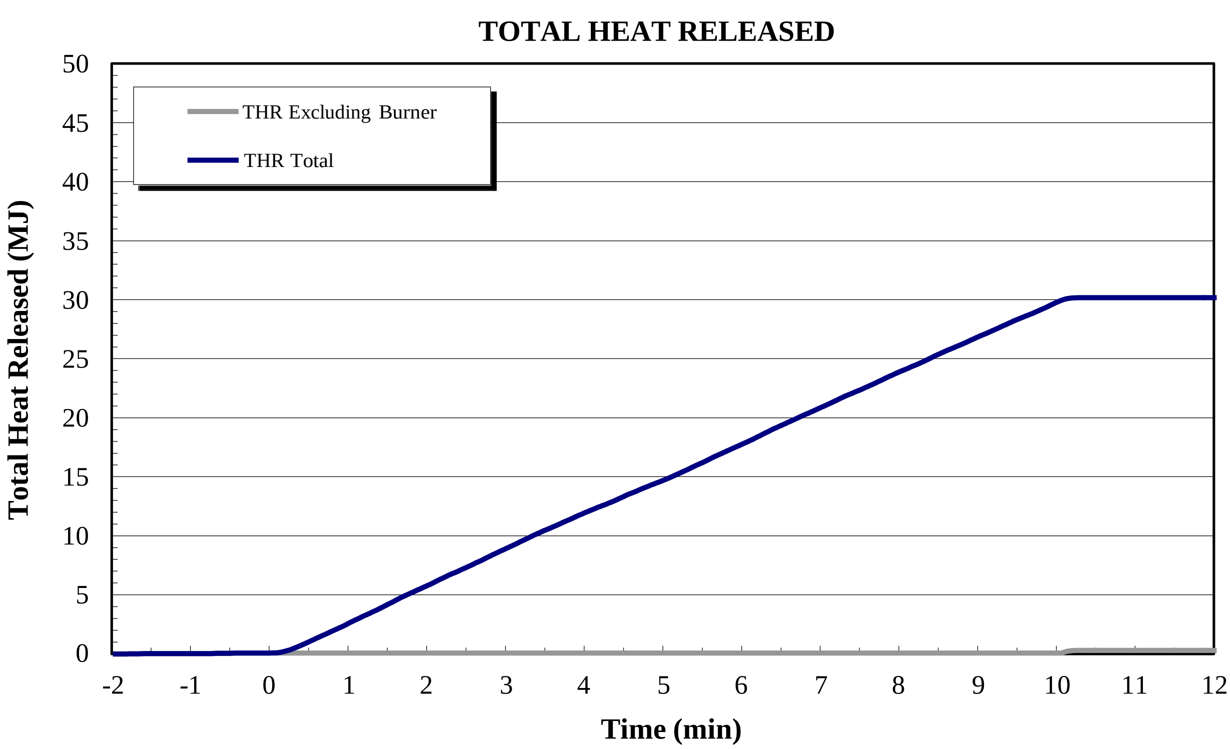
SUMMARY OF

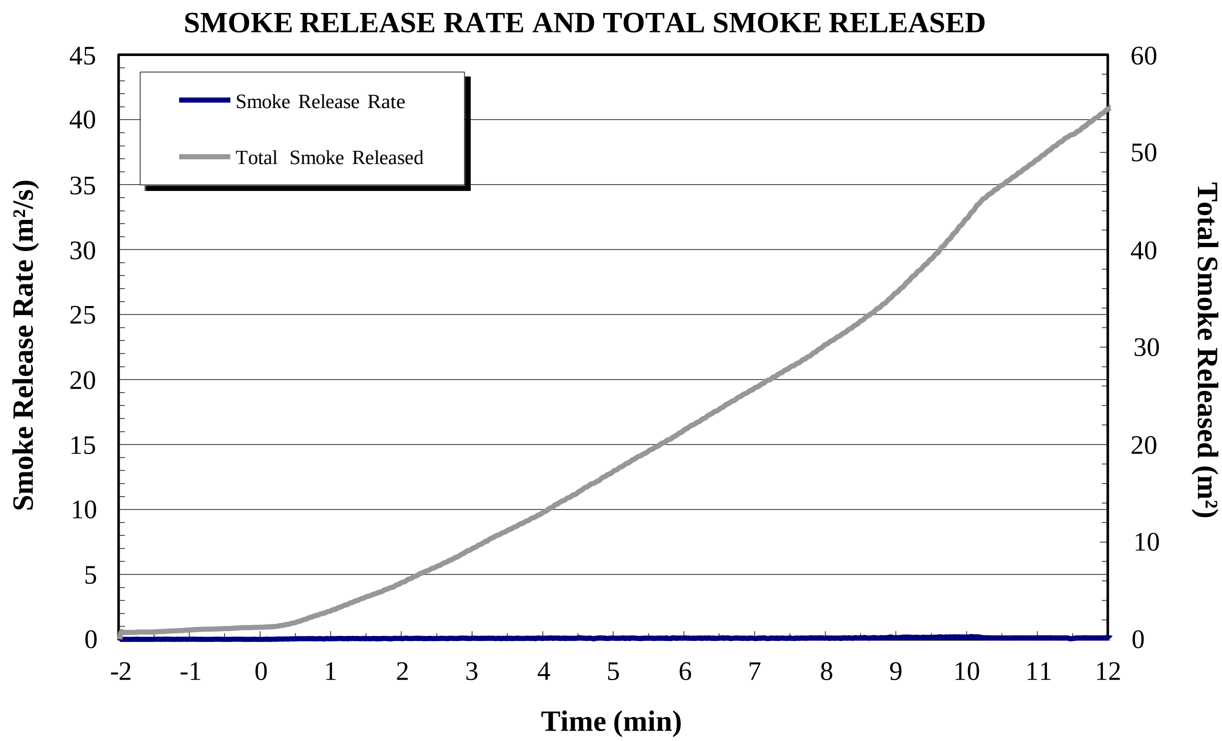
TEST RESULTS

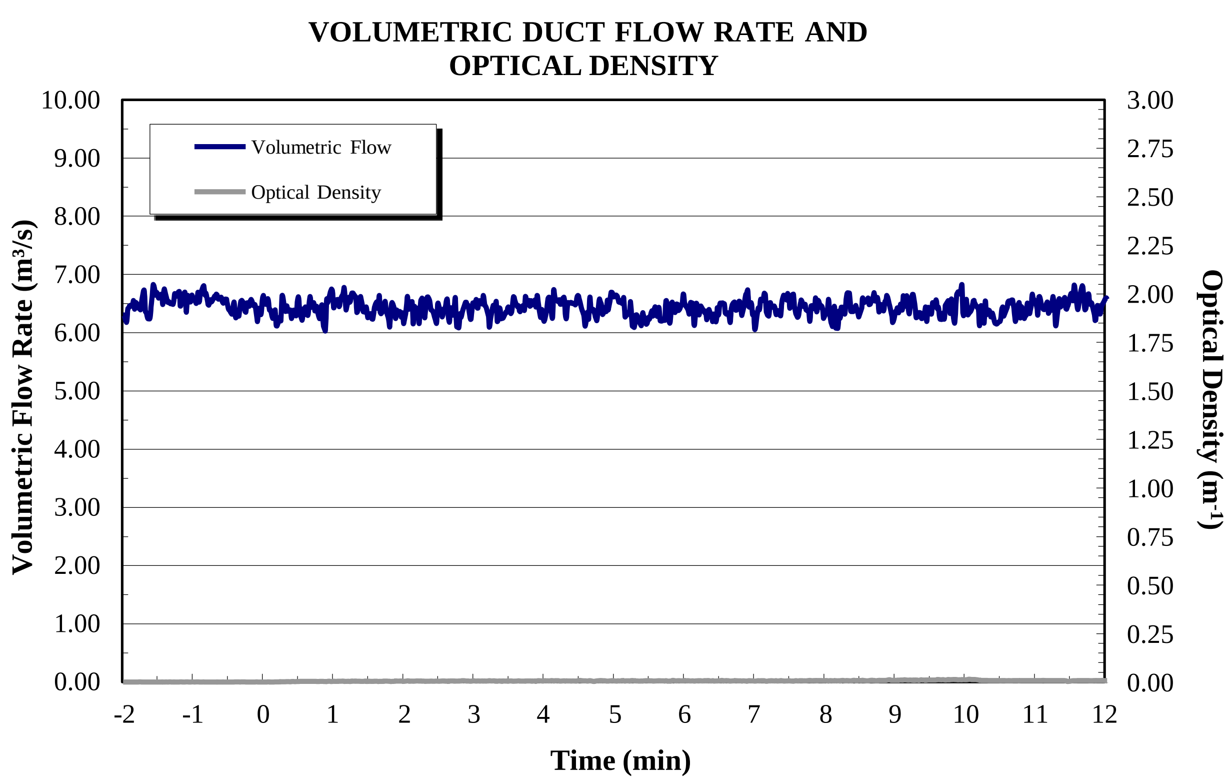
Material: ***Steel - Uncoated - Run 2***

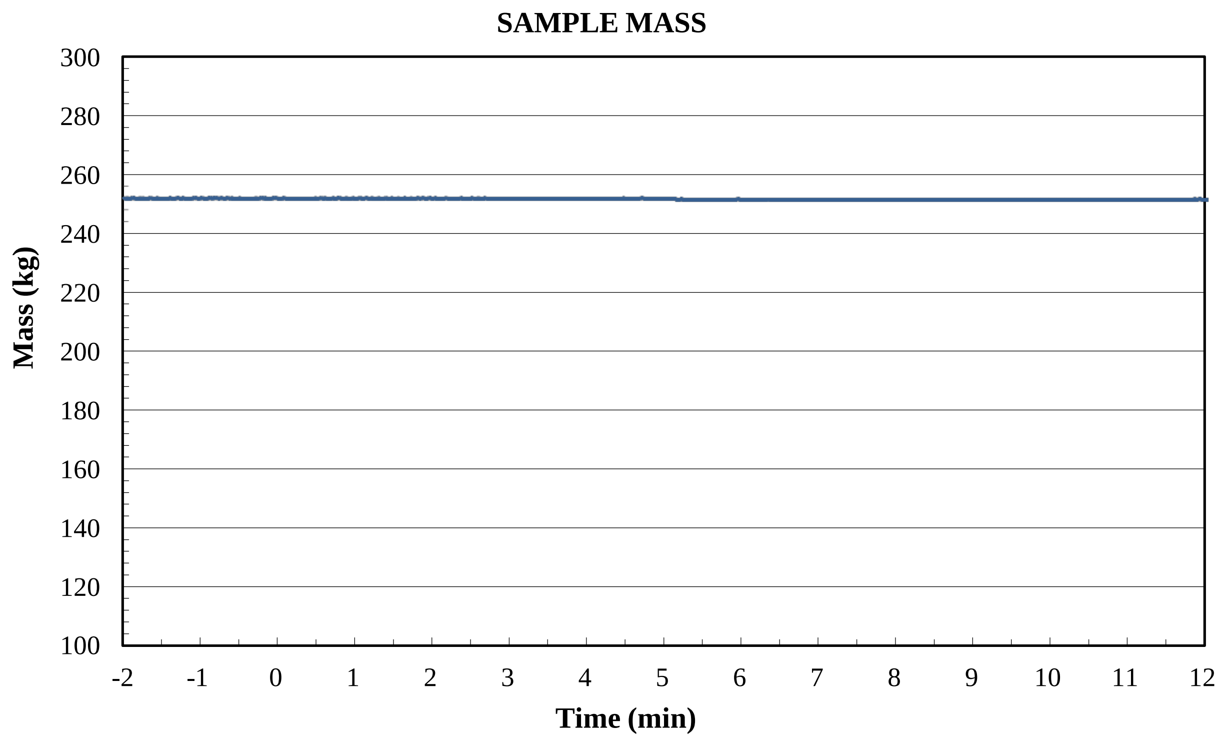
Maximum HRR_{total}	64 kW	at	1 min 36 sec
Average HRR_{total}	51 kW		
Total Heat Released	31 MJ		
Maximum $HRR_{excl.\ burner}$	55 kW	at	12 min 13 sec
Average $HRR_{excl.\ burner}$	1 kW		
Total Heat Released (Excluding Burner)	1 MJ		
Maximum $HRR_{10\ min}$	N/A*		
$HRR_{12\ min}$	N/A*		
Maximum Flame Height	> 2.4 m	at	7 min 0 sec
Heat Flux at 4 ft	3 kW/m^2	at	0 min 49 sec
Maximum Smoke Generation $Rate_{0\text{-}10\ min}$	0.02 g/s	at	9 min 46 sec
Smoke Generation $Rate_{12min}$	N/A*		
Total Smoke Generated	6 g		
Maximum Smoke Release Rate	0.21 m^2/s	at	0 min 49 sec
Average Smoke Release Rate	0.09 m^2/s		
Total Smoke Released	56 m^2		
Maximum Optical Density	0.01 1/m	at	10 min 4 sec
Maximum Duct Flow Rate	6.33 m^3/s		
Average Optical Density	0.006 1/m		
Average Volumetric Duct Flow Rate	6.43 m^3/s		
Total Mass Loss	0.54 kg		
Smoke Yield	0.011		
Maximum Sample Backside Temperature	59°C	at	11 min 48 sec

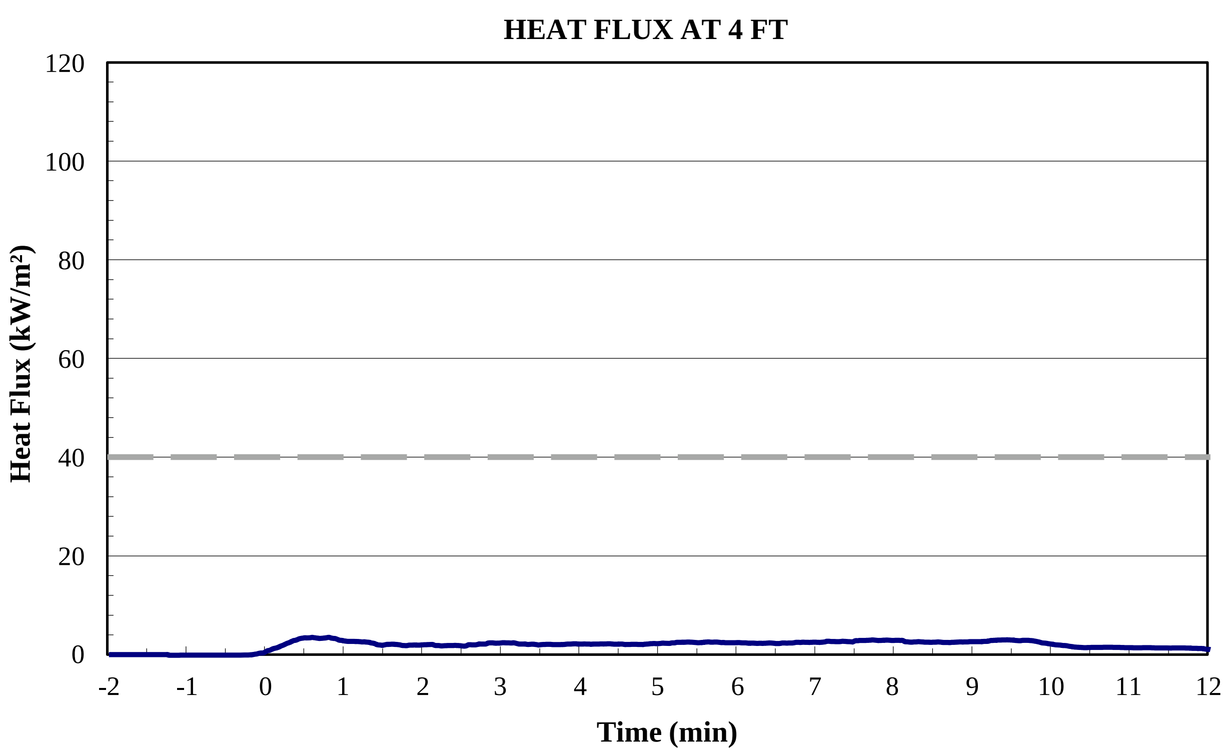

HEAT RELEASE RATE
HRR Burner
HRR Excluding Burner
HRR Total
Heat Release Rate (kW)
100
90
80
70
60
50
40
30
20
10
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)

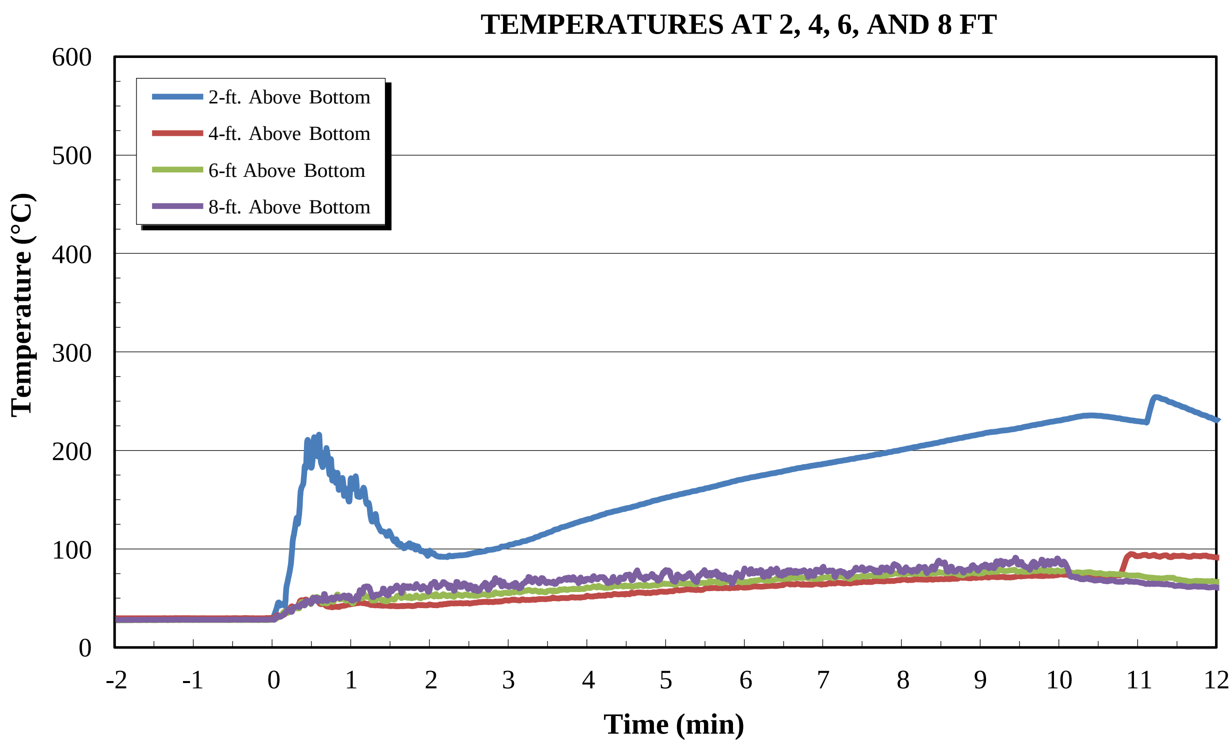

TOTAL HEAT RELEASED
THR Excluding Burner
THR Total
Total Heat Released (MJ)
50
45
40
35
30
25
20
15
10
5
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)

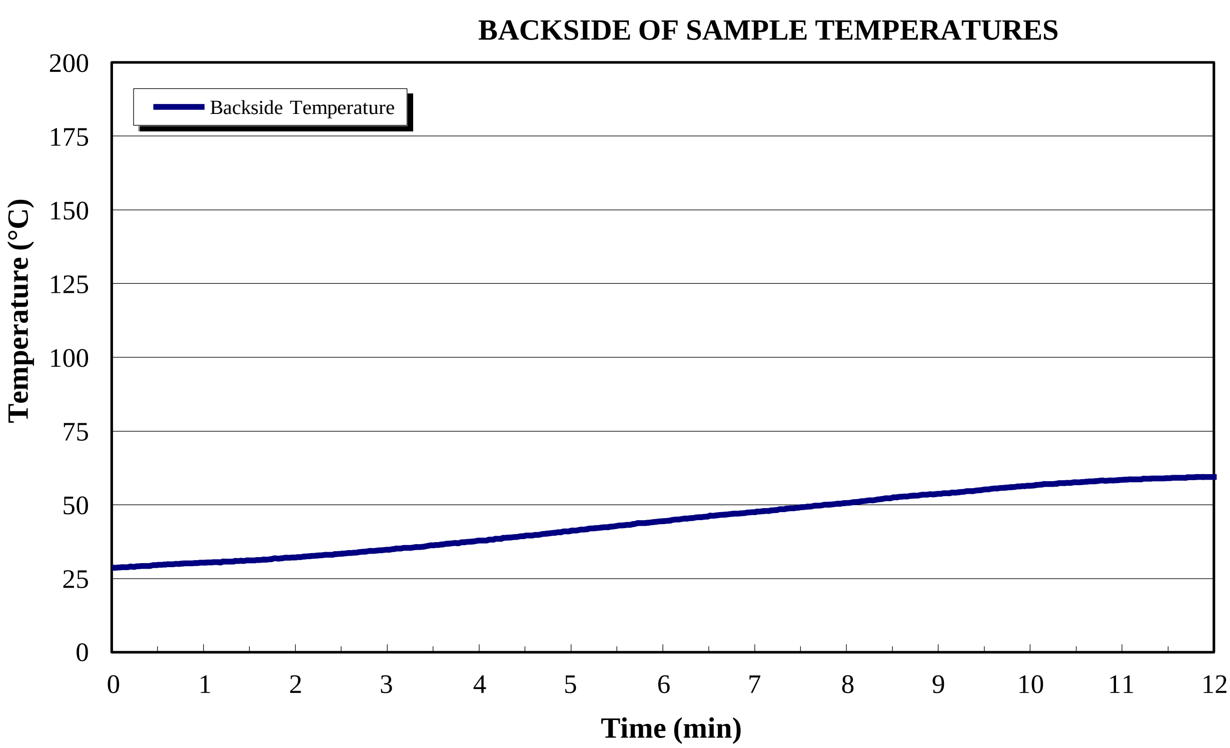

SMOKE RELEASE RATE AND TOTAL SMOKE RELEASED
Smoke Release Rate
Total Smoke Released
Smoke Release Rate (m²/s)
Total Smoke Released (m²)
Time (min)
45
40
35
30
25
20
15
10
5
0
60
50
40
30
20
10
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12


VOLUMETRIC DUCT FLOW RATE AND
OPTICAL DENSITY
Volumetric Flow
Optical Density
Volumetric Flow Rate (m³/s)
Optical Density (m-1)
Time (min)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12


SAMPLE MASS
Mass (kg)
300
280
260
240
220
200
180
160
140
120
100
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)


HEAT FLUX AT 4 FT
Heat Flux (kW/m²)
120
100
80
60
40
20
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)


TEMPERATURES AT 2, 4, 6, AND 8 FT
2-ft. Above Bottom
4-ft. Above Bottom
6-ft Above Bottom
8-ft. Above Bottom
Temperature (°C)
Time (min)
600
500
400
300
200
100
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12


BACKSIDE OF SAMPLE TEMPERATURES
Backside Temperature
Temperature (°C)
Time (min)
200
175
150
125
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12

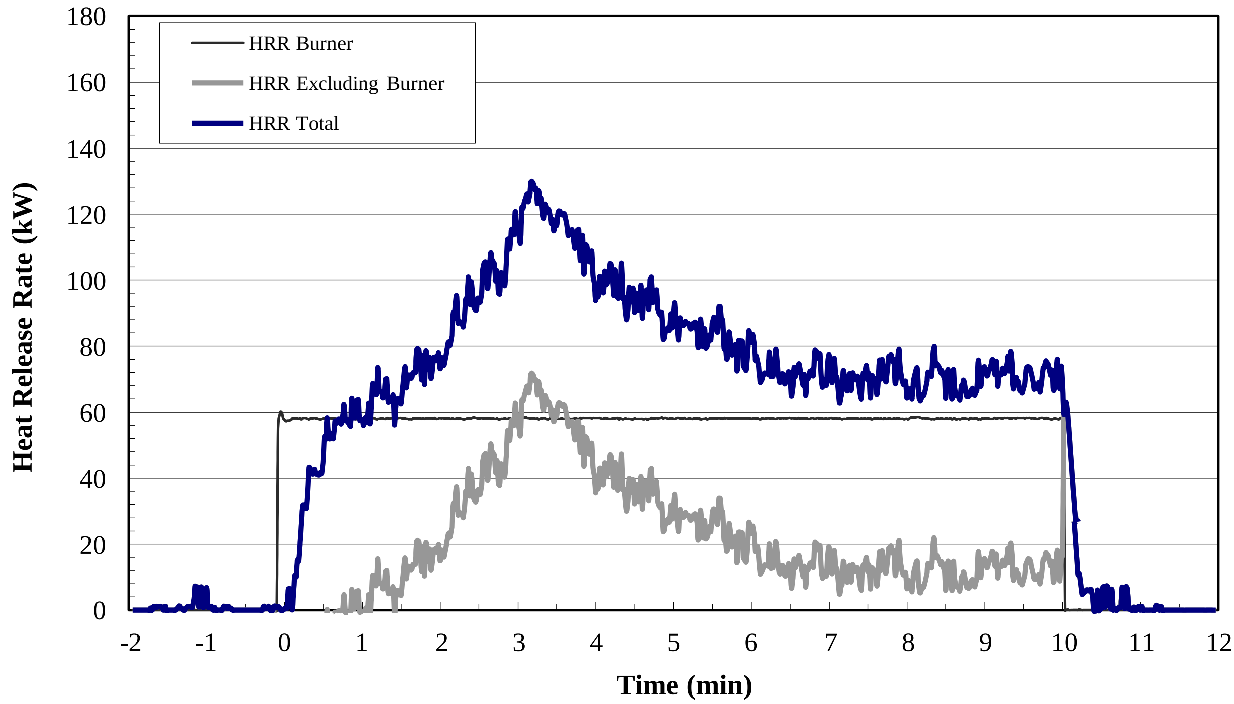
SUMMARY OF

TEST RESULTS

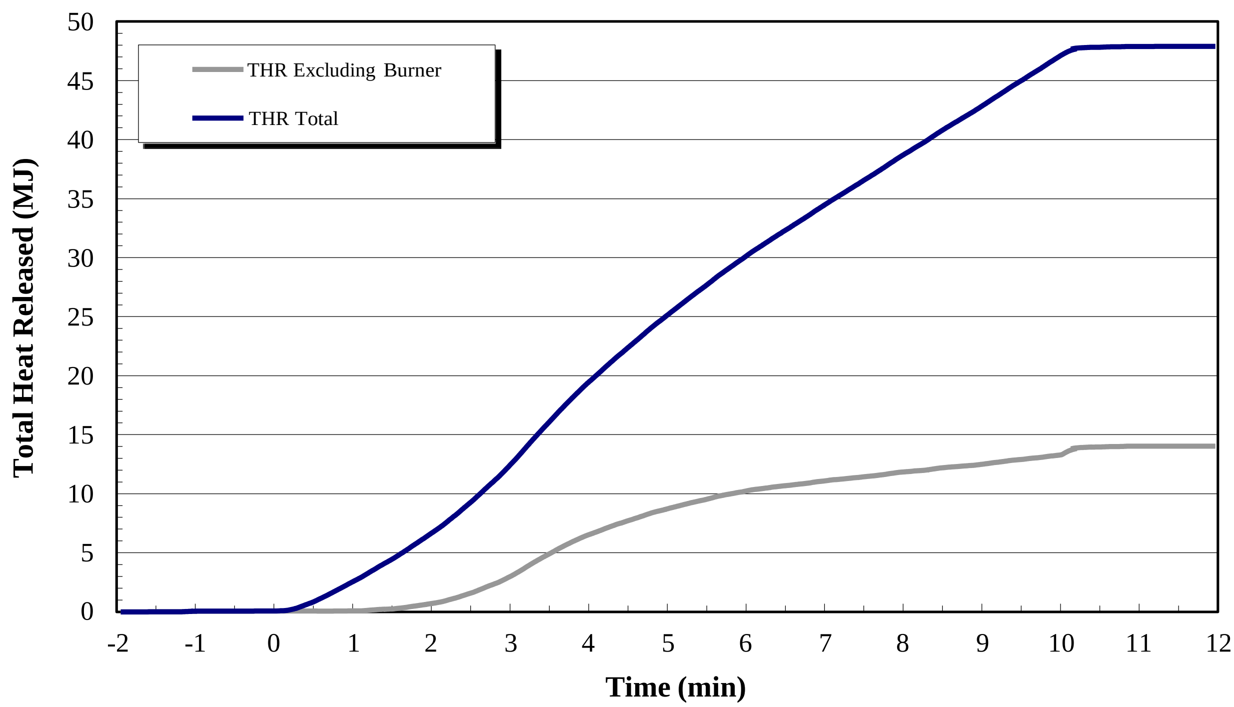
Material: ***Steel - Coated with Pitt Char XP***

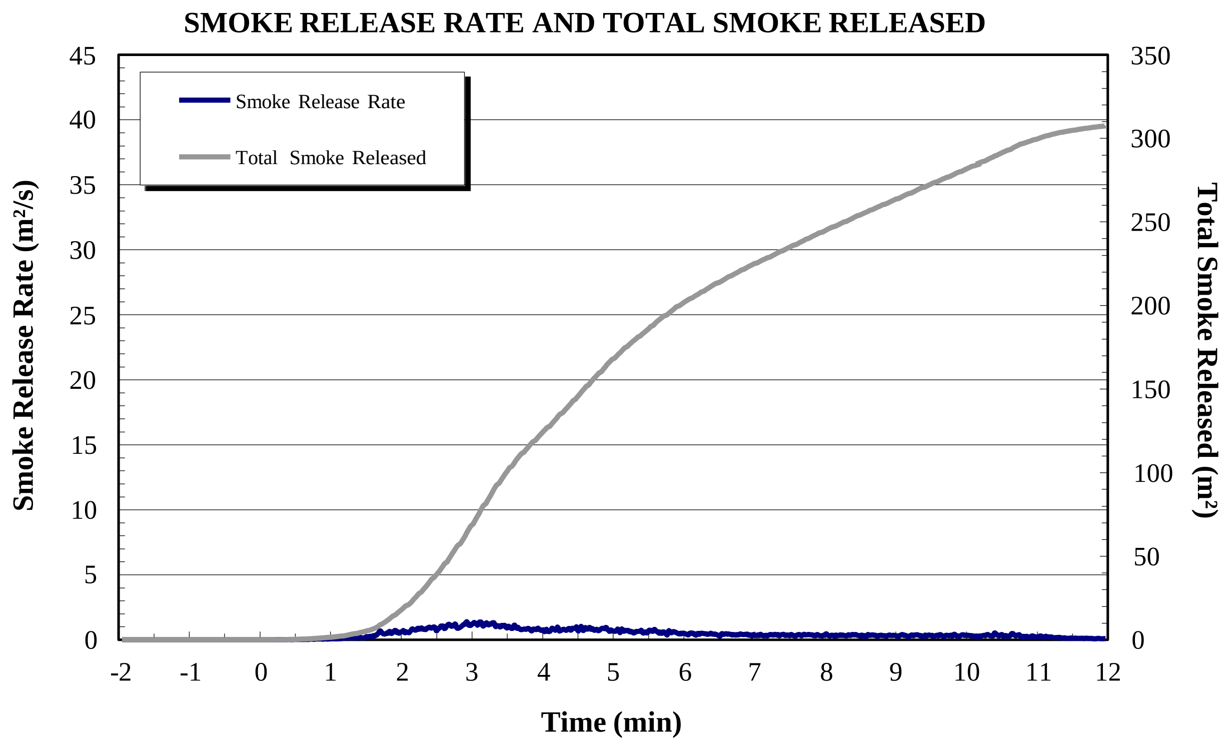
Maximum HRR_{total}	130 kW	at	3 min 7 sec
Average HRR_{total}	80 kW		
Total Heat Released	48 MJ		
Maximum $HRR_{excl.\ burner}$	72 kW	at	3 min 7 sec
Average $HRR_{excl.\ burner}$	23 kW		
Total Heat Released (Excluding Burner)	14 MJ		
Maximum $HRR_{10\ min}$	N/A*		
$HRR_{12\ min}$	N/A*		
Maximum Flame Height	> 2.4 m	at	7 min 0 sec
Heat Flux at 4 ft	28 kW/m²	at	3 min 7 sec
Maximum Smoke Generation $Rate_{0\text{-}10\ min}$	0.16 g/s	at	2 min 53 sec
Smoke Generation $Rate_{12min}$	N/A*		
Total Smoke Generated	32 g		
Maximum Smoke Release Rate	1.37 m²/s	at	3 min 7 sec
Average Smoke Release Rate	0.51 m²/s		
Total Smoke Released	307 m²		
Maximum Optical Density	0.10 1/m	at	2 min 53 sec
Maximum Duct Flow Rate	5.92 m³/s		
Average Optical Density	0.030 1/m		
Average Volumetric Duct Flow Rate	6.02 m³/s		
Total Mass Loss	1.44 kg		
Smoke Yield	0.022		
Maximum Sample Backside Temperature	62°C	at	10 min 27 sec

HEAT RELEASE RATE

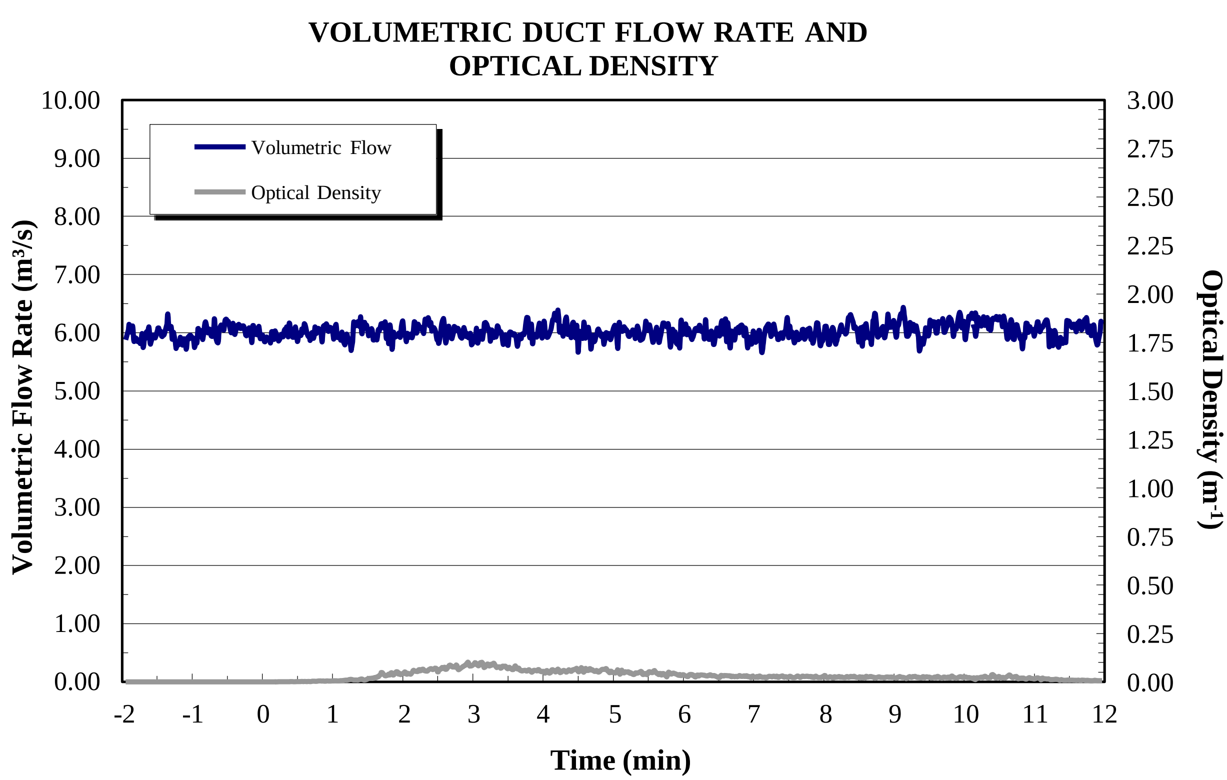


TOTAL HEAT RELEASED

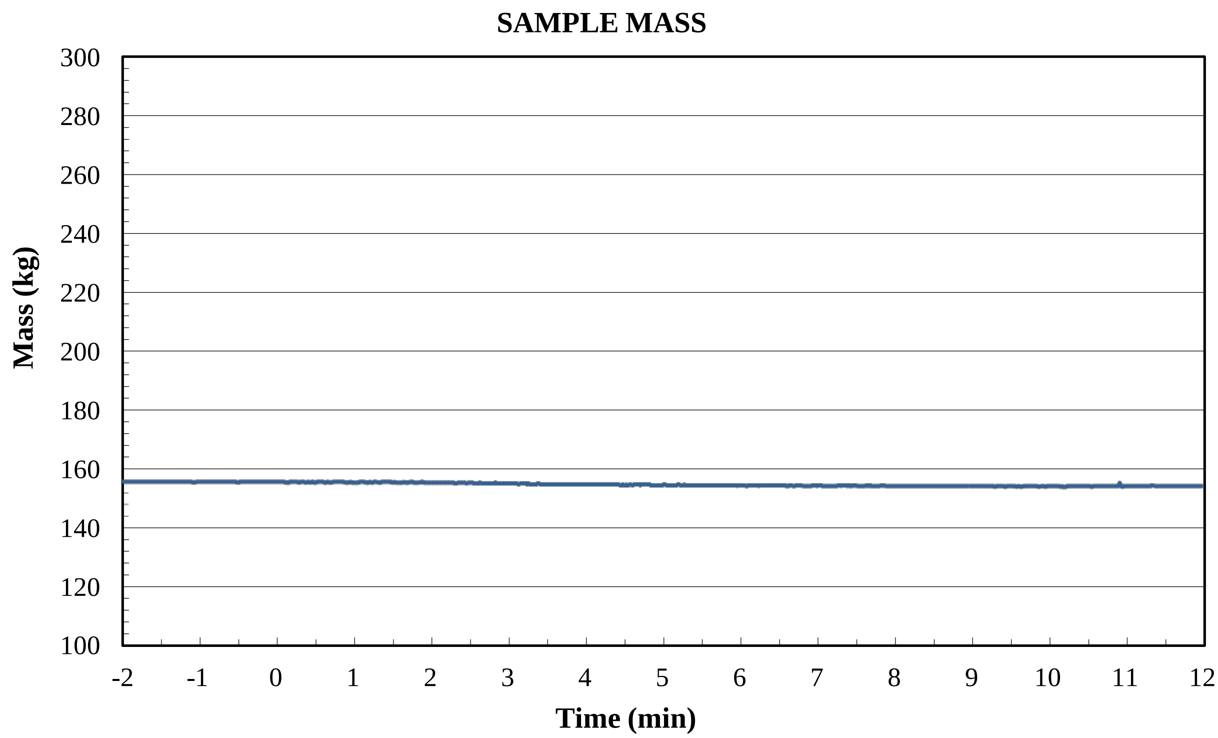


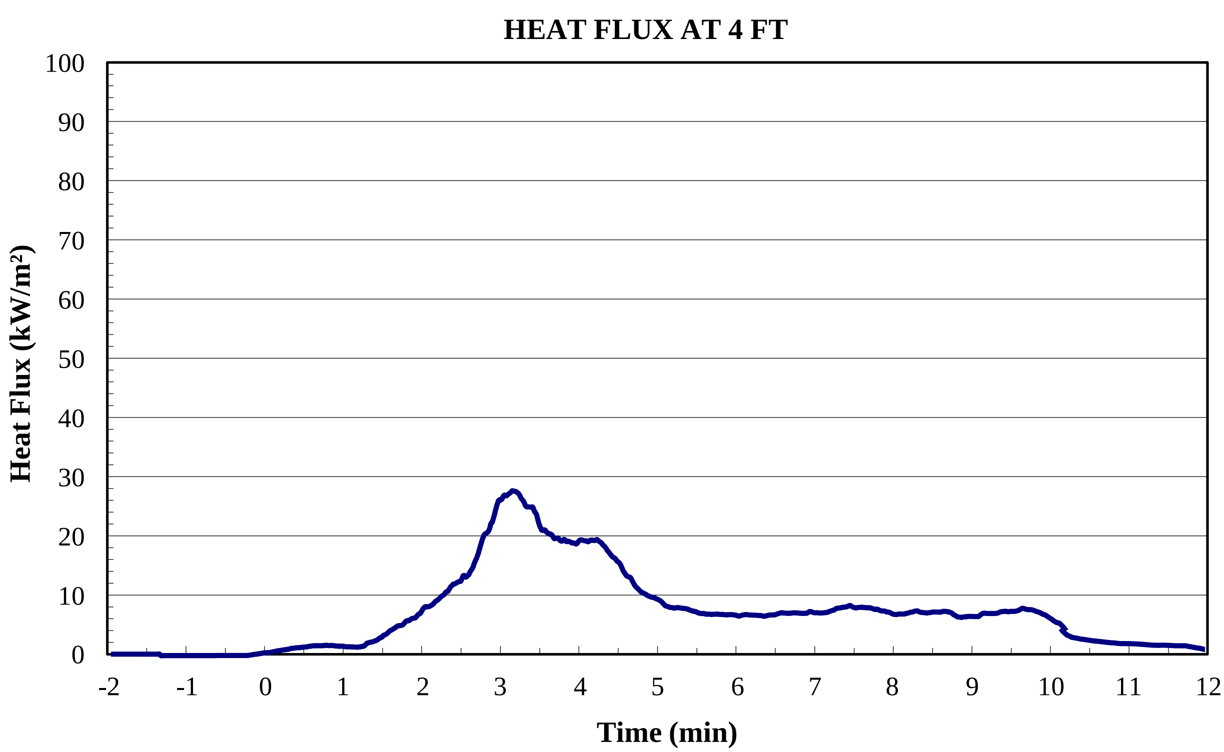


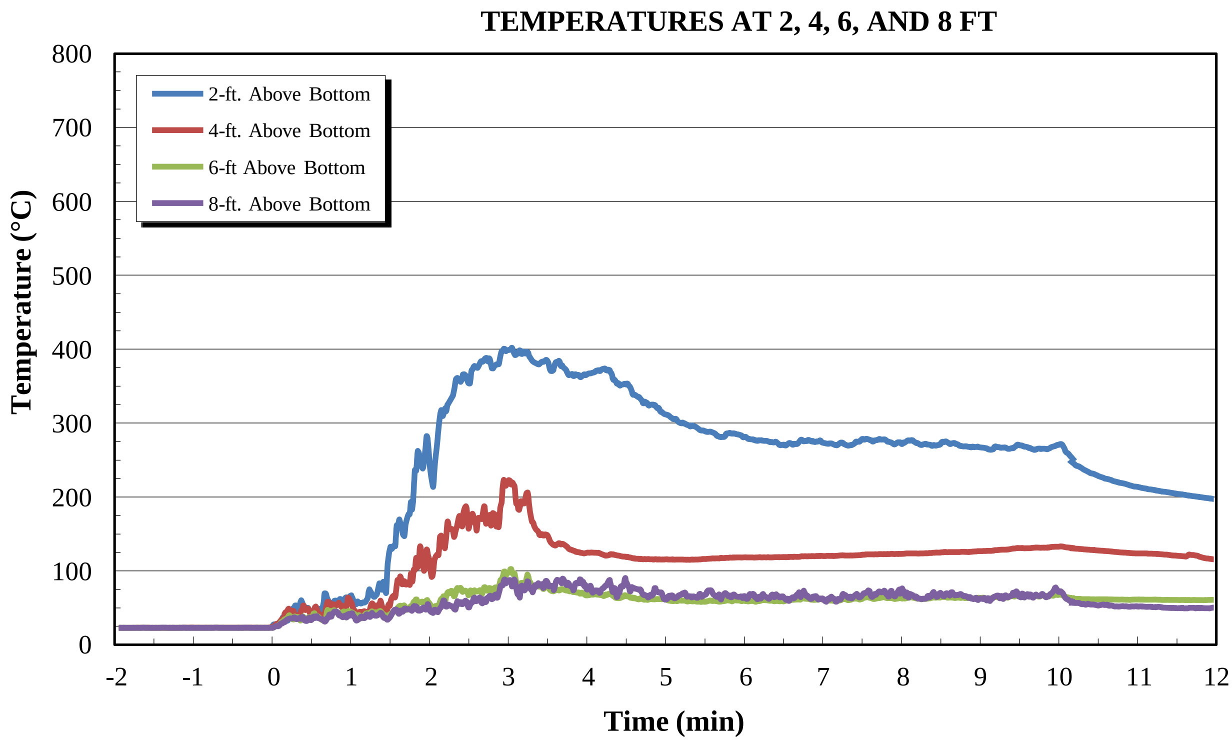
SMOKE RELEASE RATE AND TOTAL SMOKE RELEASED
Smoke Release Rate
Total Smoke Released
Smoke Release Rate (m²/s)
Total Smoke Released (m²)
Time (min)
45
40
35
30
25
20
15
10
5
0
350
300
250
200
150
100
50
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12

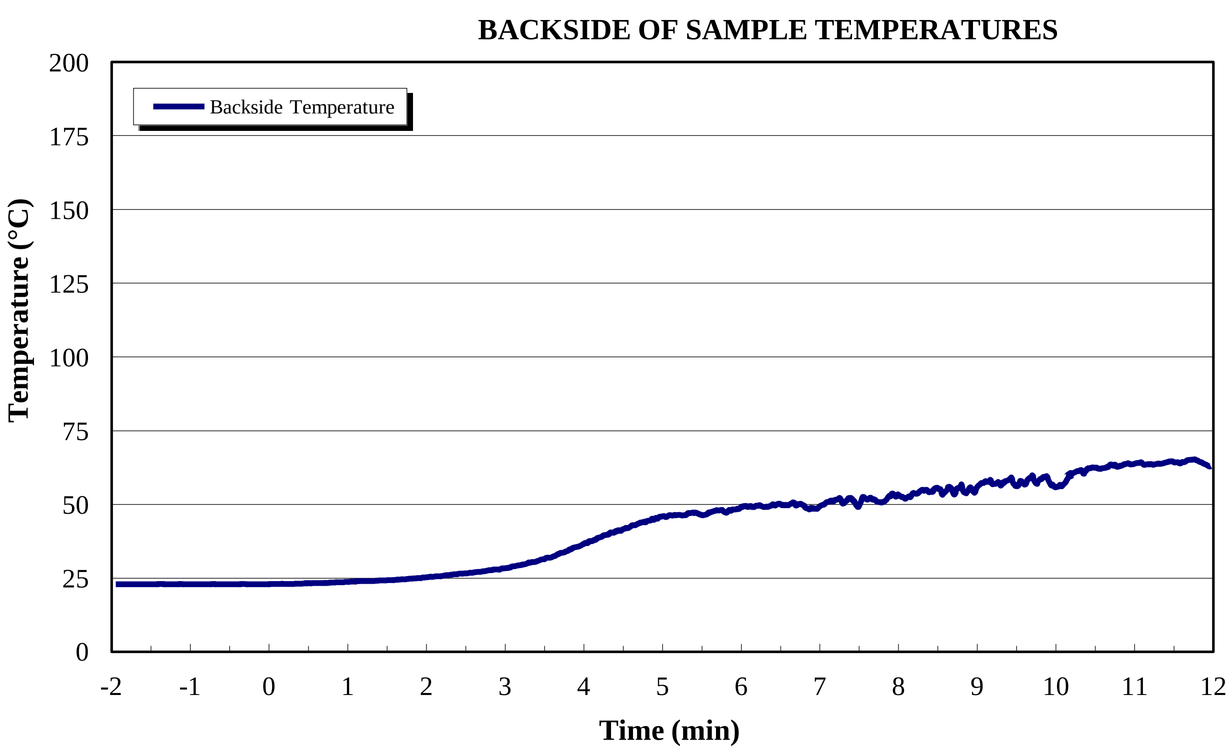


VOLUMETRIC DUCT FLOW RATE AND
OPTICAL DENSITY
Volumetric Flow
Optical Density
Volumetric Flow Rate (m³/s)
Optical Density (m⁻¹)
Time (min)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12


SAMPLE MASS
Mass (kg)
300
280
260
240
220
200
180
160
140
120
100
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)


HEAT FLUX AT 4 FT
Heat Flux (kW/m²)
100
90
80
70
60
50
40
30
20
10
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)


TEMPERATURES AT 2, 4, 6, AND 8 FT
2-ft. Above Bottom
4-ft. Above Bottom
6-ft Above Bottom
8-ft. Above Bottom
Temperature (°C)
Time (min)
0
100
200
300
400
500
600
700
800
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12

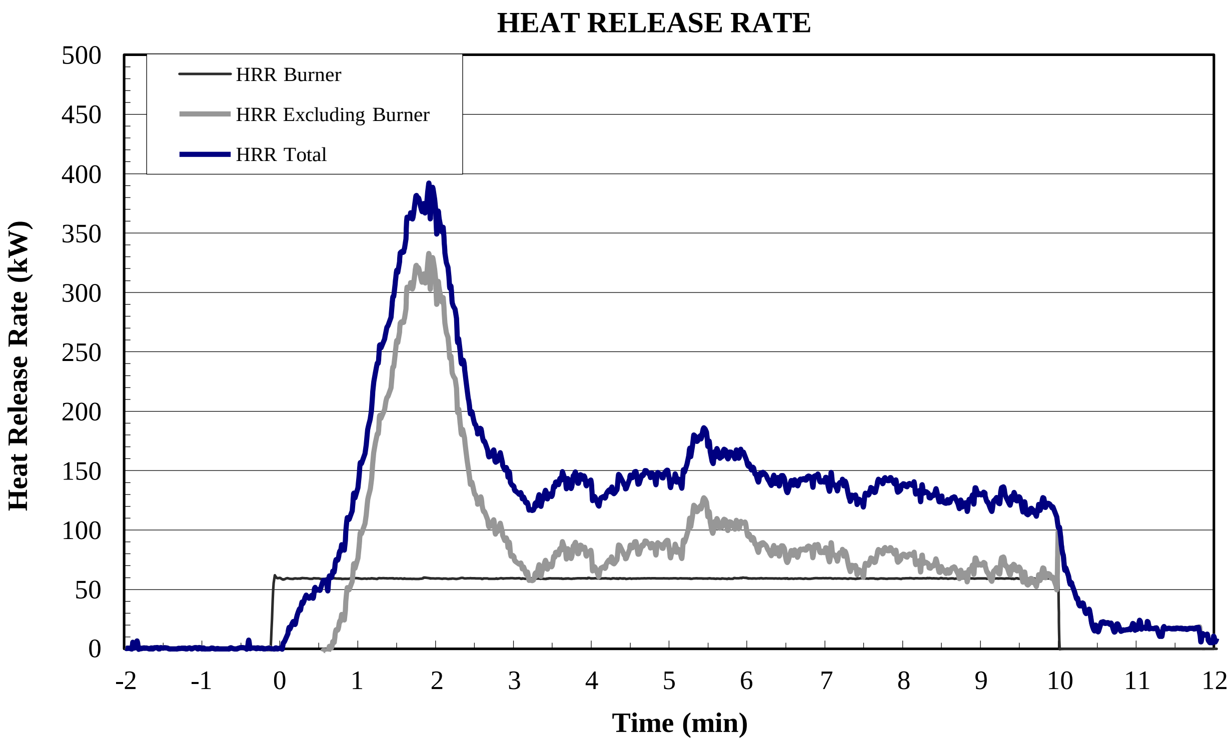

BACKSIDE OF SAMPLE TEMPERATURES
Backside Temperature
Temperature (°C)
Time (min)
0
25
50
75
100
125
150
175
200
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12

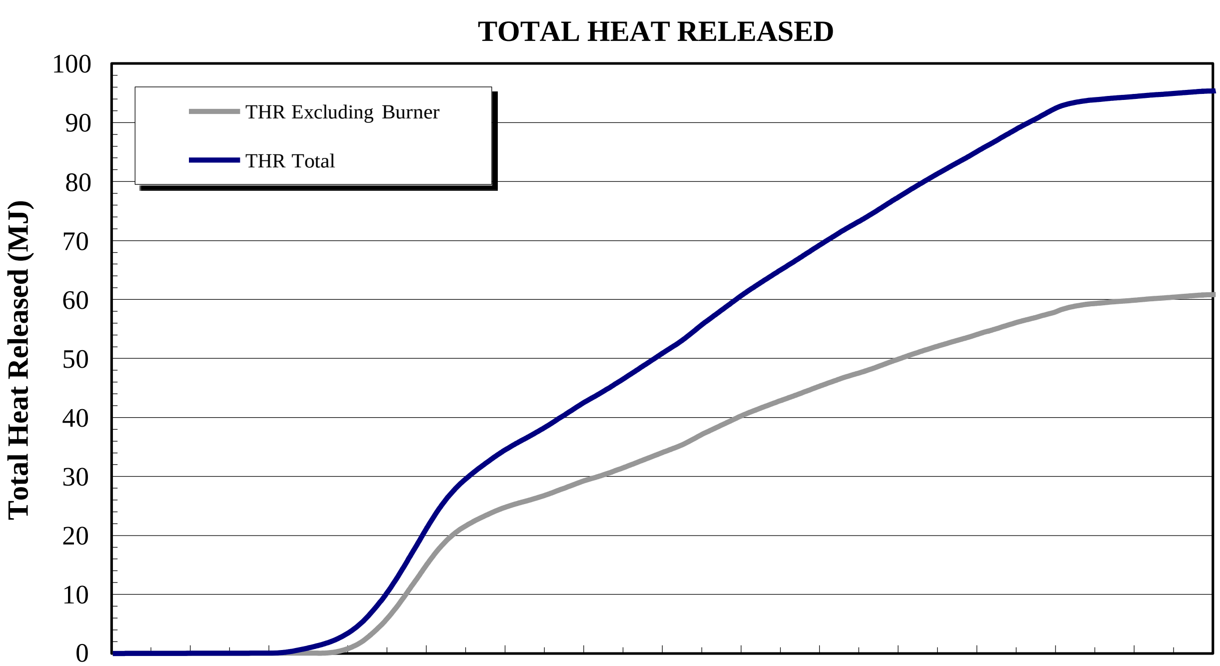
SUMMARY OF

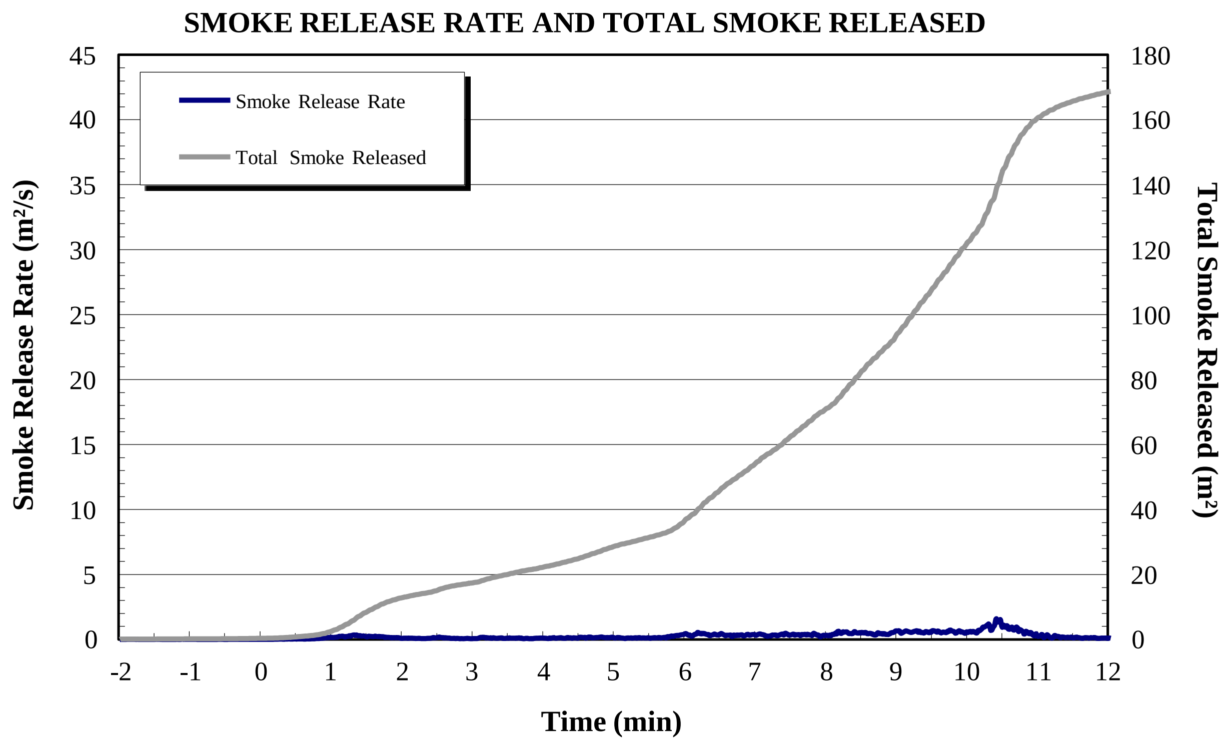
TEST RESULTS

Material: ***Red Oak Plywood - Uncoated - Run 1***

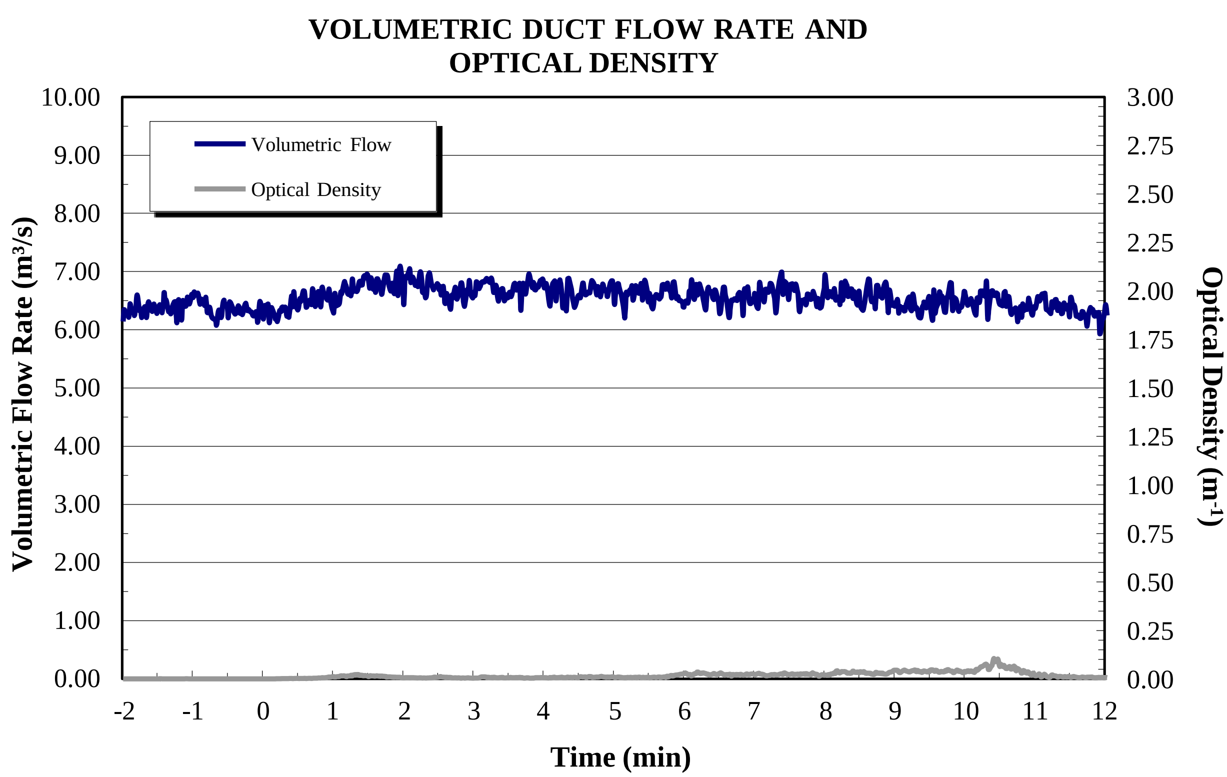
Maximum HRR_{total}	392 kW	at	1 min 55 sec
Average HRR_{total}	159 kW		
Total Heat Released	96 MJ		
Maximum $HRR_{excl.\ burner}$	333 kW	at	1 min 55 sec
Average $HRR_{excl.\ burner}$	102 kW		
Total Heat Released (Excluding Burner)	61 MJ		
Maximum $HRR_{10\ min}$	N/A*		
$HRR_{12\ min}$	N/A*		
Maximum Flame Height	> 2.4 m	at	7 min 0 sec
Heat Flux at 4 ft	58 kW/m²	at	1 min 48 sec
Maximum Smoke Generation $Rate_{0\text{-}10\ min}$	0.08 g/s	at	9 min 46 sec
Smoke Generation $Rate_{12min}$	N/A*		
Total Smoke Generated	17 g		
Maximum Smoke Release Rate	1.58 m²/s	at	1 min 48 sec
Average Smoke Release Rate	0.28 m²/s		
Total Smoke Released	170 m²		
Maximum Optical Density	0.10 1/m	at	10 min 25 sec
Maximum Duct Flow Rate	6.63 m³/s		
Average Optical Density	0.017 1/m		
Average Volumetric Duct Flow Rate	6.55 m³/s		
Total Mass Loss	7.58 kg		
Smoke Yield	0.002		
Maximum Sample Backside Temperature	70°C	at	11 min 59 sec


HEAT RELEASE RATE
HRR Burner
HRR Excluding Burner
HRR Total
Heat Release Rate (kW)
Time (min)
500
450
400
350
300
250
200
150
100
50
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12


TOTAL HEAT RELEASED
THR Excluding Burner
THR Total
Total Heat Released (MJ)
100
90
80
70
60
50
40
30
20
10
0

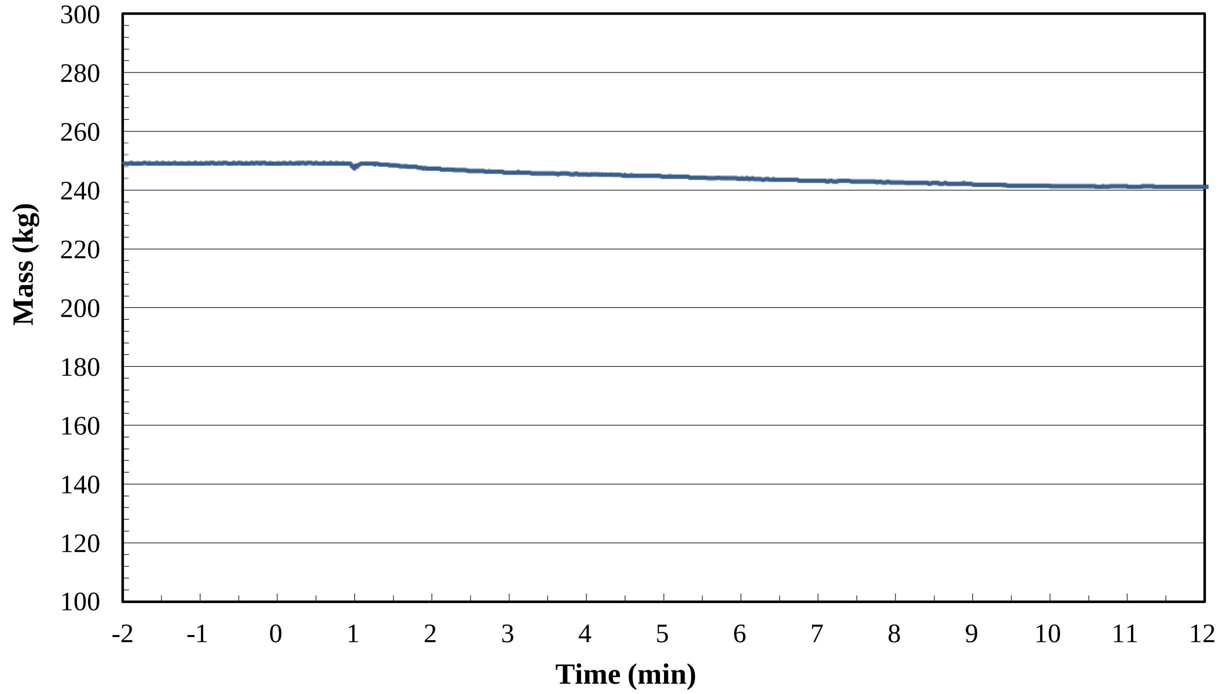


SMOKE RELEASE RATE AND TOTAL SMOKE RELEASED
Smoke Release Rate
Total Smoke Released
Smoke Release Rate (m²/s)
Total Smoke Released (m²)
Time (min)
45
40
35
30
25
20
15
10
5
0
180
160
140
120
100
80
60
40
20
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12

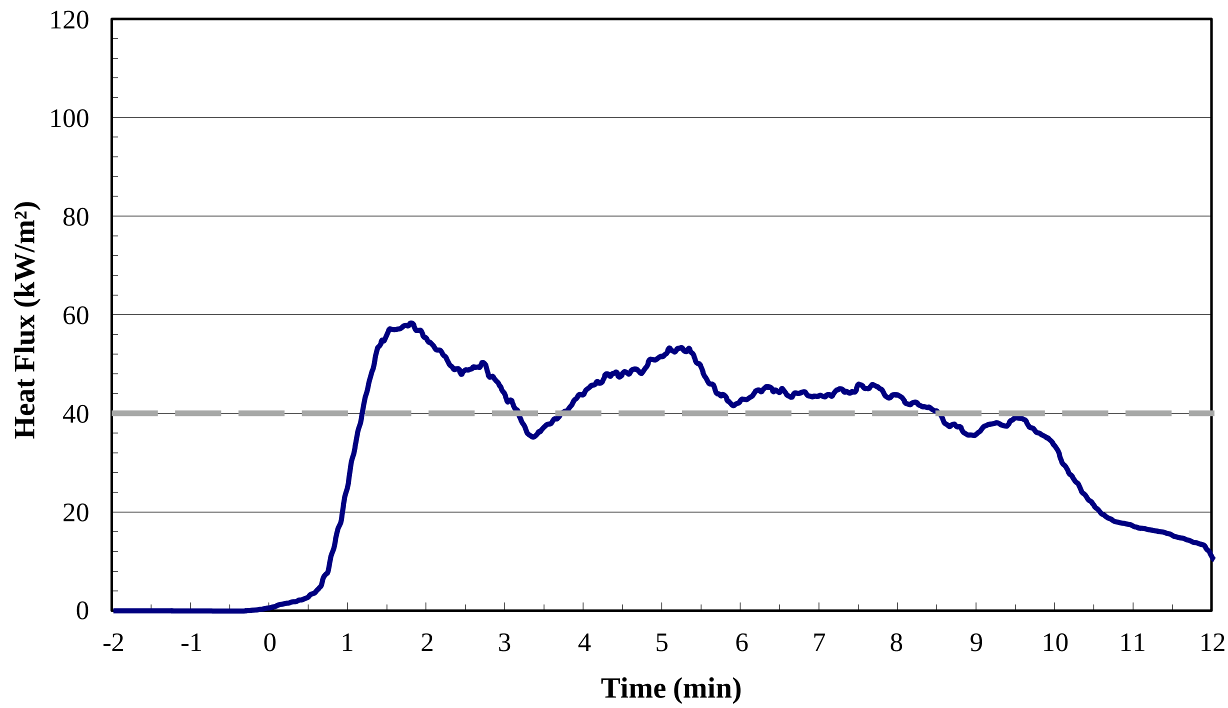


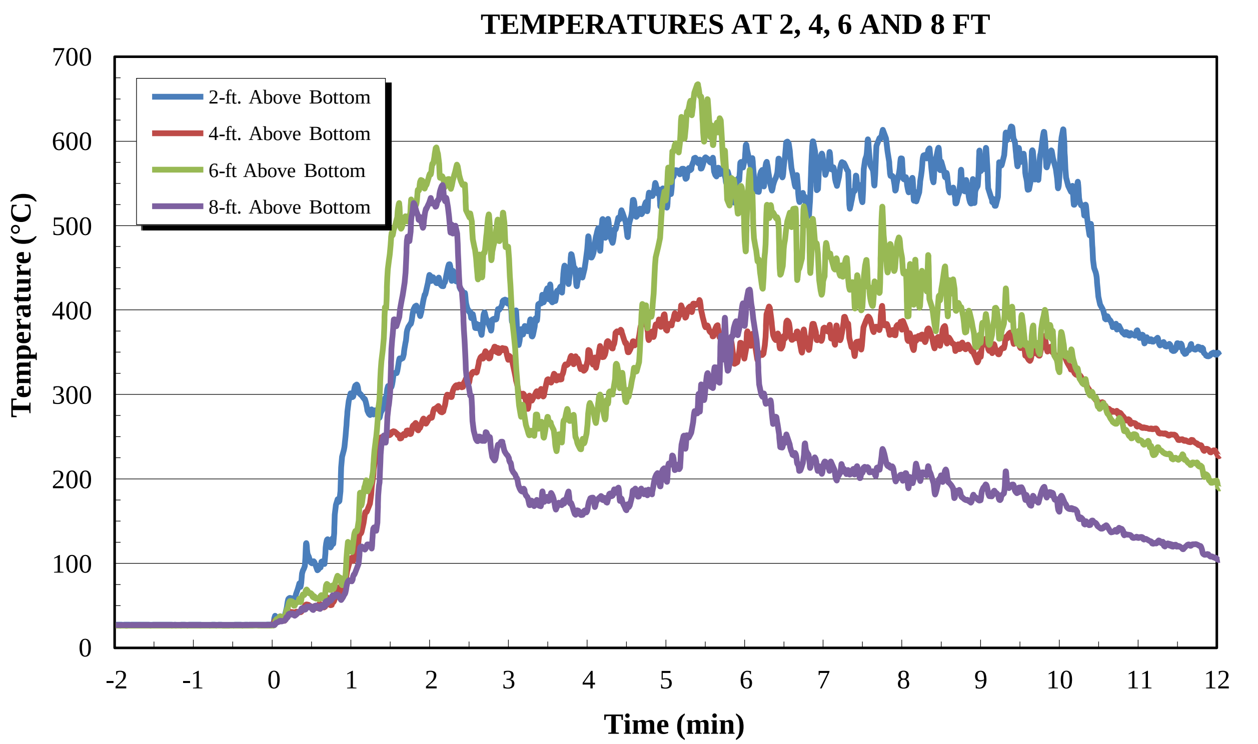
VOLUMETRIC DUCT FLOW RATE AND OPTICAL DENSITY
Volumetric Flow
Optical Density
Volumetric Flow Rate (m³/s)
Optical Density (m⁻¹)
Time (min)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12

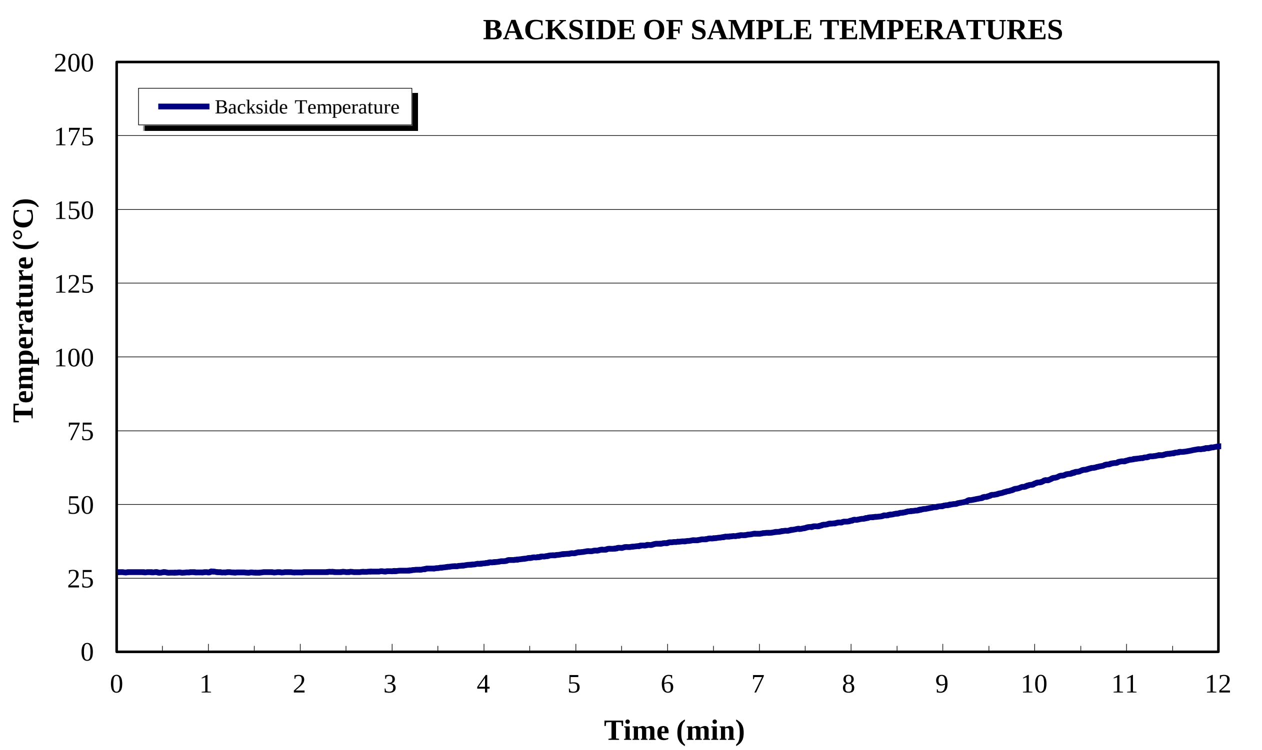
SAMPLE MASS



HEAT FLUX AT 4 FT




TEMPERATURES AT 2, 4, 6 AND 8 FT
2-ft. Above Bottom
4-ft. Above Bottom
6-ft Above Bottom
8-ft. Above Bottom
Temperature (°C)
0
100
200
300
400
500
600
700
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)

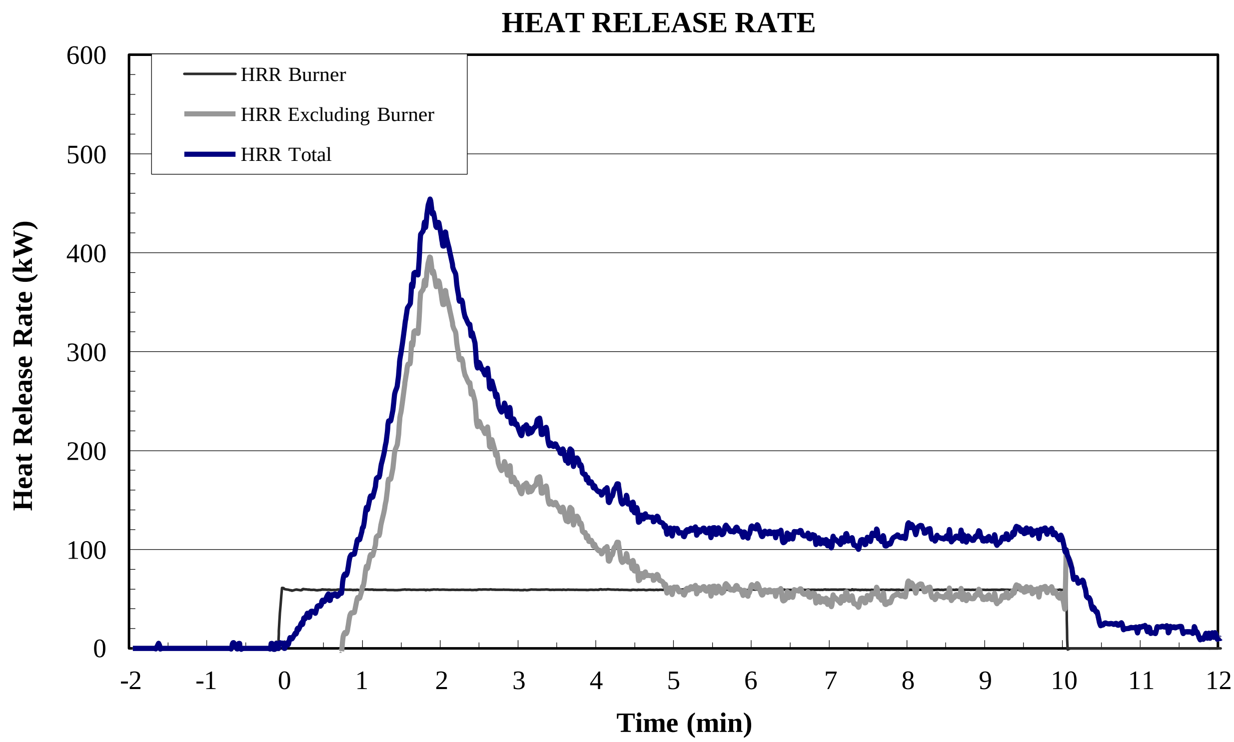

BACKSIDE OF SAMPLE TEMPERATURES
Backside Temperature
Temperature (°C)
0
25
50
75
100
125
150
175
200
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)

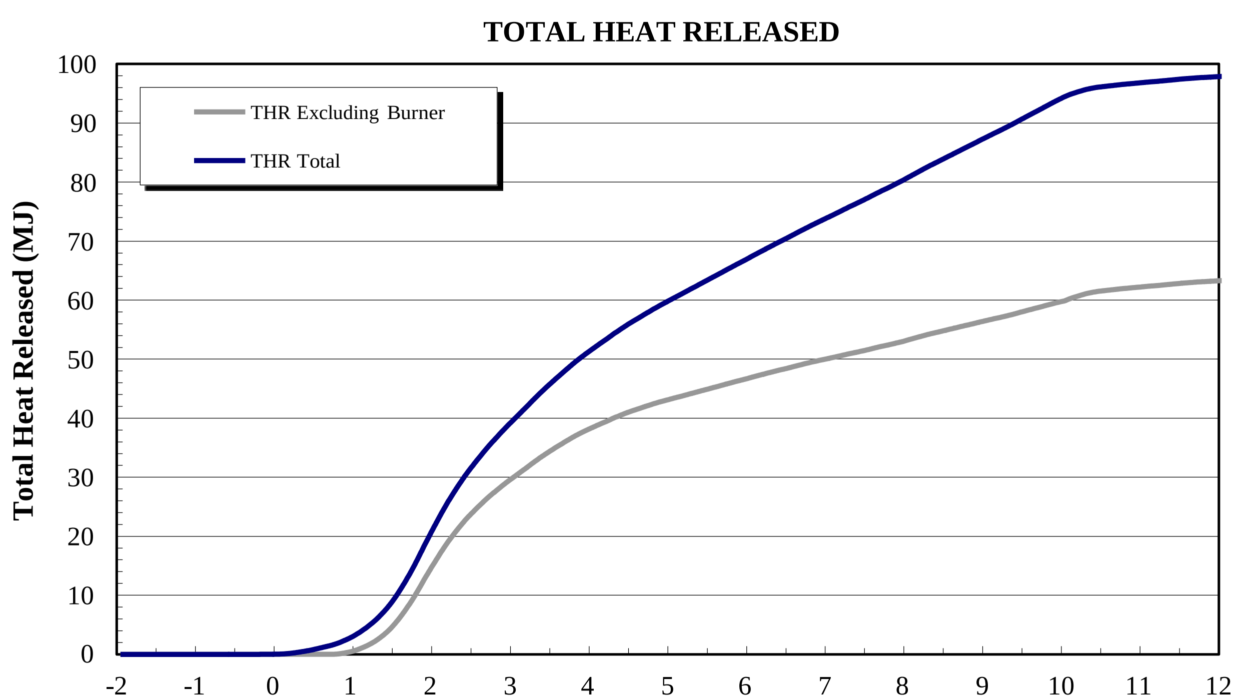
SUMMARY OF

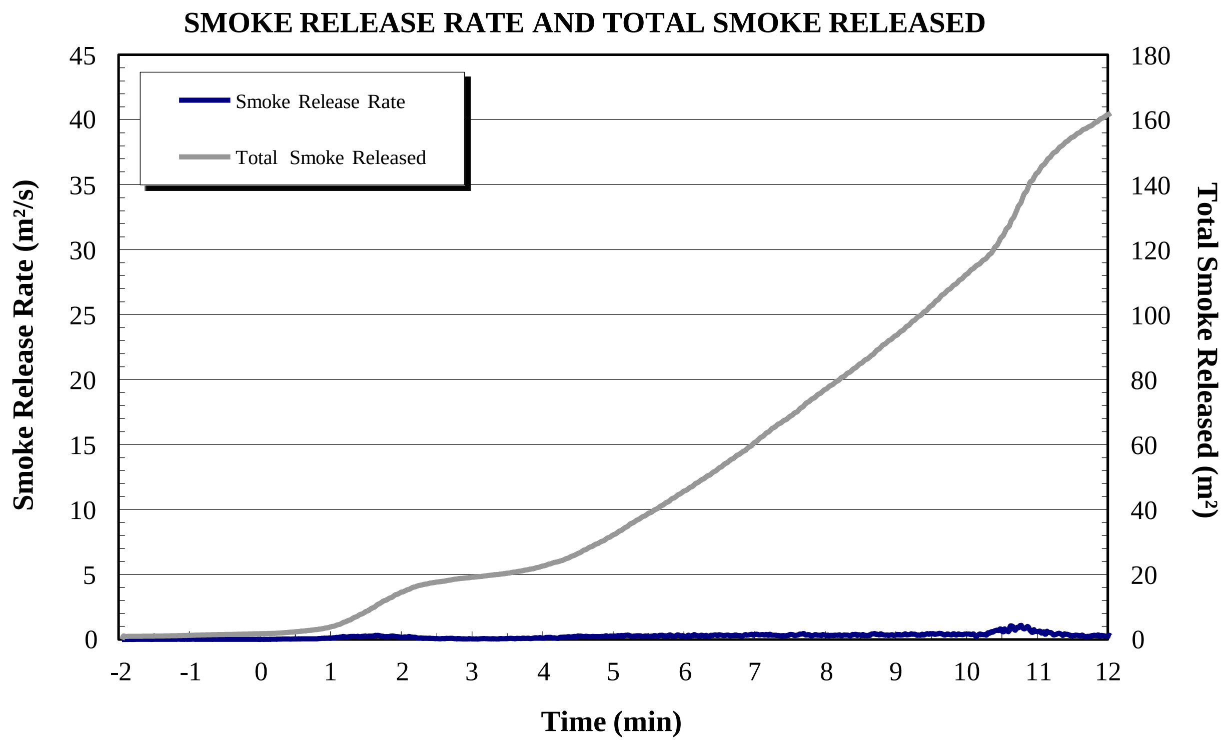
TEST RESULTS

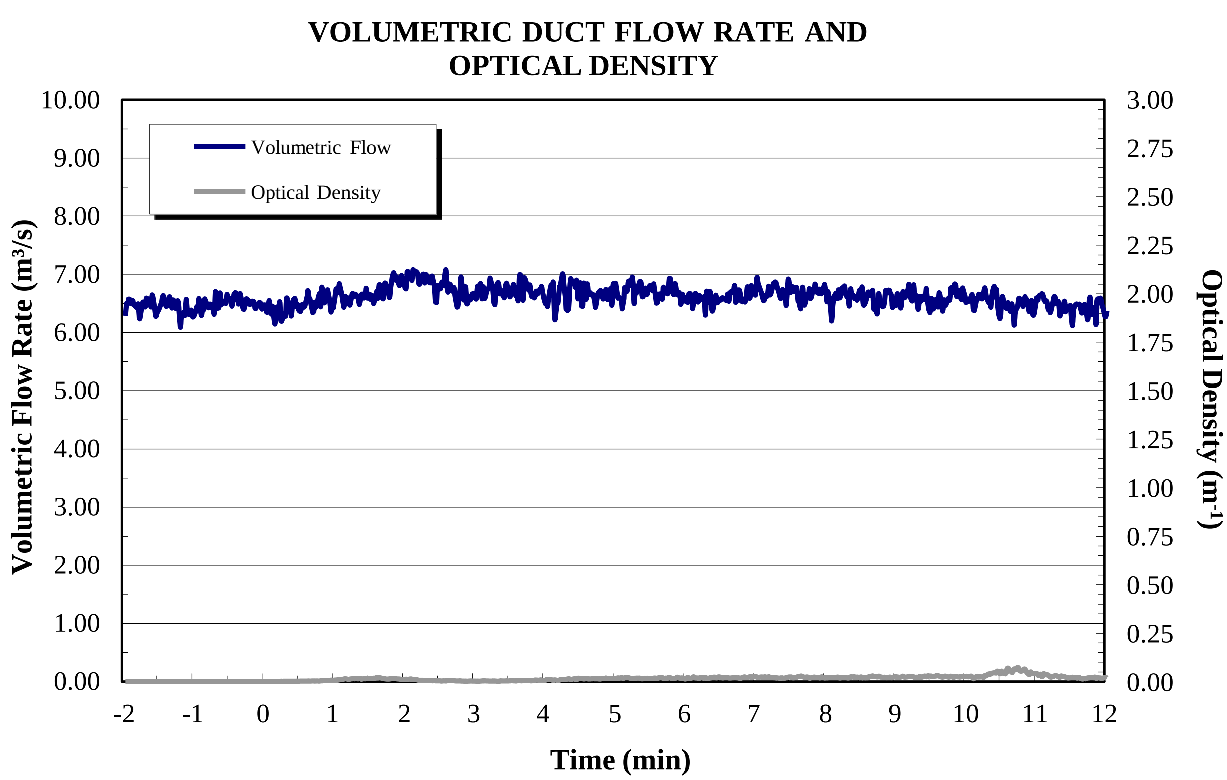
Material: ***Red Oak Plywood - Uncoated - Run 1***

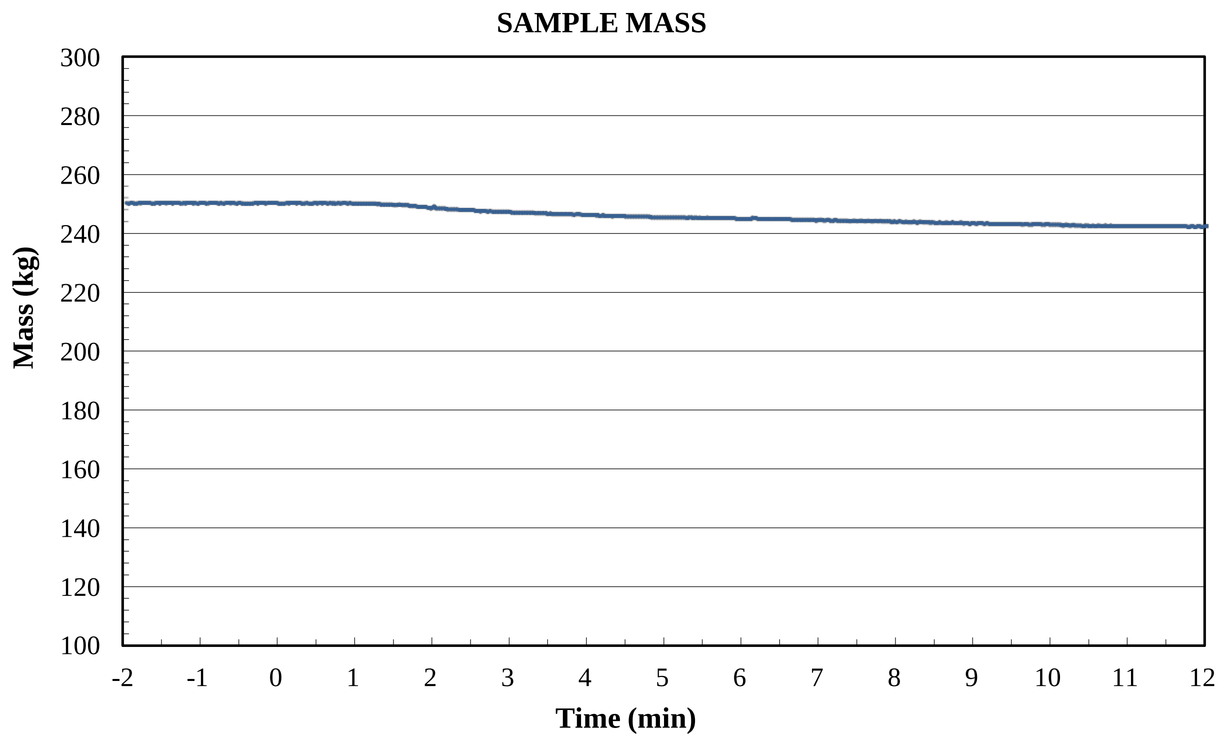
Maximum HRR_{total}	455 kW	at	1 min 52 sec
Average HRR_{total}	163 kW		
Total Heat Released	98 MJ		
Maximum $HRR_{excl.\ burner}$	396 kW	at	1 min 52 sec
Average $HRR_{excl.\ burner}$	106 kW		
Total Heat Released (Excluding Burner)	63 MJ		
Maximum $HRR_{10\ min}$	N/A*		
$HRR_{12\ min}$	N/A*		
Maximum Flame Height	> 2.4 m	at	7 min 0 sec
Heat Flux at 4 ft	62 kW/m²	at	1 min 39 sec
Maximum Smoke Generation $Rate_{0-10\ min}$	0.05 g/s	at	9 min 37 sec
Smoke Generation $Rate_{12min}$	N/A*		
Total Smoke Generated	16 g		
Maximum Smoke Release Rate	1.09 m²/s	at	1 min 39 sec
Average Smoke Release Rate	0.28 m²/s		
Total Smoke Released	165 m²		
Maximum Optical Density	0.07 1/m	at	10 min 46 sec
Maximum Duct Flow Rate	6.45 m³/s		
Average Optical Density	0.017 1/m		
Average Volumetric Duct Flow Rate	6.61 m³/s		
Total Mass Loss	7.31 kg		
Smoke Yield	0.002		
Maximum Backside Temperature	73°C	at	11 min 59 sec

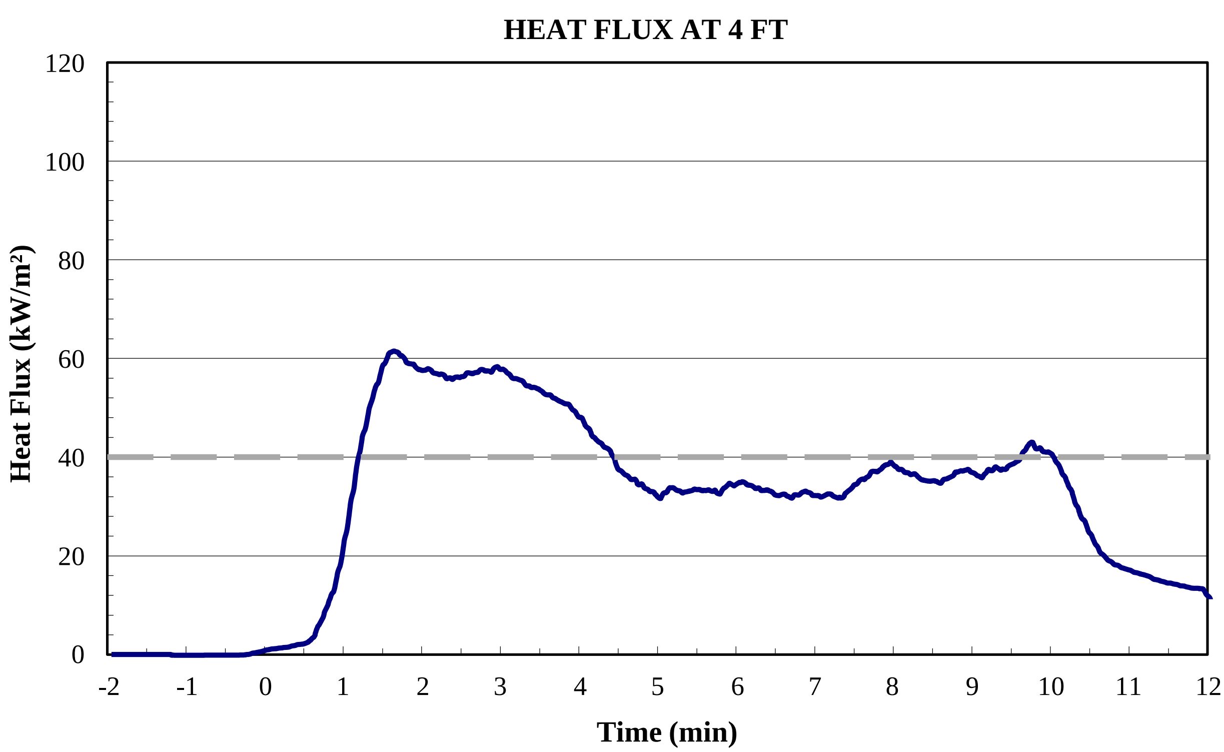

HEAT RELEASE RATE
Heat Release Rate (kW)
Time (min)
HRR Burner
HRR Excluding Burner
HRR Total
0
100
200
300
400
500
600
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12

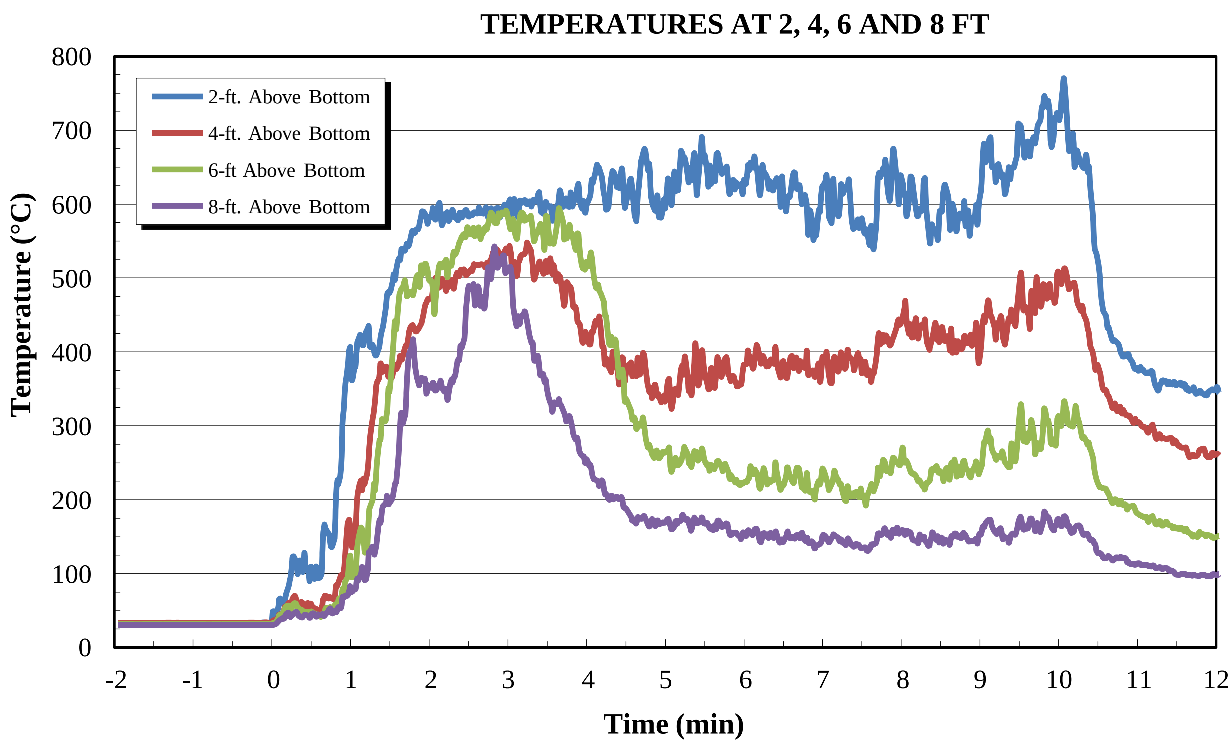

TOTAL HEAT RELEASED
Total Heat Released (MJ)
THR Excluding Burner
THR Total
0
10
20
30
40
50
60
70
80
90
100
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12

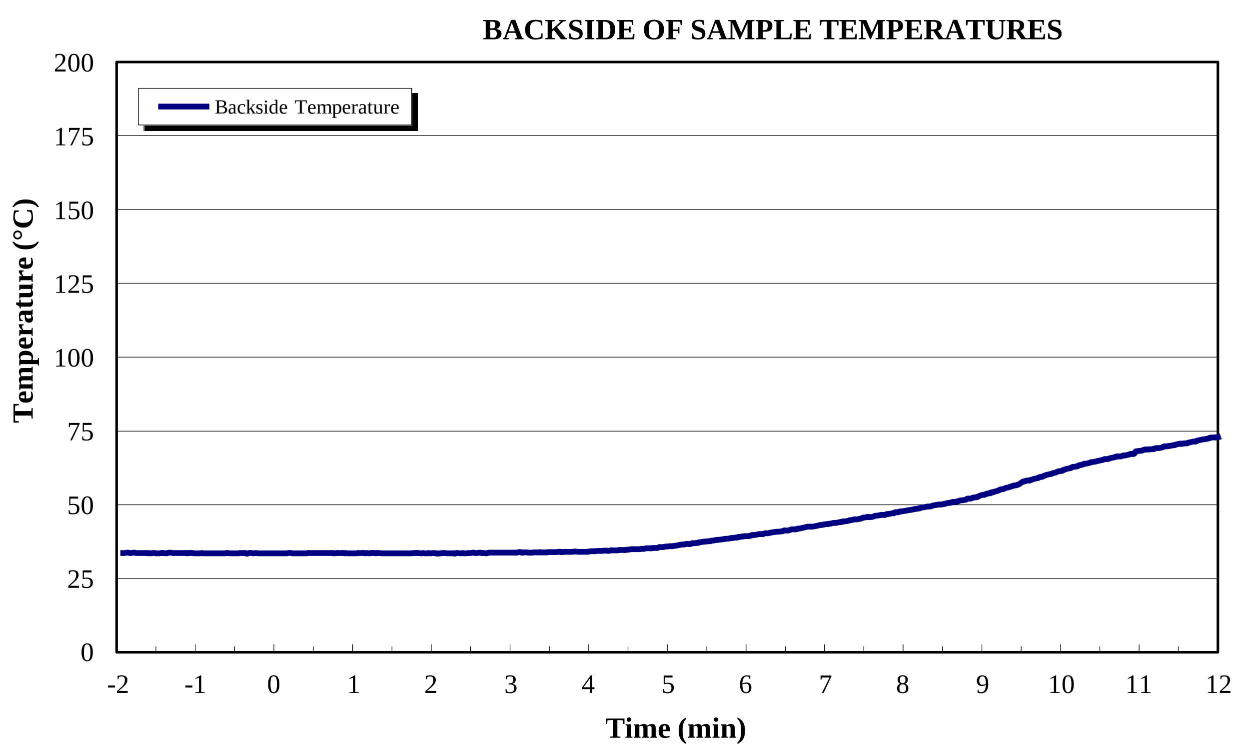

SMOKE RELEASE RATE AND TOTAL SMOKE RELEASED
Smoke Release Rate
Total Smoke Released
Smoke Release Rate (m²/s)
Total Smoke Released (m²)
Time (min)
45
40
35
30
25
20
15
10
5
0
180
160
140
120
100
80
60
40
20
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12


VOLUMETRIC DUCT FLOW RATE AND OPTICAL DENSITY
Volumetric Flow
Optical Density
Volumetric Flow Rate (m³/s)
Optical Density (m⁻¹)
Time (min)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12


SAMPLE MASS
Mass (kg)
300
280
260
240
220
200
180
160
140
120
100
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)


HEAT FLUX AT 4 FT
Heat Flux (kW/m²)
120
100
80
60
40
20
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)


TEMPERATURES AT 2, 4, 6 AND 8 FT
2-ft. Above Bottom
4-ft. Above Bottom
6-ft Above Bottom
8-ft. Above Bottom
Temperature (°C)
Time (min)
0
100
200
300
400
500
600
700
800
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12

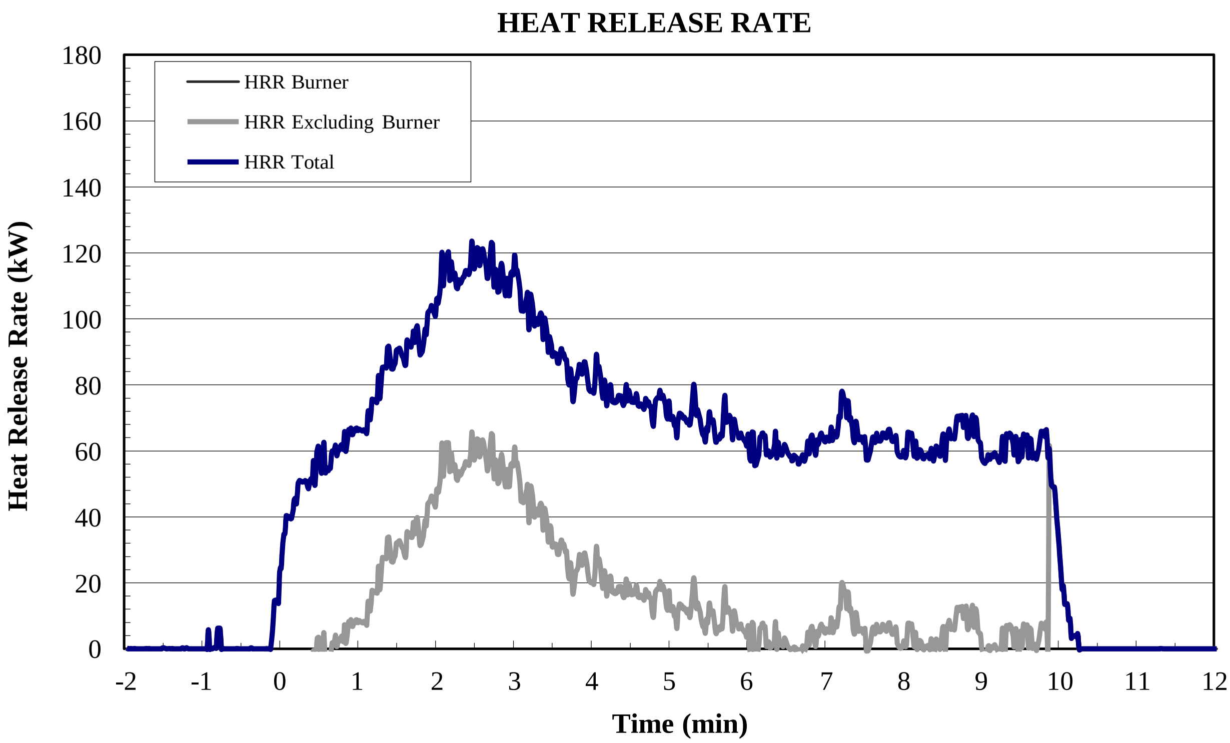

BACKSIDE OF SAMPLE TEMPERATURES
Backside Temperature
Temperature (°C)
Time (min)
0
25
50
75
100
125
150
175
200
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12

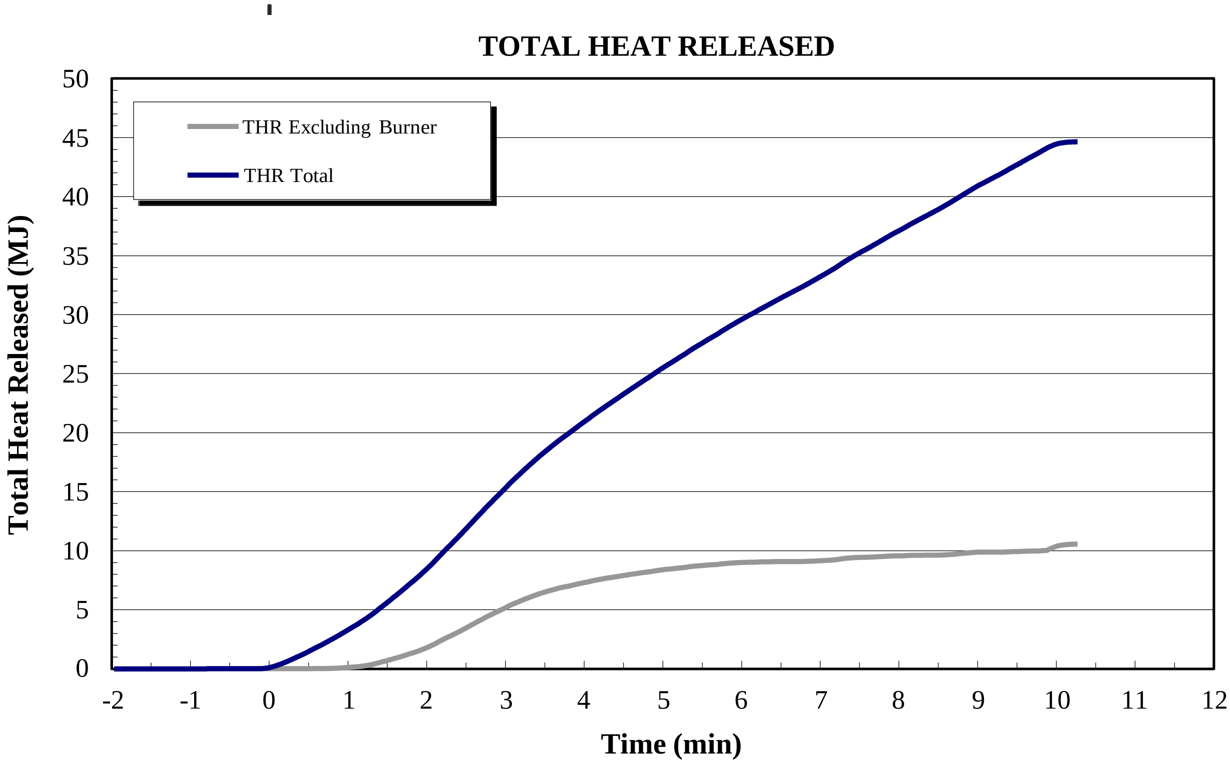
SUMMARY OF

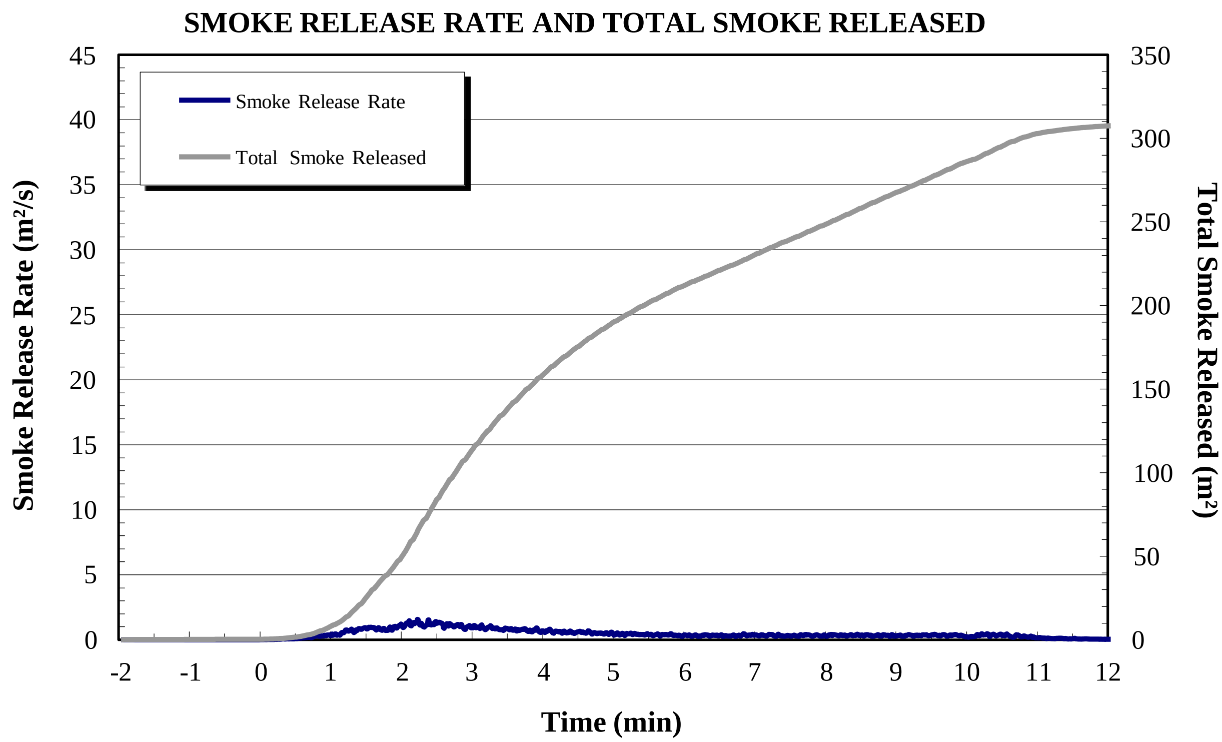
TEST RESULTS

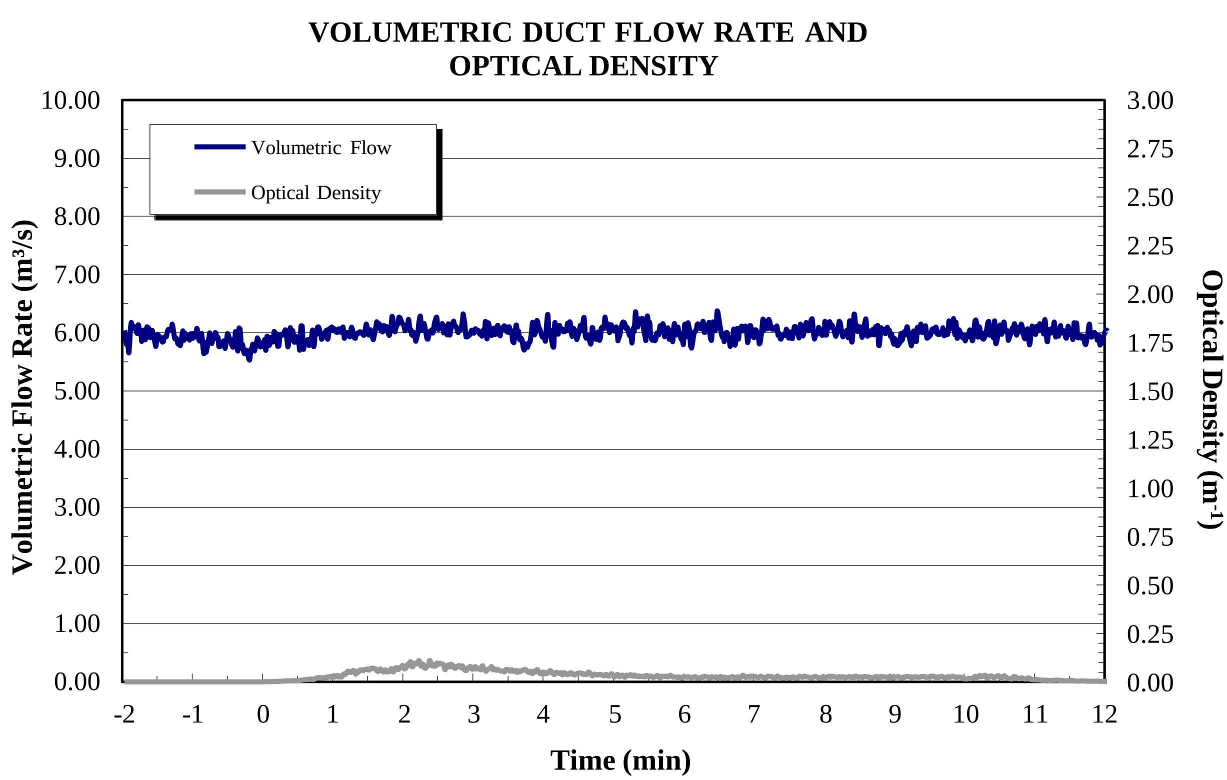
Material: ***Red Oak Plywood - Coated with Pitt Char XP***

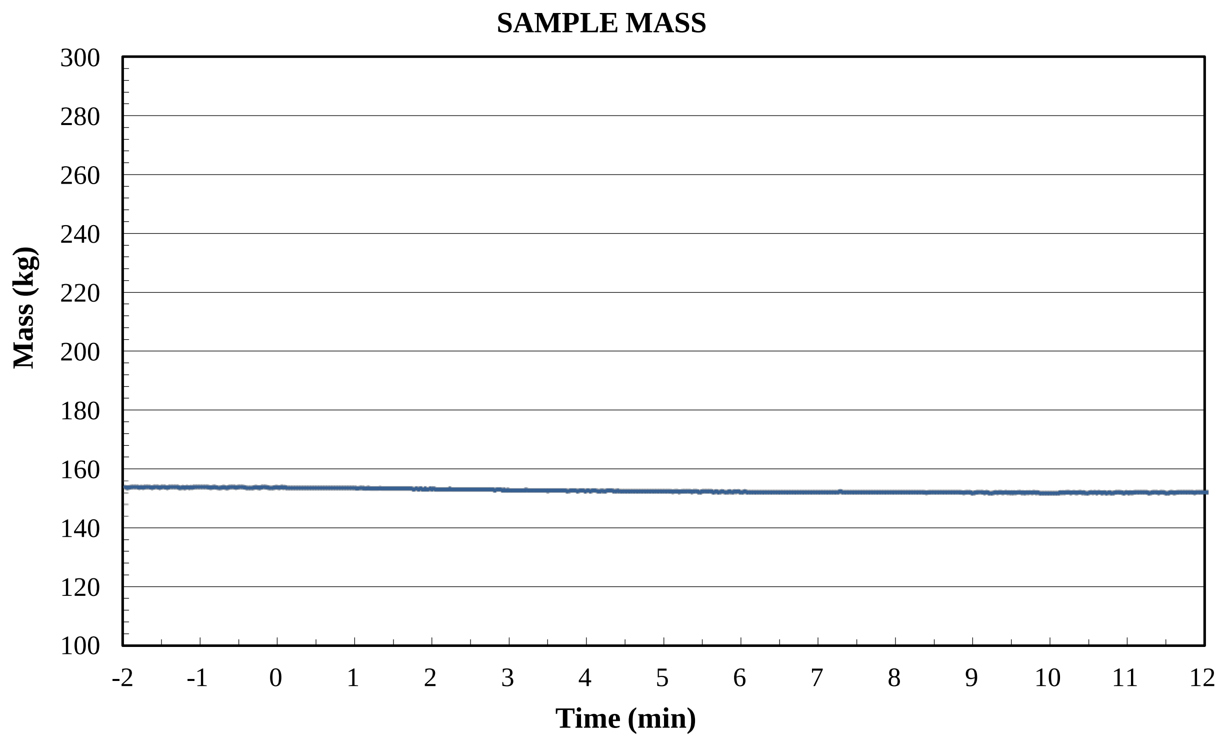
Maximum HRR_{total}	124 kW	at	2 min 28 sec
Average HRR_{total}	74 kW		
Total Heat Released	45 MJ		
Maximum $HRR_{excl.\ burner}$	66 kW	at	2 min 28 sec
Average $HRR_{excl.\ burner}$	18 kW		
Total Heat Released (Excluding Burner)	11 MJ		
Maximum $HRR_{10\ min}$	N/A*		
$HRR_{12\ min}$	N/A*		
Maximum Flame Height	> 2.4 m	at	7 min 0 sec
Heat Flux at 4 ft	22 kW/m²	at	2 min 30 sec
Maximum Smoke Generation $Rate_{0\text{-}10\ min}$	0.18 g/s	at	2 min 14 sec
Smoke Generation $Rate_{12min}$	N/A*		
Total Smoke Generated	32 g		
Maximum Smoke Release Rate	1.56 m²/s	at	2 min 30 sec
Average Smoke Release Rate	0.51 m²/s		
Total Smoke Released	308 m²		
Maximum Optical Density	0.11 1/m	at	2 min 23 sec
Maximum Duct Flow Rate	6.02 m³/s		
Average Optical Density	0.030 1/m		
Average Volumetric Duct Flow Rate	6.00 m³/s		
Total Mass Loss	2.01 kg		
Smoke Yield	0.016		
Maximum Sample Backside Temperature	38°C	at	11 min 55 sec


HEAT RELEASE RATE
HRR Burner
HRR Excluding Burner
HRR Total
Heat Release Rate (kW)
Time (min)
180
160
140
120
100
80
60
40
20
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12

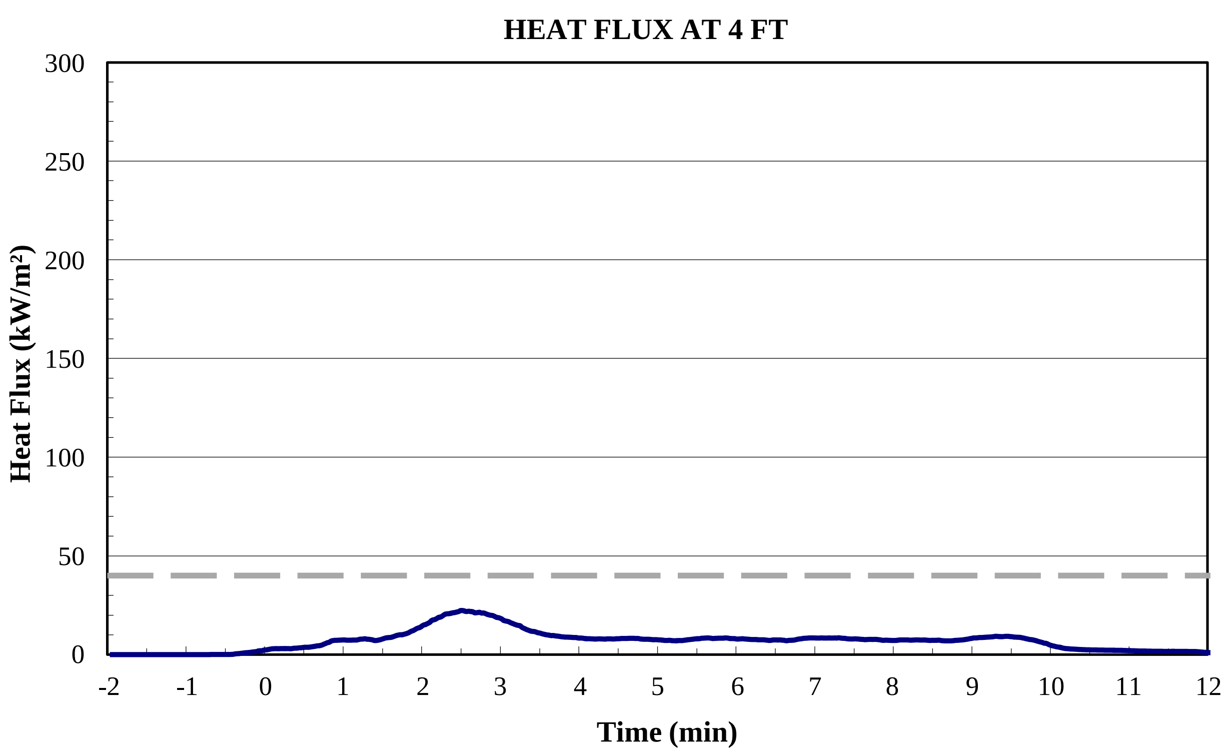

TOTAL HEAT RELEASED
THR Excluding Burner
THR Total
Total Heat Released (MJ)
Time (min)
50
45
40
35
30
25
20
15
10
5
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12


SMOKE RELEASE RATE AND TOTAL SMOKE RELEASED
Smoke Release Rate
Total Smoke Released
Smoke Release Rate (m²/s)
Total Smoke Released (m²)
Time (min)
45
40
35
30
25
20
15
10
5
0
350
300
250
200
150
100
50
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12

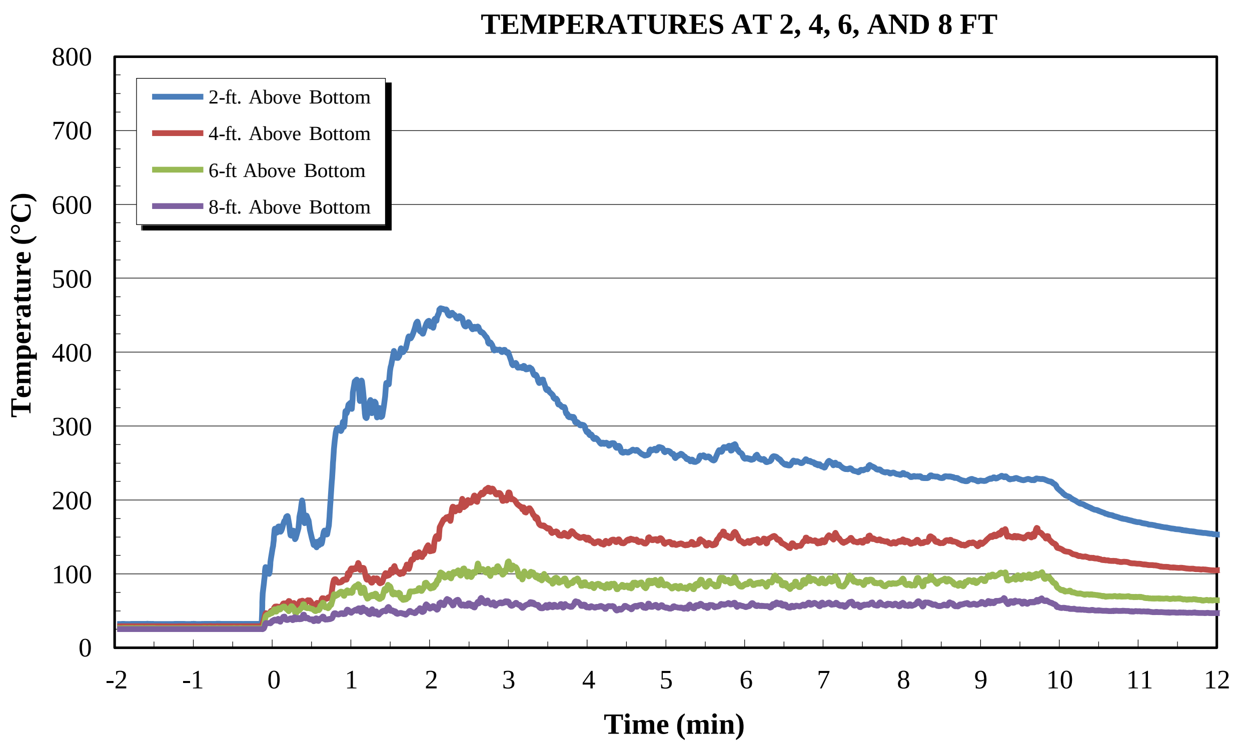

VOLUMETRIC DUCT FLOW RATE AND OPTICAL DENSITY
Volumetric Flow
Optical Density
Volumetric Flow Rate (m³/s)
Optical Density (m⁻¹)
Time (min)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12

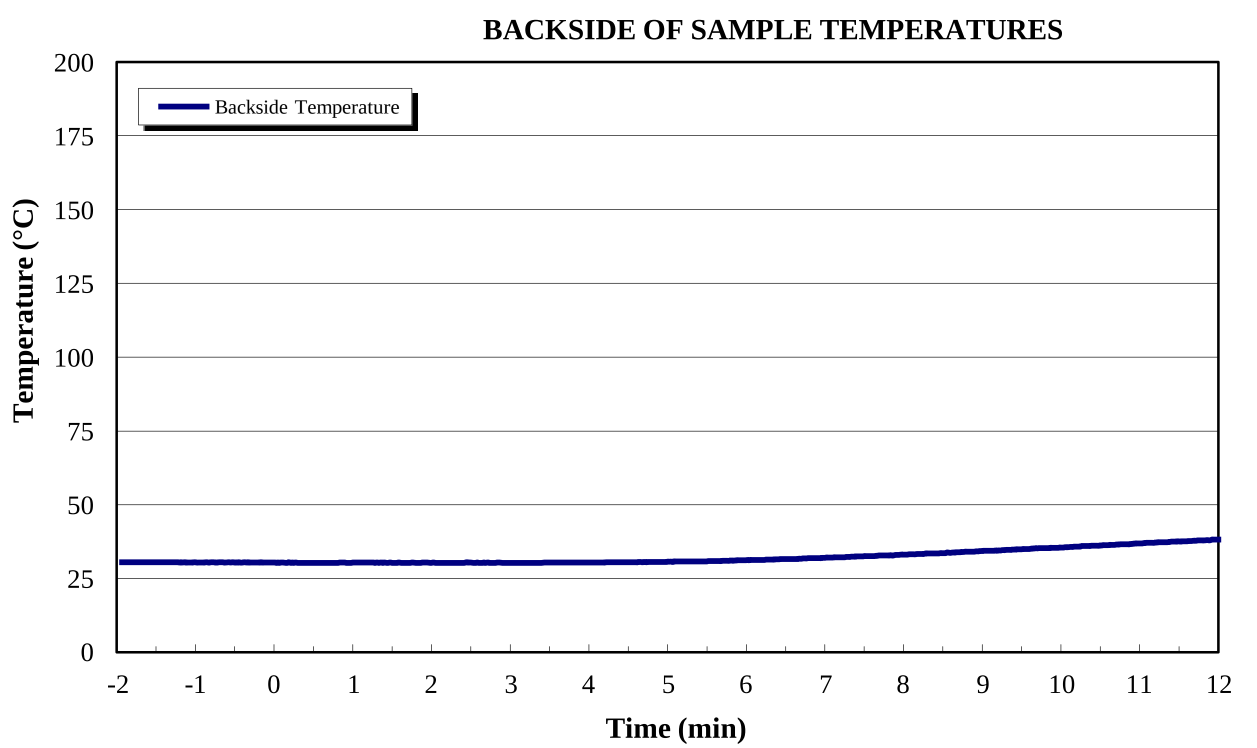


SAMPLE MASS
Mass (kg)
300
280
260
240
220
200
180
160
140
120
100
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)



HEAT FLUX AT 4 FT
Heat Flux (kW/m²)
300
250
200
150
100
50
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)


TEMPERATURES AT 2, 4, 6, AND 8 FT
2-ft. Above Bottom
4-ft. Above Bottom
6-ft Above Bottom
8-ft. Above Bottom
Temperature (°C)
Time (min)
800
700
600
500
400
300
200
100
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12

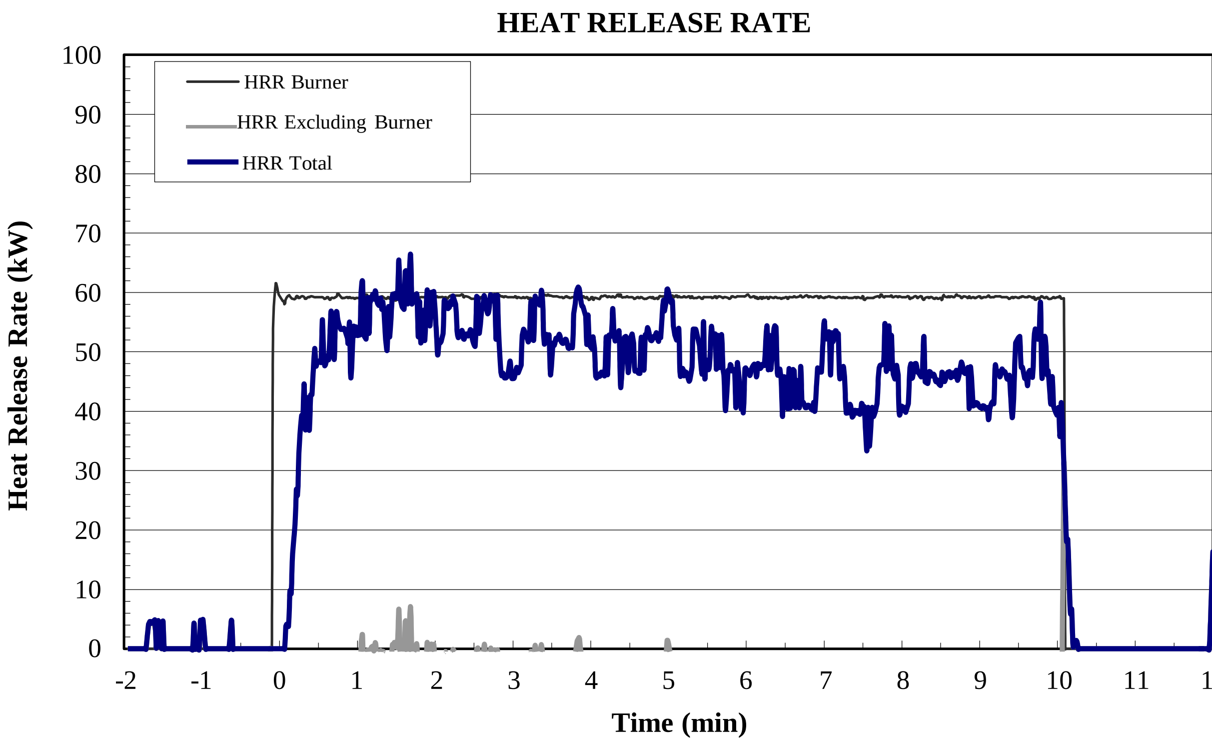

BACKSIDE OF SAMPLE TEMPERATURES
Backside Temperature
Temperature (°C)
Time (min)
200
175
150
125
100
75
50
25
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12

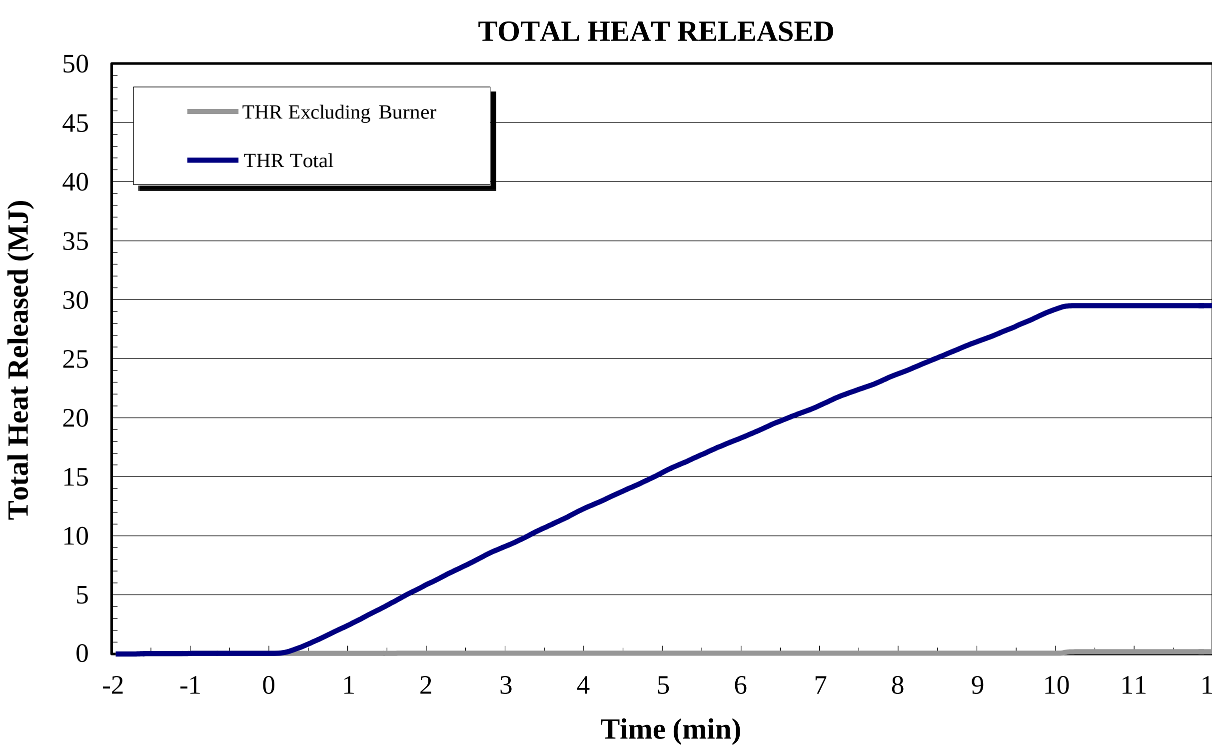
SUMMARY OF

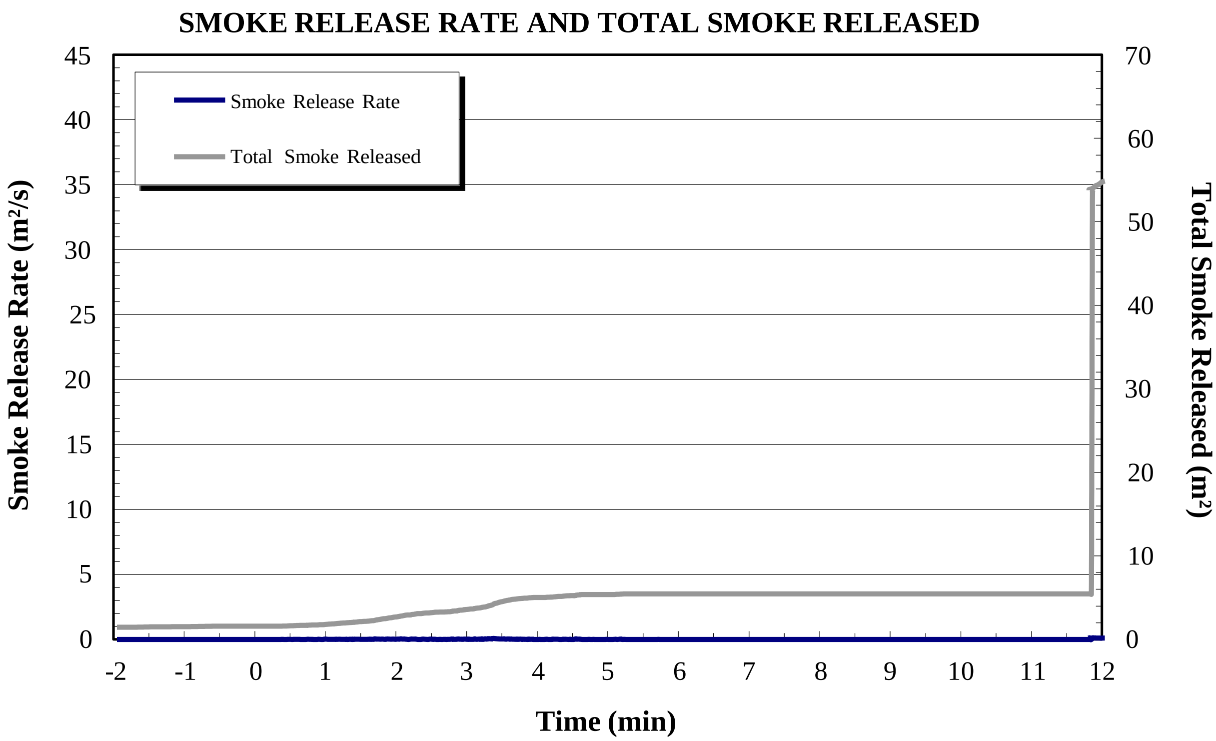
TEST RESULTS

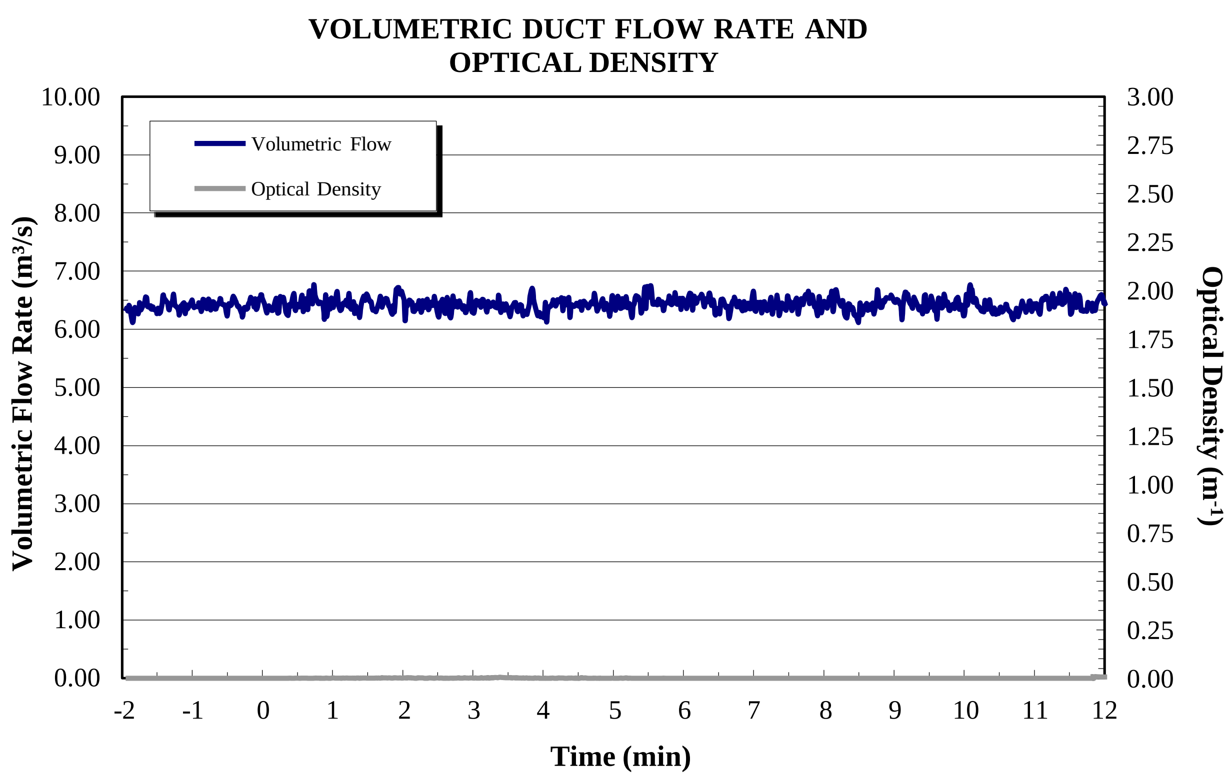
Material: ***Gypsum Wallboard - Uncoated - Run 1***

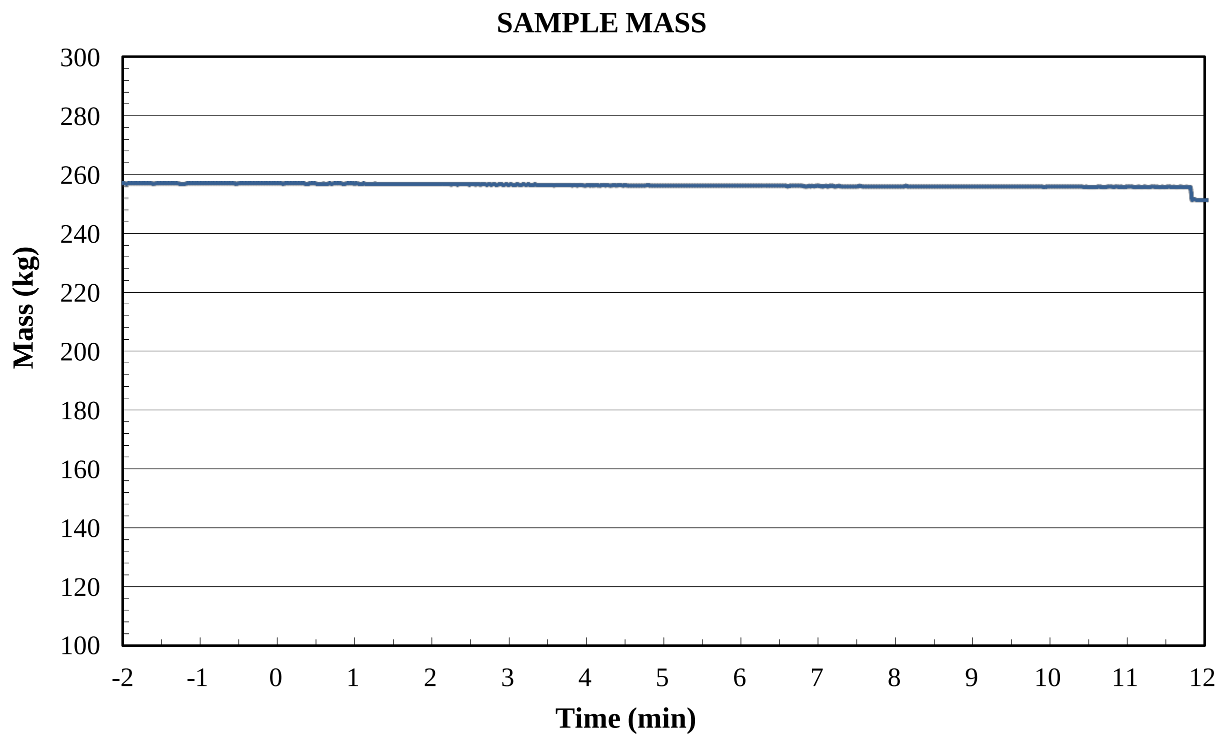
Maximum HRR_{total}	67 kW	at	1 min 38 sec
Average HRR_{total}	50 kW		
Total Heat Released	30 MJ		
Maximum $HRR_{excl. burner}$	55 kW	at	12 min 9 sec
Average $HRR_{excl. burner}$	1 kW		
Total Heat Released (Excluding Burner)	1 MJ		
Maximum $HRR_{10 min}$	N/A*		
$HRR_{12 min}$	N/A*		
Maximum Flame Height	> 2.4 m	at	7 min 0 sec
Heat Flux at 4 ft	4 kW/m²	at	1 min 45 sec
Maximum Smoke Generation $Rate_{0-10 min}$	0.01 g/s	at	3 min 20 sec
Smoke Generation $Rate_{12min}$	N/A*		
Total Smoke Generated	1 g		
Maximum Smoke Release Rate	0.12 m²/s	at	1 min 45 sec
Average Smoke Release Rate	0.09 m²/s		
Total Smoke Released	56 m²		
Maximum Optical Density	0.01 1/m	at	11 min 54 sec
Maximum Duct Flow Rate	6.48 m³/s		
Average Optical Density	0.001 1/m		
Average Volumetric Duct Flow Rate	6.43 m³/s		
Total Mass Loss	1.08 kg		
Smoke Yield	0.001		
Maximum Sample Backside Temperature	40°C	at	11 min 49 sec

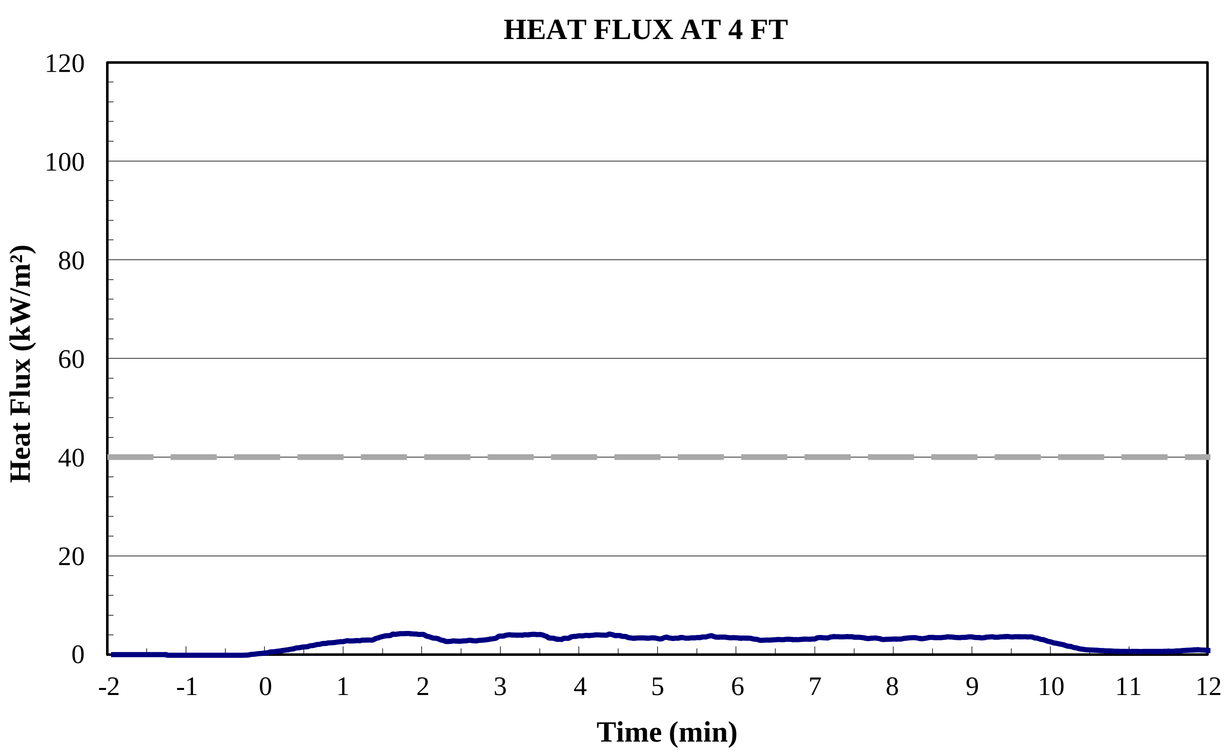

HEAT RELEASE RATE
HRR Burner
HRR Excluding Burner
HRR Total
Heat Release Rate (kW)
Time (min)
100
90
80
70
60
50
40
30
20
10
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12

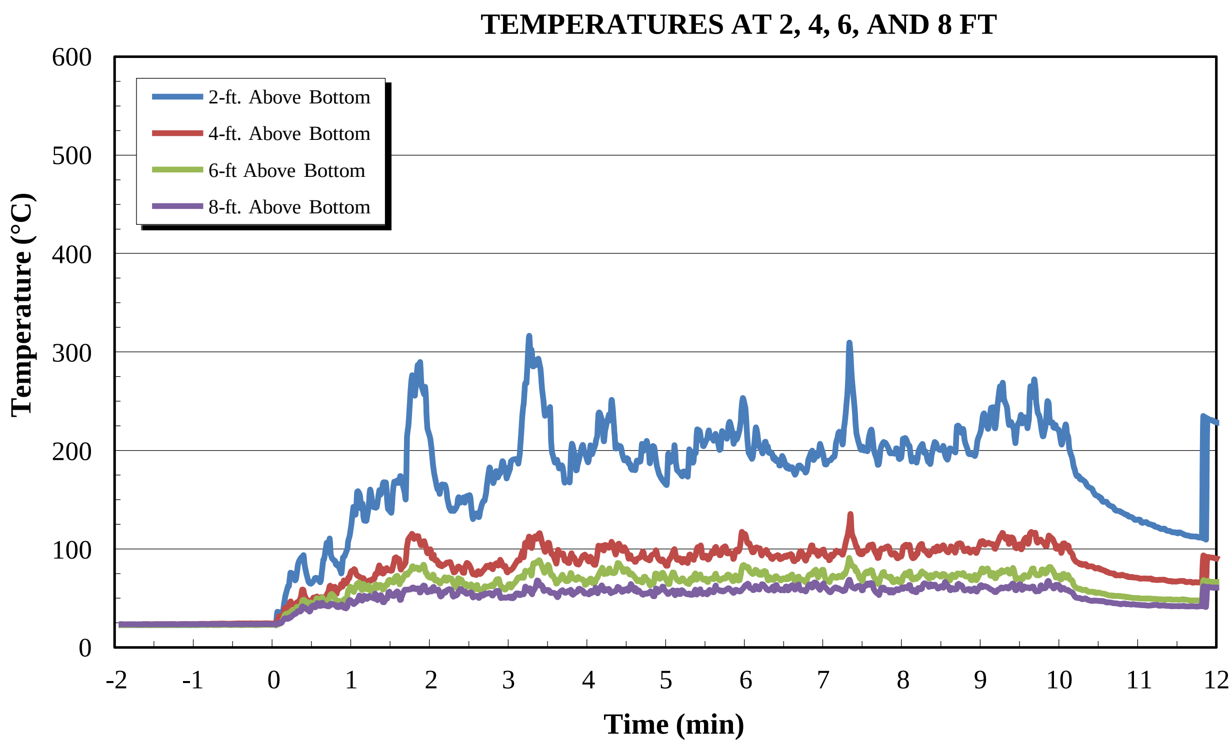

TOTAL HEAT RELEASED
THR Excluding Burner
THR Total
Total Heat Released (MJ)
Time (min)
50
45
40
35
30
25
20
15
10
5
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12


SMOKE RELEASE RATE AND TOTAL SMOKE RELEASED
Smoke Release Rate
Total Smoke Released
Smoke Release Rate (m²/s)
Total Smoke Released (m²)
Time (min)
45
40
35
30
25
20
15
10
5
0
70
60
50
40
30
20
10
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12

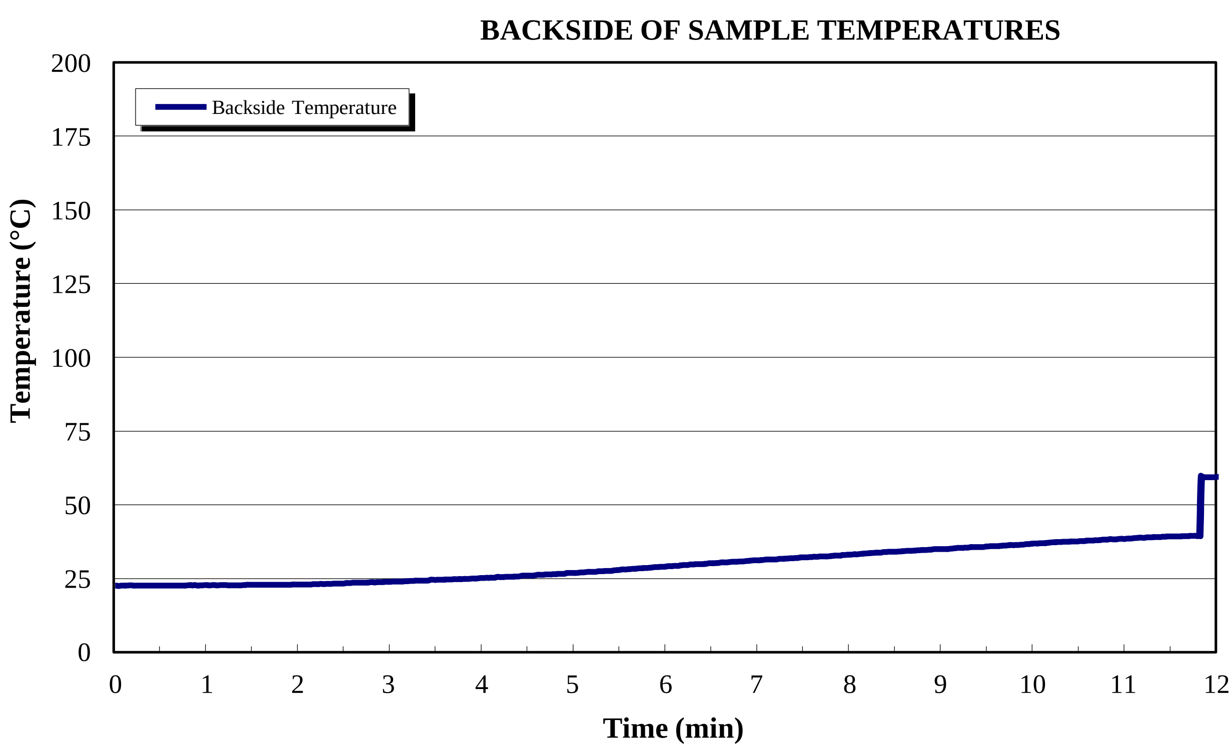

VOLUMETRIC DUCT FLOW RATE AND
OPTICAL DENSITY
Volumetric Flow
Optical Density
Volumetric Flow Rate (m³/s)
Optical Density (m⁻¹)
Time (min)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12


SAMPLE MASS
Mass (kg)
300
280
260
240
220
200
180
160
140
120
100
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)


HEAT FLUX AT 4 FT
Heat Flux (kW/m²)
120
100
80
60
40
20
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)



TEMPERATURES AT 2, 4, 6, AND 8 FT
2-ft. Above Bottom
4-ft. Above Bottom
6-ft Above Bottom
8-ft. Above Bottom
Temperature (°C)
0
100
200
300
400
500
600
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)



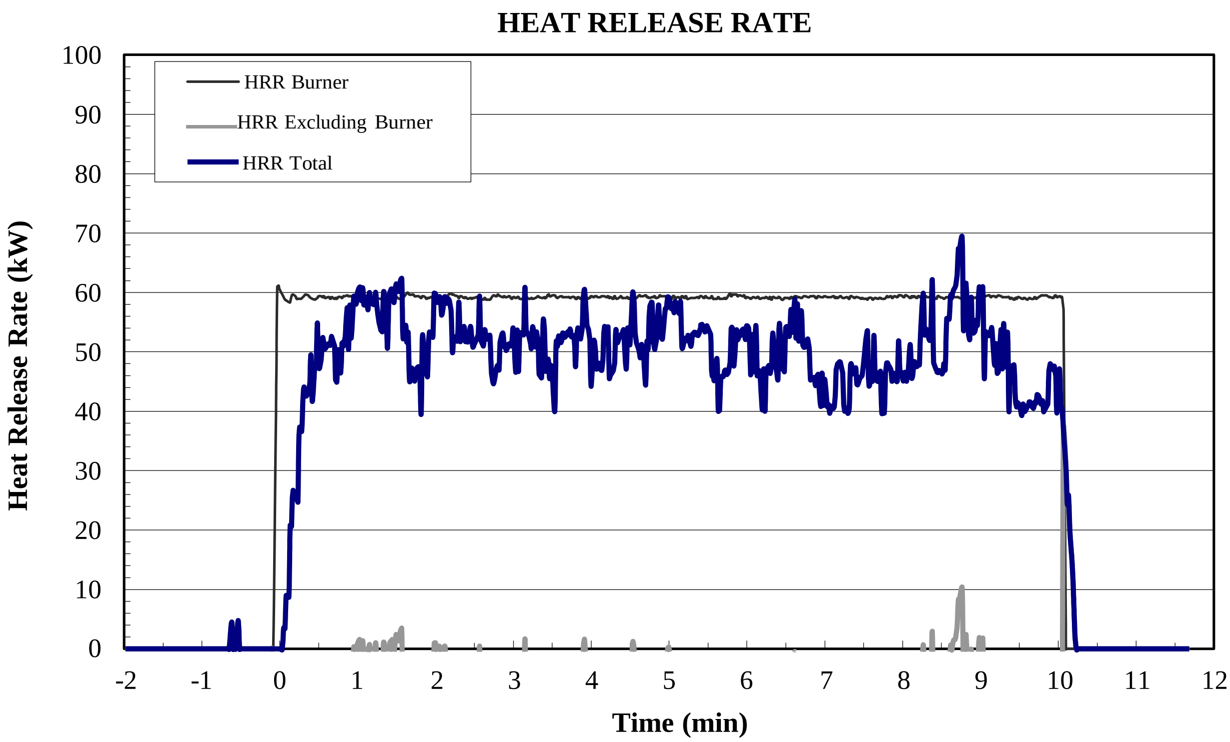
BACKSIDE OF SAMPLE TEMPERATURES
Backside Temperature
Temperature (°C)
0
25
50
75
100
125
150
175
200
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)

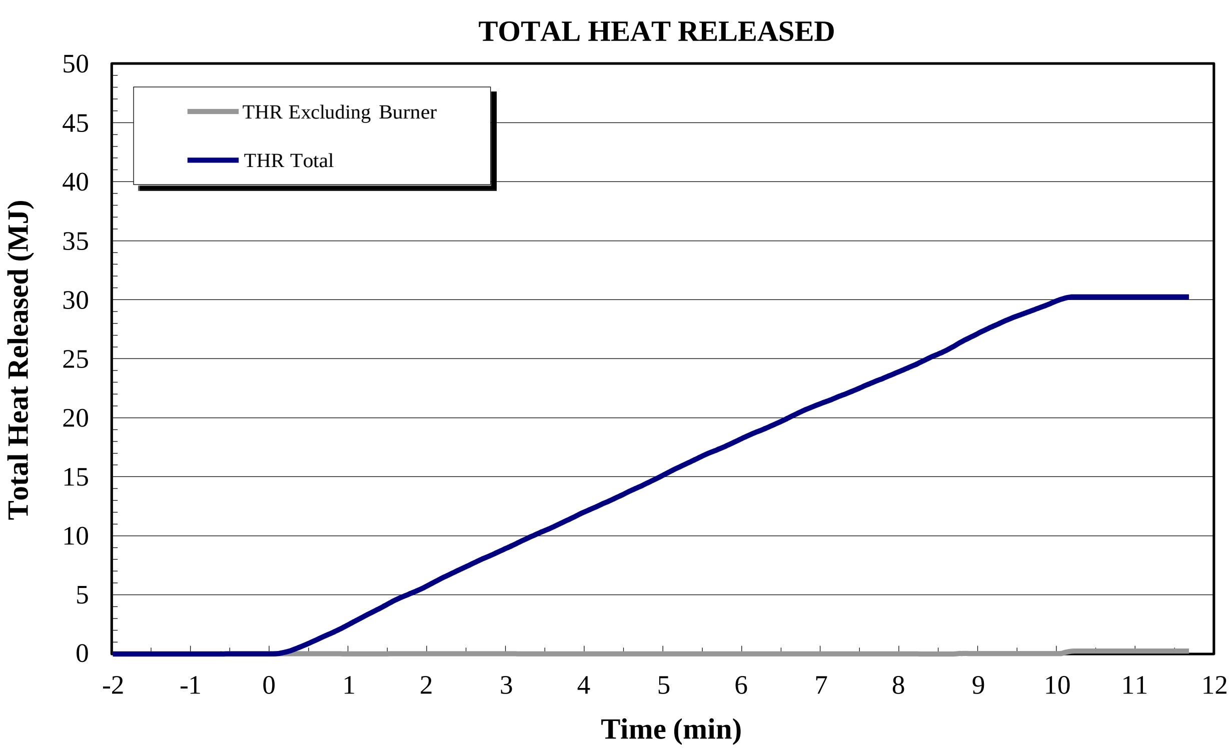
SUMMARY OF

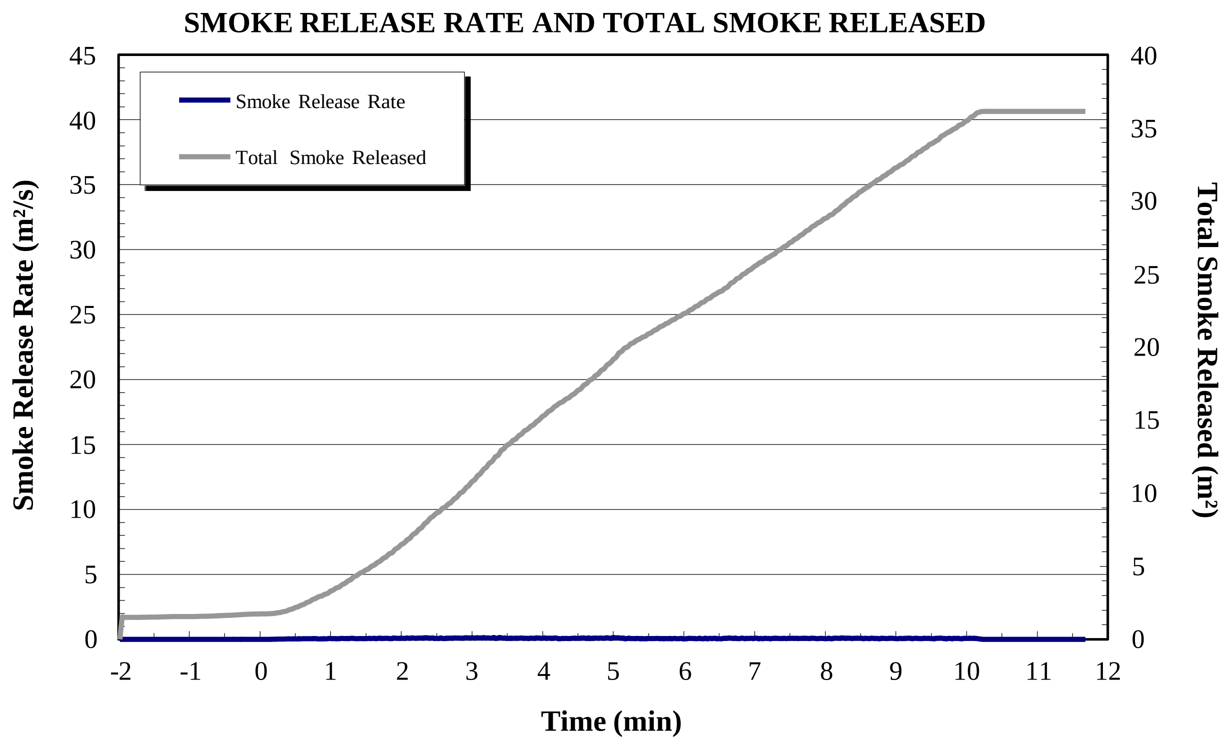
TEST RESULTS

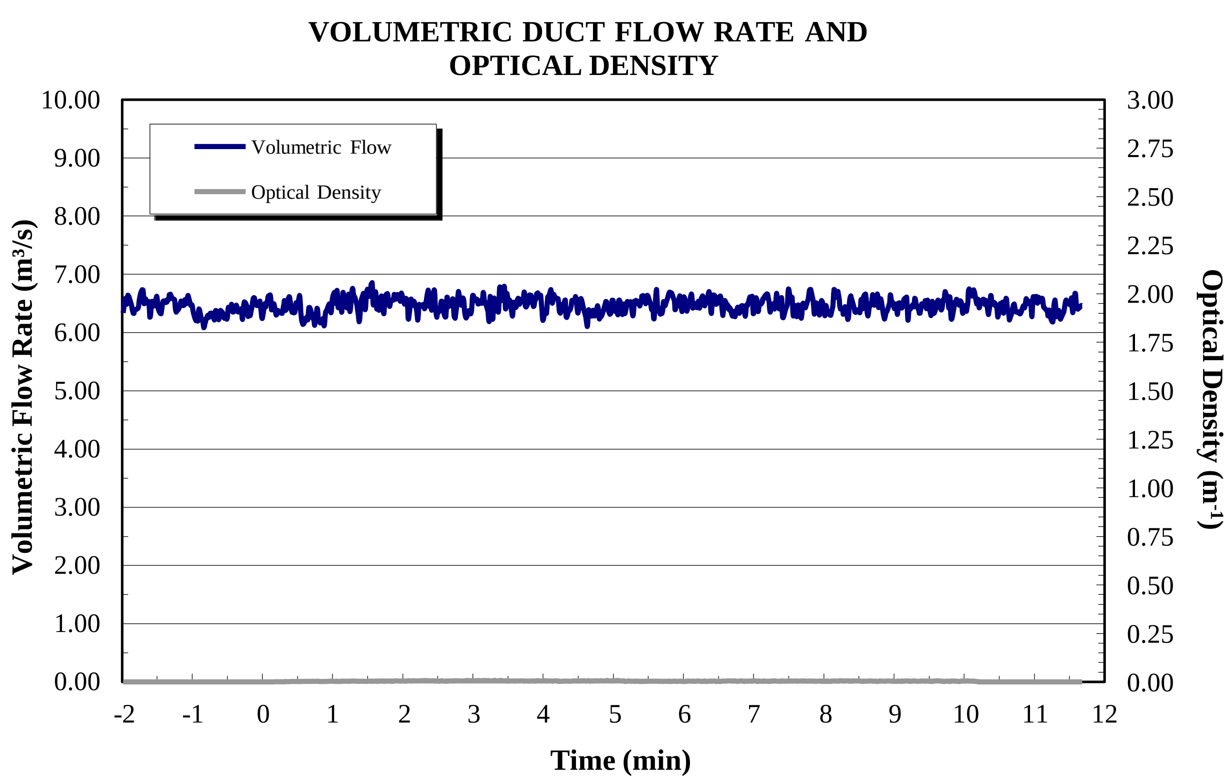
Material: ***Gypsum Wallboard - Uncoated - Run 2***

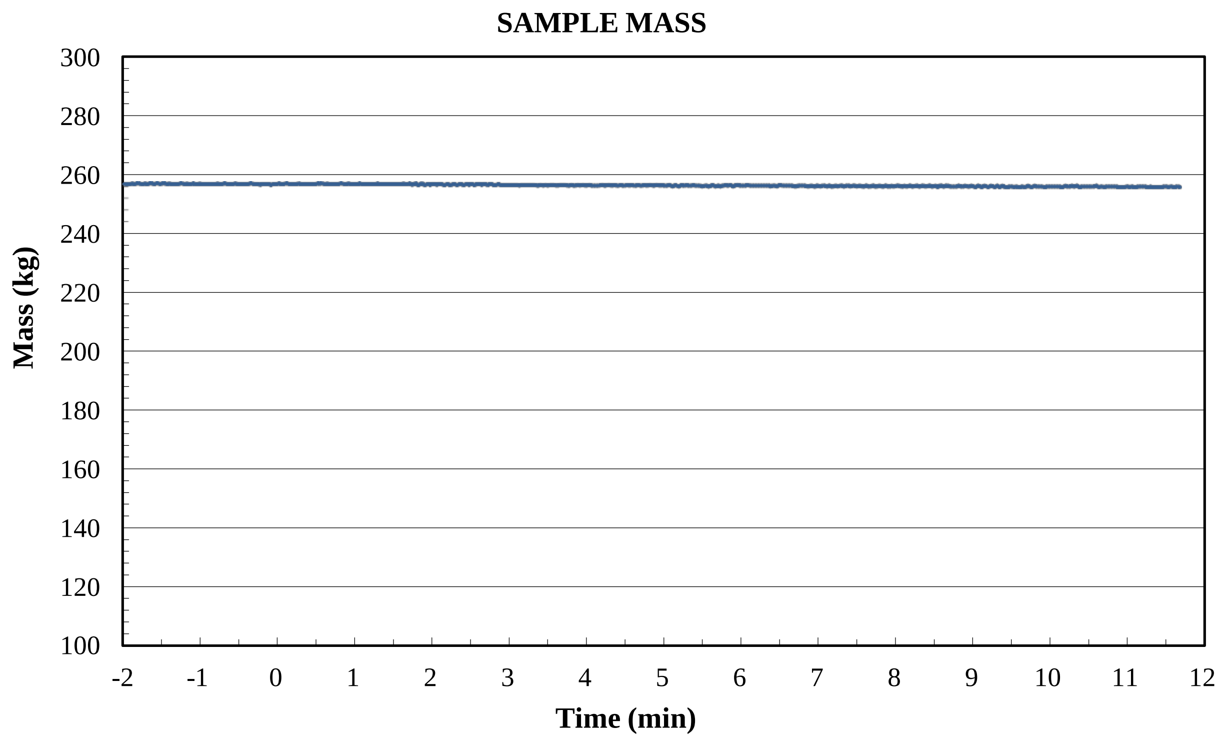
Maximum HRR_{total}	69 kW	at	8 min 46 sec
Average HRR_{total}	50 kW		
Total Heat Released	30 MJ		
Maximum $HRR_{excl.\ burner}$	37 kW	at	10 min 4 sec
Average $HRR_{excl.\ burner}$	0 kW		
Total Heat Released (Excluding Burner)	0 MJ		
Maximum $HRR_{10\ min}$	N/A*		
$HRR_{12\ min}$	N/A*		
Maximum Flame Height	> 2.4 m	at	7 min 0 sec
Heat Flux at 4 ft	6 kW/m²	at	3 min 48 sec
Maximum Smoke Generation $Rate_{0\text{-}10\ min}$	0.02 g/s	at	3 min 24 sec
Smoke Generation $Rate_{12min}$	N/A*		
Total Smoke Generated	5 g		
Maximum Smoke Release Rate	0.13 m²/s	at	3 min 48 sec
Average Smoke Release Rate	0.06 m²/s		
Total Smoke Released	36 m²		
Maximum Optical Density	0.01 1/m	at	3 min 10 sec
Maximum Duct Flow Rate	6.52 m³/s		
Average Optical Density	0.004 1/m		
Average Volumetric Duct Flow Rate	6.46 m³/s		
Total Mass Loss	1.35 kg		
Smoke Yield	0.004		
Maximum Sample Backside Temperature	60°C		

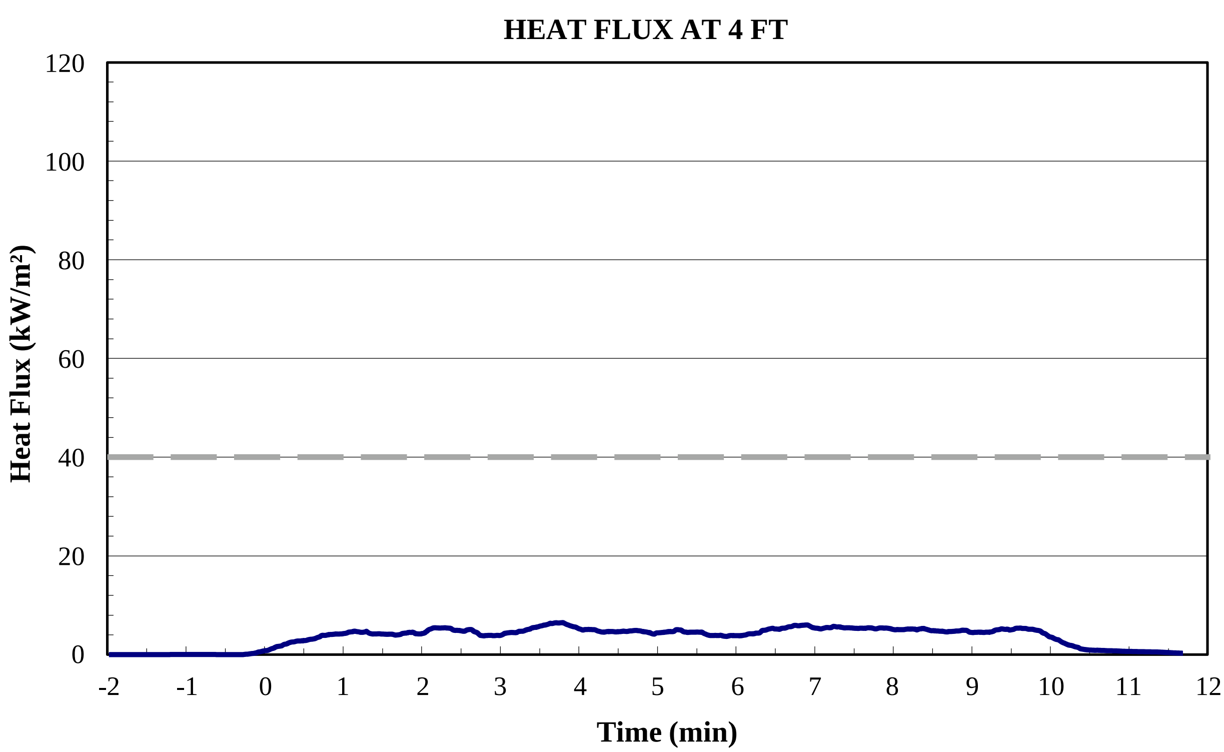

HEAT RELEASE RATE
HRR Burner
HRR Excluding Burner
HRR Total
Heat Release Rate (kW)
Time (min)
100
90
80
70
60
50
40
30
20
10
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12

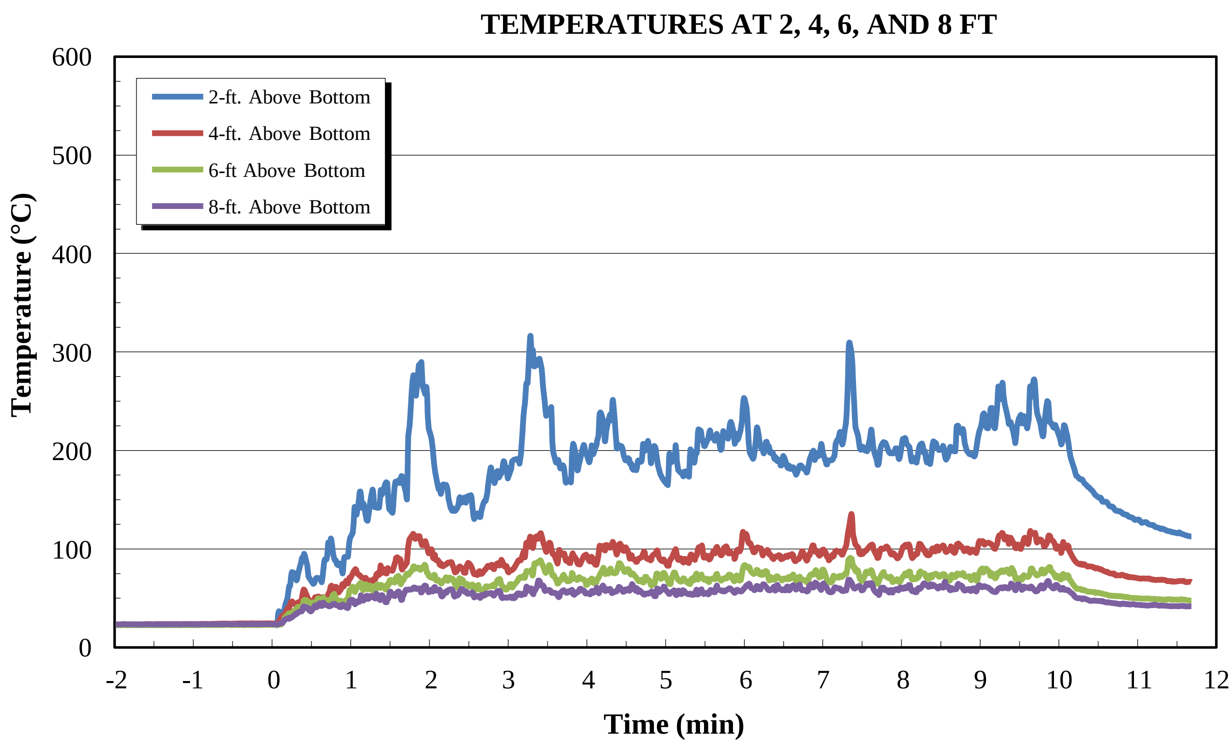

TOTAL HEAT RELEASED
THR Excluding Burner
THR Total
Total Heat Released (MJ)
Time (min)
50
45
40
35
30
25
20
15
10
5
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12

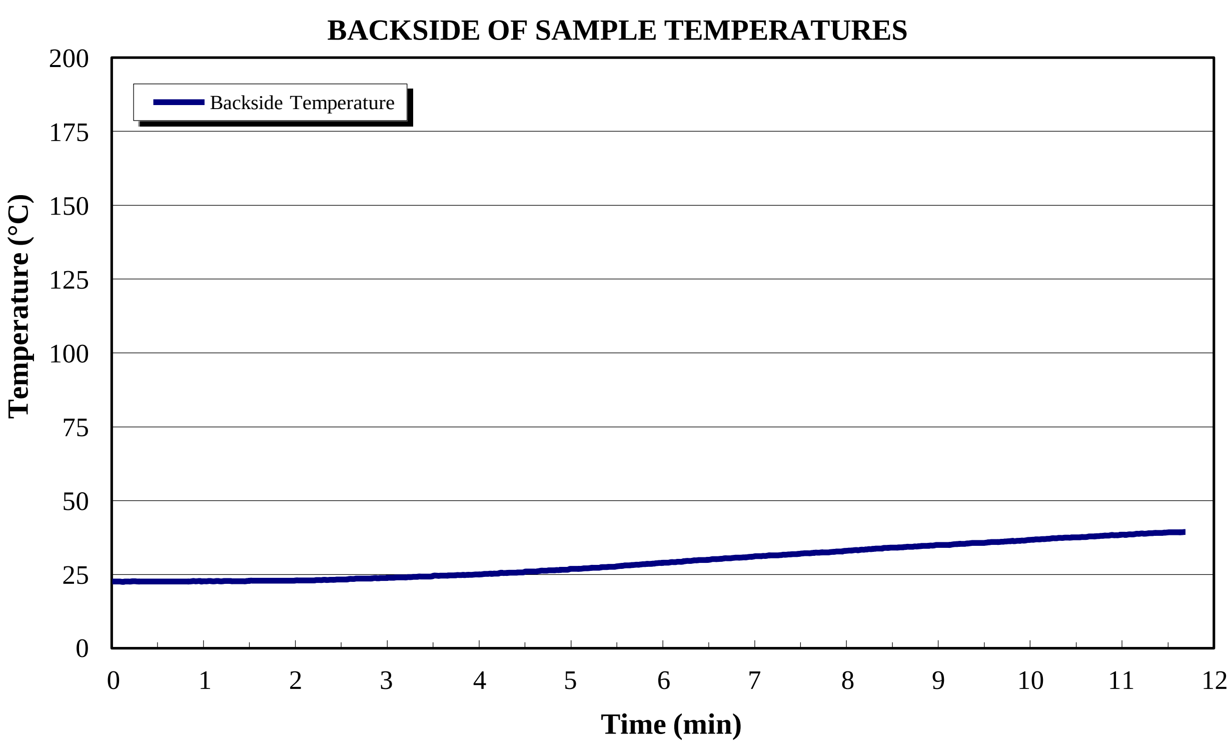

SMOKE RELEASE RATE AND TOTAL SMOKE RELEASED
Smoke Release Rate
Total Smoke Released
Smoke Release Rate (m²/s)
Total Smoke Released (m²)
Time (min)
45
40
35
30
25
20
15
10
5
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12


VOLUMETRIC DUCT FLOW RATE AND OPTICAL DENSITY
Volumetric Flow
Optical Density
Volumetric Flow Rate (m³/s)
Optical Density (m⁻¹)
Time (min)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00


SAMPLE MASS
Mass (kg)
300
280
260
240
220
200
180
160
140
120
100
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)


HEAT FLUX AT 4 FT
Heat Flux (kW/m²)
120
100
80
60
40
20
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)


TEMPERATURES AT 2, 4, 6, AND 8 FT
2-ft. Above Bottom
4-ft. Above Bottom
6-ft Above Bottom
8-ft. Above Bottom
Temperature (°C)
600
500
400
300
200
100
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)

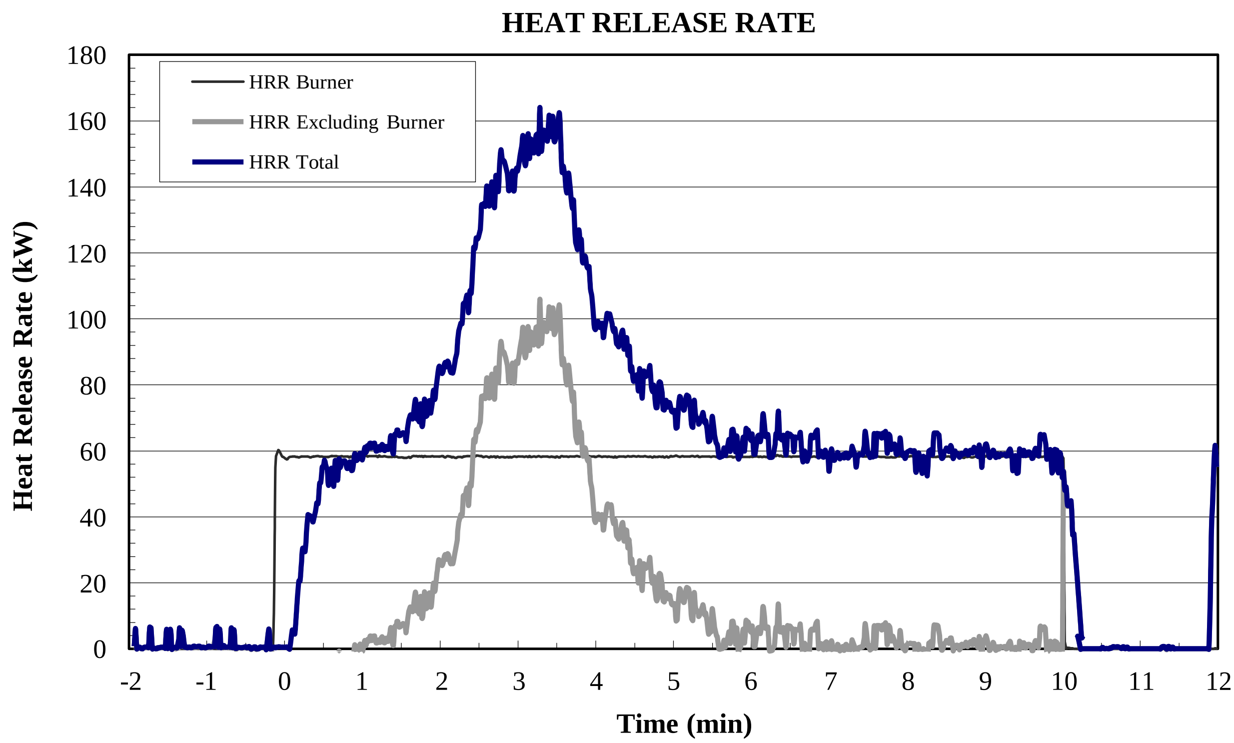

BACKSIDE OF SAMPLE TEMPERATURES
Backside Temperature
Temperature (°C)
200
175
150
125
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)

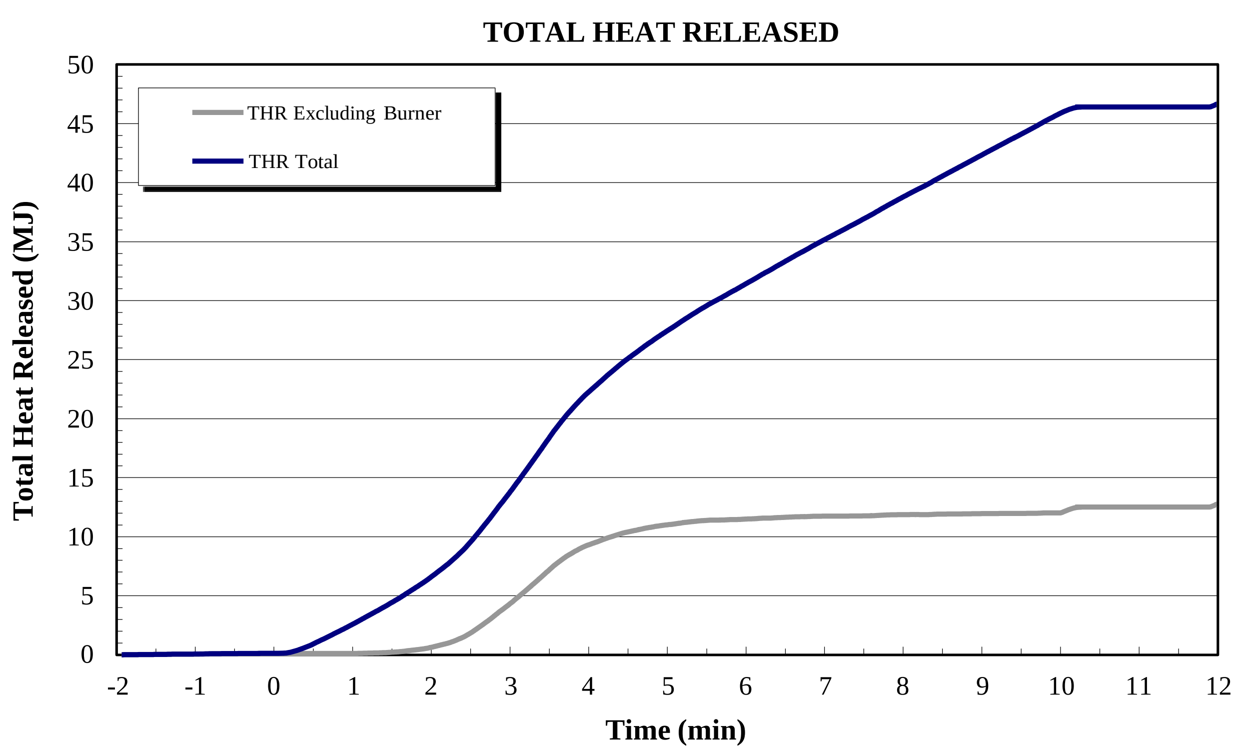
SUMMARY OF

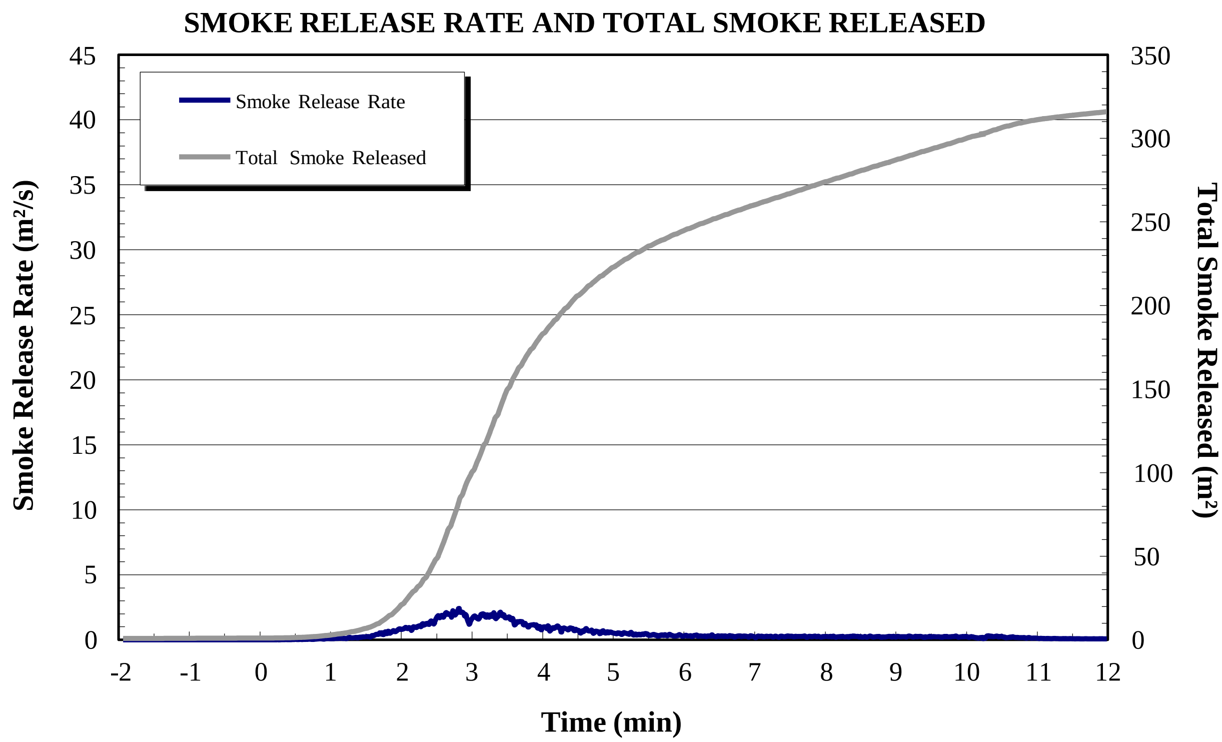
TEST RESULTS

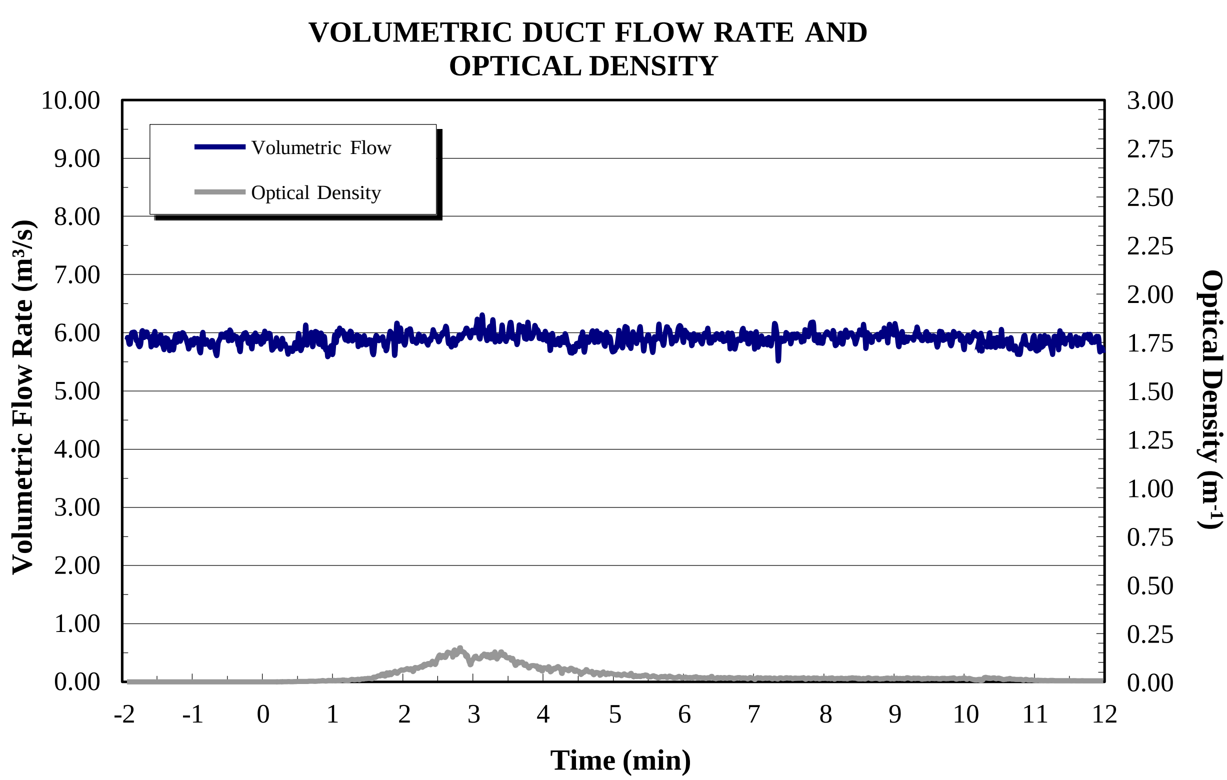
Material: ***Gypsum Wallboard - Coated with Pitt Char XP***

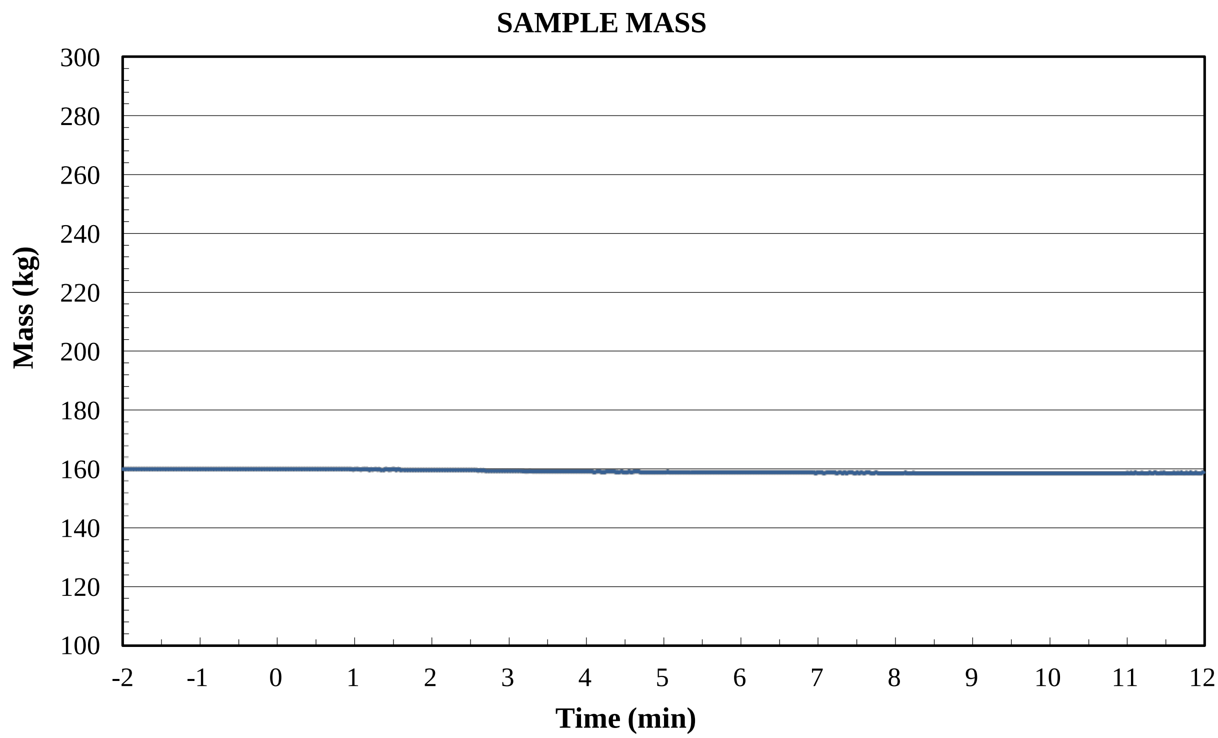
Maximum HRR_{total}	164 kW	at	3 min 13 sec
Average HRR_{total}	78 kW		
Total Heat Released	47 MJ		
Maximum $HRR_{excl.\ burner}$	106 kW	at	3 min 13 sec
Average $HRR_{excl.\ burner}$	21 kW		
Total Heat Released (Excluding Burner)	13 MJ		
Maximum $HRR_{10\ min}$	N/A*		
$HRR_{12\ min}$	N/A*		
Maximum Flame Height	> 2.4 m	at	7 min 0 sec
Heat Flux at 4 ft	35 kW/m²	at	3 min 19 sec
Maximum Smoke Generation $Rate_{0\text{-}10\ min}$	0.28 g/s	at	2 min 45 sec
Smoke Generation $Rate_{12min}$	N/A*		
Total Smoke Generated	36 g		
Maximum Smoke Release Rate	2.41 m²/s	at	3 min 19 sec
Average Smoke Release Rate	0.53 m²/s		
Total Smoke Released	316 m²		
Maximum Optical Density	0.18 1/m	at	2 min 45 sec
Maximum Duct Flow Rate	5.96 m³/s		
Average Optical Density	0.031 1/m		
Average Volumetric Duct Flow Rate	5.90 m³/s		
Total Mass Loss	1.44 kg		
Smoke Yield	0.025		
Maximum Sample Backside Temperature	87°C	at	10 min 25 sec

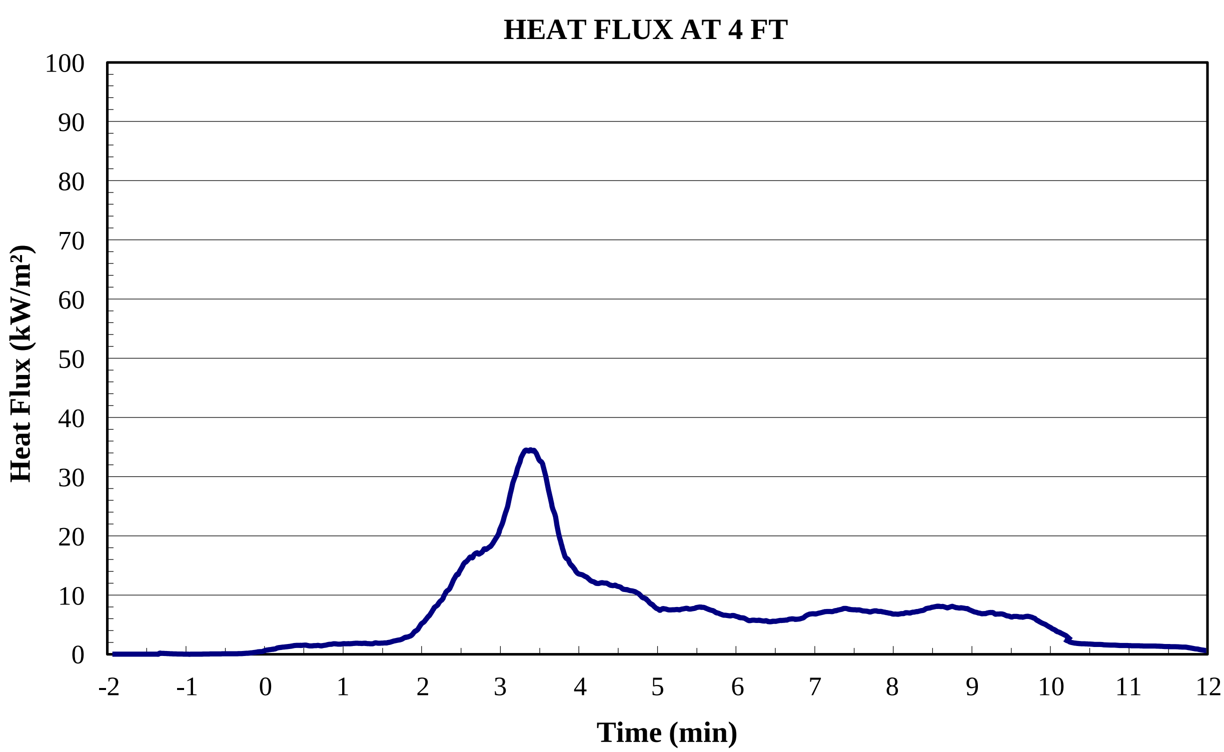

HEAT RELEASE RATE
HRR Burner
HRR Excluding Burner
HRR Total
Heat Release Rate (kW)
180
160
140
120
100
80
60
40
20
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)

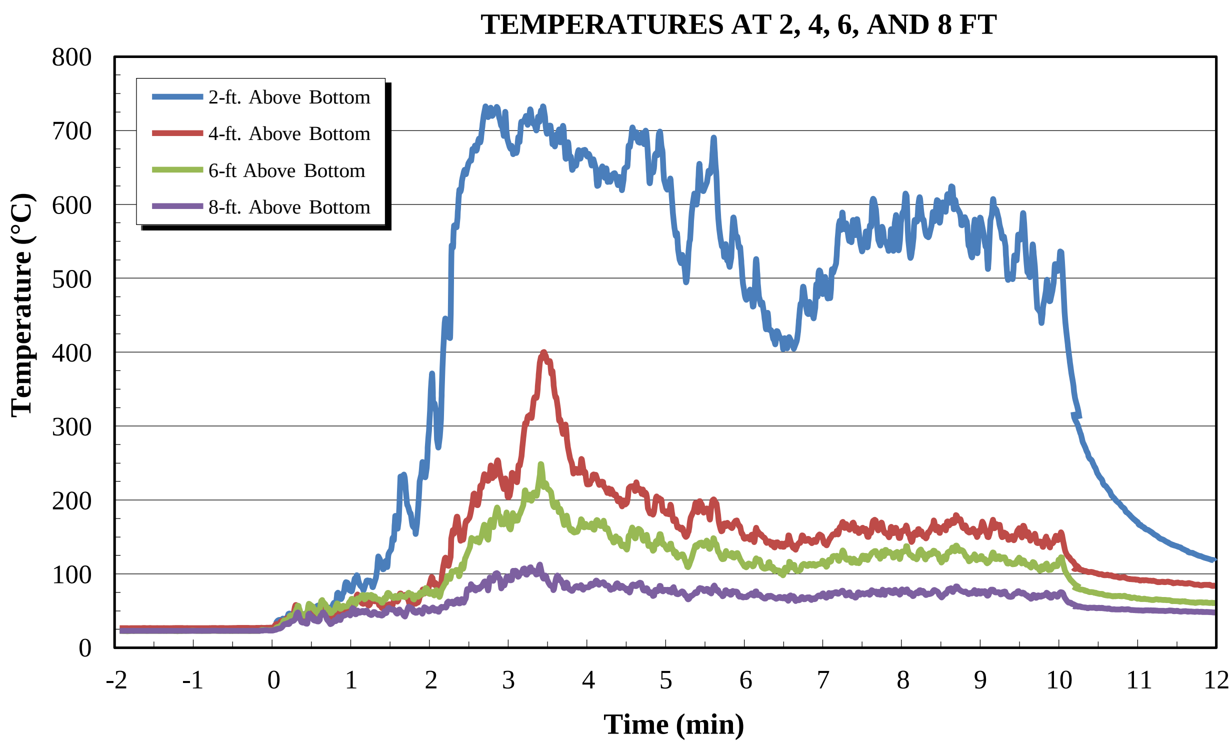

TOTAL HEAT RELEASED
THR Excluding Burner
THR Total
Total Heat Released (MJ)
50
45
40
35
30
25
20
15
10
5
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)


SMOKE RELEASE RATE AND TOTAL SMOKE RELEASED
Smoke Release Rate
Total Smoke Released
Smoke Release Rate (m²/s)
Total Smoke Released (m²)
Time (min)
45
40
35
30
25
20
15
10
5
0
350
300
250
200
150
100
50
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12

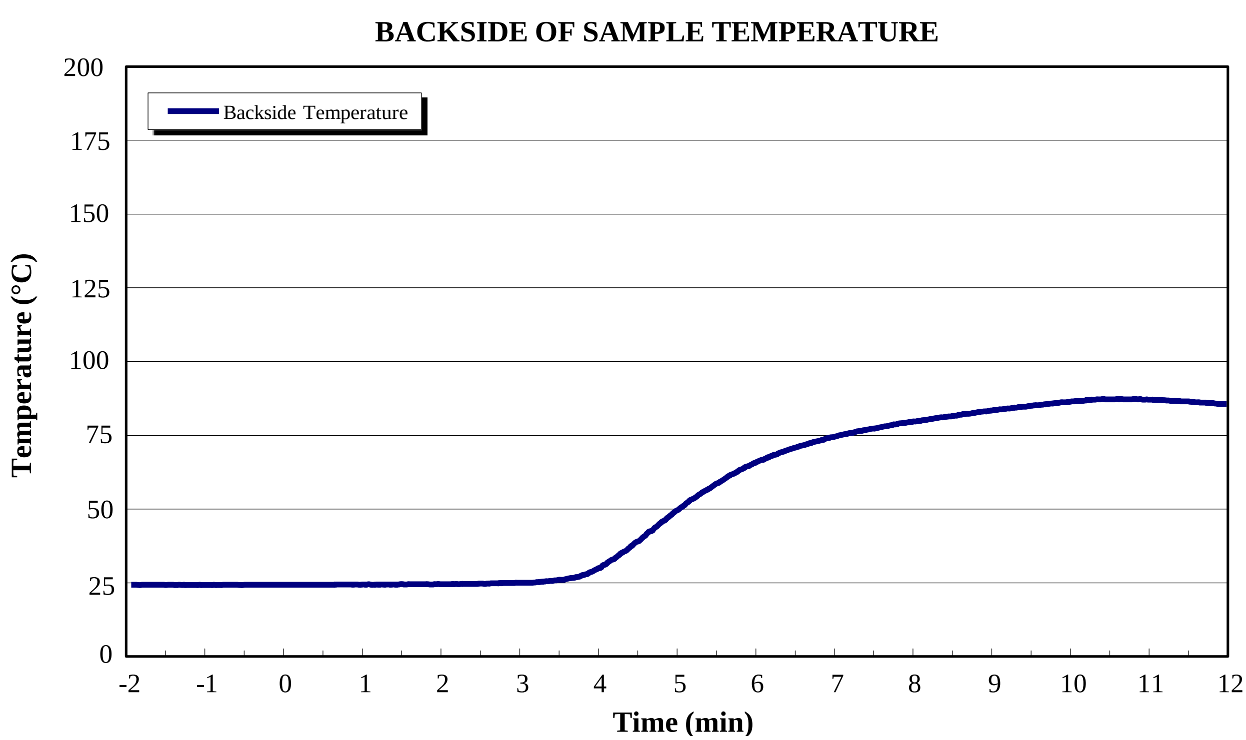

VOLUMETRIC DUCT FLOW RATE AND
OPTICAL DENSITY
Volumetric Flow
Optical Density
Volumetric Flow Rate (m³/s)
Optical Density (m⁻¹)
Time (min)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12


SAMPLE MASS
Mass (kg)
300
280
260
240
220
200
180
160
140
120
100
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)


HEAT FLUX AT 4 FT
Heat Flux (kW/m²)
100
90
80
70
60
50
40
30
20
10
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)



TEMPERATURES AT 2, 4, 6, AND 8 FT
2-ft. Above Bottom
4-ft. Above Bottom
6-ft Above Bottom
8-ft. Above Bottom
Temperature (°C)
0
100
200
300
400
500
600
700
800
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)



BACKSIDE OF SAMPLE TEMPERATURE
Backside Temperature
Temperature (°C)
0
25
50
75
100
125
150
175
200
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
Time (min)

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November 2015

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