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Foam Application for High Hazard Flammable Train (HHFT) Fires

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FOREWORD

The overall goal of the project was to develop a compendium of foam application data and related fire suppression information on High Hazard Flammable Train (HHFT) fire events and three dimensional, free flowing flammable liquid fire scenarios. Through a literature review, information gathered from responders and technical response teams, and analysis of published after action reviews, the findings of this project serve to clarify the planning estimates for application of foam during suppression of an HHFT derailment incident for the responder community.

The Fire Protection Research Foundation expresses gratitude to the report authors Jerry Back and Brianna Gillespie, who are with Jensen Hughes located in Baltimore, MD and Bobby Breed, who is with Specialized Response Solutions located in Fort Worth, TX. The Research Foundation appreciates the guidance provided by the Project Technical Panelists, and all others that contributed to this research effort. Thanks are also expressed to the National Fire Protection Association (NFPA) for providing the project funding through the NFPA Annual Research Fund.

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About the National Fire Protection Association (NFPA)

Founded in 1896, NFPA is a global, nonprofit organization devoted to eliminating death, injury, property and economic loss due to fire, electrical and related hazards. The association delivers information and knowledge through more than 300 consensus codes and standards, research, training, education, outreach and advocacy; and by partnering with others who share an interest in furthering the NFPA mission.

All NFPA codes and standards can be viewed online for free.

NFPA's membership totals more than 65,000 individuals around the world.

Keywords: high hazard flammable train (HHFT), foam application, derailment, tank car, crude oil, ethanol

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EXECUTIVE SUMMARY

There has been rising number of large scale fires involving high hazard flammable trains (HHFTs), some with catastrophic consequences. HHFT fires are typically complex scenarios consisting of flowing fuel, pools, and saturated substrates. HHFT events have the potential to quickly evolve into major conflagrations in which heat from initial fires can produce cascading effects due to increased thermal stress on surrounding railcars, leading to heat induced tears, pressure relief venting, and additional breaches.

Class B firefighting foams, more specifically alcohol resistant aqueous film-forming foams (AR-AFFFs), are the industry standard for mitigating and combatting flammable liquid pool fire-type hazards. First responders currently default to using an area-based method defined in NFPA 11, the Standard for Low-, Medium-, and High-Expansion Foam, for calculating foam application rates and quantities needed to fight HHFT fires. The values determined using NFPA 11 may not be accurate when considering the complex, three-dimensional, and potentially highly obstructed and limited access nature of these fires. Specifically, three-dimensional flowing fuel fires are extremely challenging to extinguish using solely Class B foams. In any case, the values determined using the “area-based” method based in NFPA 11 needed to be verified through comparison with actual incident data and applicable research.

The Fire Protection Research Foundation (FPRF) initiated this program to develop a database of HHFT derailments and the associated understanding of the foam application rates and total foam quantities needed to effectively mitigate these incidents. The information was gathered for the responder community to clarify the requirements and may ultimately be used for planning purposes and guidance for combating these fires.

HHFT incidents are a relatively new problem facing the first responder community. In addition to increased production, transporting by rail allows for greater geographic flexibility than pipelines and therefore allows the ability to quickly shift product destinations in response to market needs. Because of this factor alone, it is likely that transport of crude oil and ethanol by rail will continue to play a key role in the industry.

A literature review was conducted on foam application during HHFT events and focused on incident reports, professional articles, and academic publications. Upon completion of the literature review, it was determined that there was insufficient data regarding foam usage during HHFT events to develop guidance for first responders, and thus an alternate approach was required. Specialized Response Solutions (SRS) in Fort Worth, Texas had significant experience in combatting these incidents and was identified as a resource for data on foam usage and overall guidance in best practices for foam application in HHFT events. As a reference, SRS provides emergency response services for hazardous materials incidents and has responded to, and has a great deal of experience in extinguishing many HHFT rail cars in derailments. SRS was hired by JENSEN HUGHES to review their database and provide detailed descriptions and foam usage values for 12 representative HHFT incidents. Bobby Breed of SRS was the lead on the data preparation and has been included as a co-author to this document.

The SRS data package includes detailed information on the following twelve representative HHFT derailment incidents. The data includes incidents involving ethanol, crude oil, petroleum, denatured alcohol, and/or a combination of fuels. During these incidents, between 7 to 39 cars derailed. The incidents cover a range of weather conditions from severe cold weather to extreme heat. The foam concentrate usage ranged from 0 to 2,520 gallons. The water usage ranged from 0 to 2,200,000 gallons.

During the ten representative incidents, effective foam usage only occurred during the equilibrium phase. During 50% of these incidents, less than 100 gallons of foam concentrate was used (equates to ~3300 gallons of foam solution). During the remaining 50%, approximately 300 gallons of foam concentrate was used (equates to ~10,000 gallons of foam solution). On average, about 50% of the foam discharged during the equilibrium phase was applied directly into the burning cars (~ 14 gallons per car on average) to suppress and extinguish the fires within the car. The remainder was used to extinguish pool/spill fires and to seal fuel vapors during overhaul.

The foam use values from the incident data were then compared to the analytical values (area method) determined using NFPA 11. The analytical values were typically about five times that actually used during the event. With this said, the empirical values may be skewed toward the lower end of the range due to the extensive experience of the first responders. The data illustrated that water usage (for cooling) is equally important as foam usage when mitigating these types of incidents. The amount of water used during these scenarios was typically on the order of hundreds of thousands of gallons and approximately two orders of magnitude greater than the amount foam solution (foam concentrate/water solution) discharged during the event.

In addition to water and foam usage, information was also gathered and assessed on variables such as arrival time, fuel type, railroad substrate, weather, railcar construction (i.e., jacket tank cars) and first responder tactics. In general, arrival time, fuel type, railroad substrate, weather and railcar construction all had minimal effects on the incident. However, tactics were shown to play a major role in the outcome. Inexperienced first responders tend to use foam ineffectively and can prolong the overall duration of the incident. Resources such as the On-Scene Incident Commander Field Guide and Transport Canada’s Competency Guidelines for Responders to Incidents of Flammable Liquids in Transport, High-Hazard Flammable Trains provide crucial knowledge and assist responders in making appropriate response decisions. The timeline and associated variables developed during this program provides a good high-level overview of the recommended tactics for combatting HHFT fires.

Since water usage for cooling purposes is equally as important as foam usage when mitigating these types of events, optimized cooling agents and techniques may be worth considering in areas of limited water supply/availability.

The information documented during this program helps to bracket the overall amount of foam concentrate needed to respond to an HHFT incident. During the 10 incidents documented in this report, approximately 300 gallons of foam concentrate or less was sufficient to suppress and extinguish these fires. This was the quantity used by a group of well trained, experienced firefighters and may need to be adjusted based on the expected level of training/experience of first responders. The main lessoned learned from the review of data and discussions with SRS centers around using foam only after railcars have been properly cooled and after a car can be responded to with an individual tactical plan. Parallel to foam application, the use of cooling water serves as a vital preemptive step to any offensive response. Increased knowledge more than any amount of available foam concentrate will affect the overall outcome, duration, and severity of an HHFT incident. With proper knowledge of HHFT derailments and the accompanied training, first responders in areas near railroads carrying high-hazard flammable liquids will be more prepared and able to respond to an accident should it occur.

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FOAM APPLICATION FOR HIGH HAZARD FLAMMABLE TRAIN (HHFT) FIRES

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1. INTRODUCTION

There has been rising number of large scale fires involving high hazard flammable trains (HHFTs), some with catastrophic consequences. HHFT fires are typically complex scenarios consisting of flowing fuel, pools, and saturated substrates. HHFT events have the potential to quickly evolve into major conflagrations in which heat from initial fires can produce cascading effects due to increased thermal stress on surrounding railcars, leading to heat induced tears, pressure relief venting, and additional breaches.

Class B firefighting foams, more specifically alcohol resistant aqueous film-forming foams (AR-AFFFs), are the industry standard for mitigating and combatting flammable liquid pool fire-type hazards. First responders currently default to using an area-based method defined in NFPA 11, the Standard for Low-, Medium-, and High-Expansion Foam[1], for calculating foam application rates and quantities needed to fight HHFT fires. The values determined using NFPA 11 may not be accurate when considering the complex, three-dimensional, and potentially highly obstructed and limited access nature of these fires. Specifically, three-dimensional flowing fuel fires are extremely challenging to extinguish using solely Class B foams. In any case, the values determined using the "area-based" method based in NFPA 11 needed to be verified through comparison with actual incident data and applicable research.

The Fire Protection Research Foundation (FPRF) initiated this project to develop a database of HHFT derailments and the associated understanding of the foam application rates and total foam quantities needed to effectively mitigate these incidents. The information was gathered for the responder community to clarify the requirements and may ultimately be used for planning purposes and guidance for combating these fires. The information will also be included in the recently published "High-Hazard Flammable Trains (HHFT) On-Scene Incident Commander Field Guide"[2] and will be used to augment the information included in NFPA 472, Standard for Competence of Responders to Hazardous Materials/Weapons of Mass Destruction Incidents in the development of an Incident Action Plan (IAP)[3]. The field guide provides tactical guidance and information for the On-Scene Incident Commander responsible for the management of bulk flammable liquid emergencies involving High-Hazard Flammable Trains (HHFT).

2. BACKGROUND

2.1. History of HHFT Events

HHFT incidents are a relatively new problem facing the first responder community[4]. According to the National Conference of State Legislatures, the amount of U.S. produced crude oil has increased dramatically in recent years. The increased production has exceeded the capacity of many pipelines resulting in the shift to railways as an alternative for crude oil transportation. In fact, according to the Association of American Railroads (AAR)[5], the number of rail carloads carrying crude oil in 2014 rose by more than 5,000 percent when compared with the numbers in 2008, and reached a 30 year high water mark in 2014[6]. Meanwhile, ethanol shipping has remained somewhat constant over the past five years (see Figure 1).

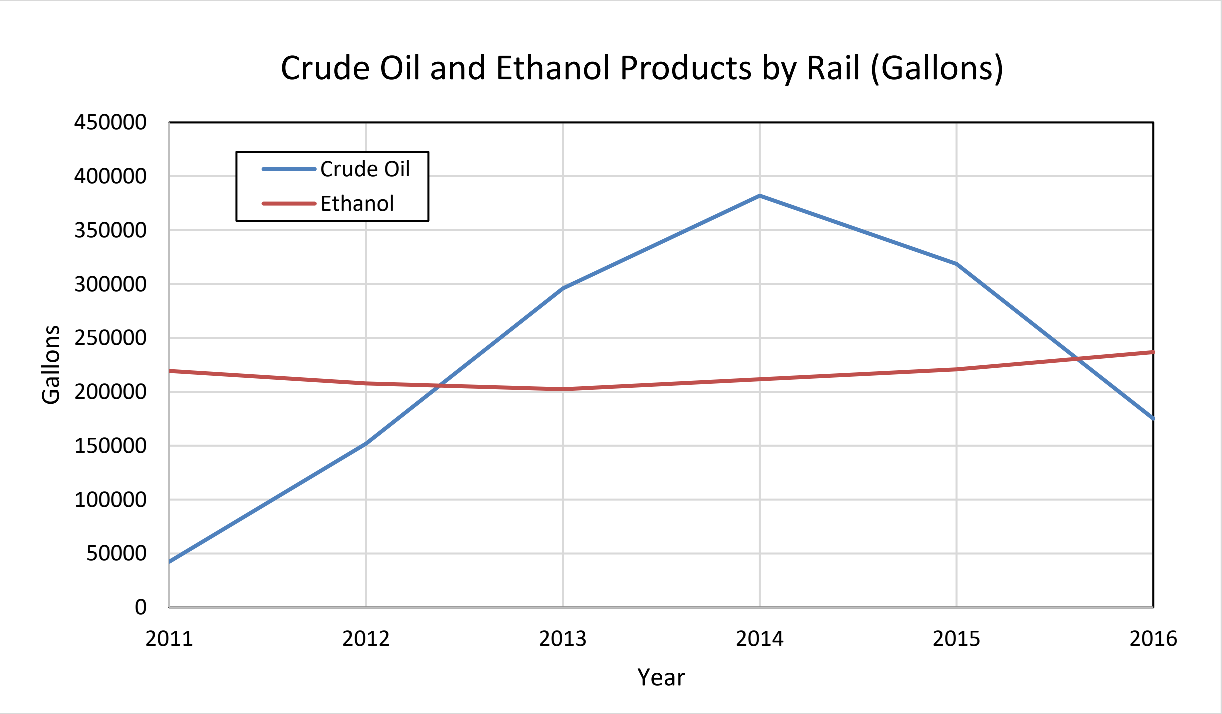

Figure 1 – Crude Oil and Ethanol Products by Rail[6]

(U.S. Energy Information Administration, Movements of Crude and Selected Products by Rail, June 30, 2017, https://www.eia.gov/dnav/pet/pet_move_railNA_a_EPC0_RAIL_mbbl_a.htm)

In addition, transporting by rail allows for greater geographic flexibility than pipelines and therefore allows the ability to quickly shift product destinations in response to market needs. Because of this factor alone, it is likely that transport of crude oil and ethanol by rail will continue to play a key role in the industry.

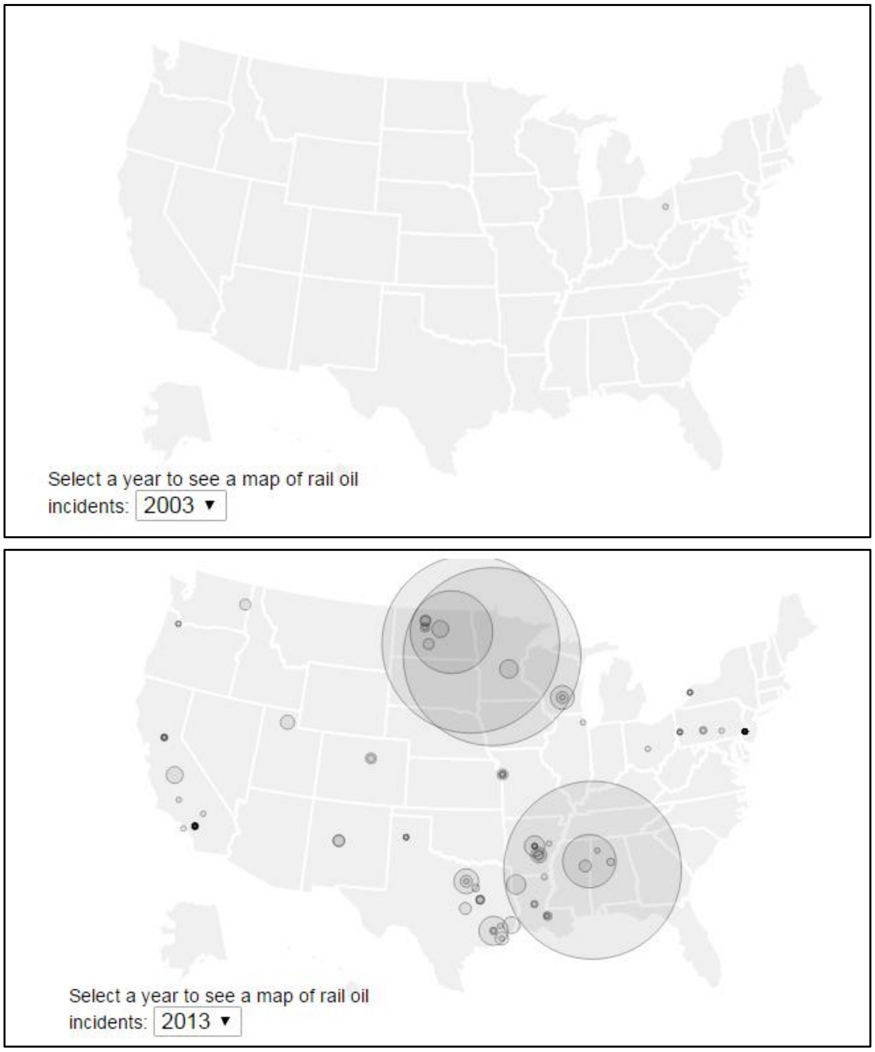

Figure 2 – Increase in crude oil spills in the United States between 2003 (top) and 2013 (bottom)[5]

(“U.S. Rail Crude Oil Traffic”, Association of American Railroads, November 2015, https://www.aar.org/BackgroundPapers/US%20Rail%20Crude%20Oil%20Traffic.pdf)

Figure 2 above depicts the increase in crude oil spills in the United States between 2003 and 2013. While shipping has become more flexible and market responsive, major accidents have accompanied the dramatic increase in HHFTs moving throughout the country. Although somewhat rare, derailments have led to massive spills and associated fire events. As an extreme/worst case example, a train originating in North Dakota and carrying crude oil derailed during a runaway train incident caused by human error in Lac-Megantic, Quebec on July 6, 2013 and spilled an estimated 1.5 million gallons, resulting in explosions and fire that killed 47. A large number of other crude oil and ethanol spill incidents have also resulted in large explosions and major conflagrations.

2.2. HHFT Event Description

The risks posed by an HHFT incident can vary greatly depending upon incident location, exposures, product involved, number of tank cars derailed and breached, and the level of available resources. Upon arrival, first responders will likely find a large and rapidly increasing problem scenario. During an incident, any number of tank cars are likely to derail. As noted by the HHFT On-Scene Incident Commander Field Guide[2], the initial stress and release behaviors of railcars will be directly influenced by the speed of the train and kinetic energy associated with the derailment. In the data set of twelve HHFT events examined in this report, an average of 22 cars were derailed per incident, with an average of 14 railcars subsequently experiencing a breach and/or on fire. Figure 3 below depicts the scene of a derailment that occurred in Lac-Megantic, Quebec[7] on July 9, 2013, in which the destructive nature and three-dimensional aftermath of an HHFT incident can be seen.

Figure 3 – Derailment in Lac-Megantic, Quebec on July 9, 2013
Credit: Sûreté du Québec

Due to the far-reaching extent of railroad lines, a derailment may occur many miles from the closest hydrant or water source; or contrary to this, a derailment may occur in the center of a town resulting in tactical complexities in a well populated area. Experience has shown that railroad corridors are often not in close proximity to large volume water supplies. As a result, water supplies to sustain cooling and extinguishment operations have often been a significant response challenge. In contrast, derailments occurring in and around waterways can generate both short-term and long-term environmental clean-up issues[8] (see Figure 4).

Figure 4 – Derailment in Lynchburg, Virginia effecting the James River

Credit: The Associated Press

HHFT incidents begin with the early incident phase during which the derailment has just occurred, and a number of cars may have breached and flammable liquid is leaking from punctured cars. Fire and the beginnings of three-dimensional fires can be observed as burning flammable liquid continues to leak and flow. In the data set examined in this report, first responders reached derailments in a time range of a matter of minutes to approximately 30 minutes after the incident. Few to no HHFT events are extinguished during the early incident phase, most often because of the time needed for size up tactical decision making and the lack of immediate resources needed for quick extinguishment once decisions have been made (e.g. foam concentrate, nozzles, dedicated cooling streams). Additionally first responders may spend early moments on scene focusing on evacuation if necessary and any possible isolation of the incident.

Independent of the size and duration of the incident, most HHFT derailments follow a characteristic timeline. The timeline depicted in Figure 5 was released by a group of emergency response and industry technical specialists in August 2015, and then incorporated into the "High-Hazard Flammable Train (HHFT) On-Scene Incident Commander Field Guide" and has been adapted for the purposes of this work.

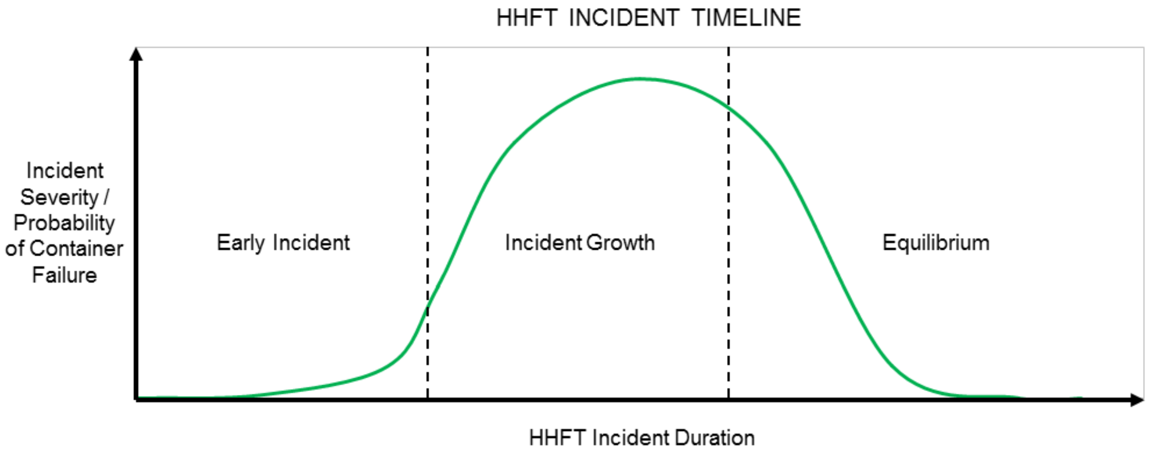

Figure 5 – High hazard flammable train incident timeline and phases

(Adapted from Figure 3 of the HHFT On-Scene Incident Commander Field Guide [2])

The incident growth phase occurs as a result of mounting heat from initial derailment fires. Per both the data set discussed in this report and the On-Scene Incident Commander Field Guide[2], incident growth occurs over a time period somewhere in the range of 30 minutes to 4 hours. As fire spreads throughout the derailment wreckage, thermal stress may be inflicted on surrounding railcars not initially involved in the fire. Extreme heat and pool fires can quickly produce heat induced tears, increased pool fire sizes, and cause pressure relief venting; all which consequently lead to greater involvement at the scene. Additional railcar breaches may occur, and if left completely unchecked, deflagrations and explosions can take place as the event continues to intensify[9] (see Figure 6).

Figure 6 – Tank car explosion during the Casselton, ND derailment December 30, 2013[9]

Photograph by Dawn Faught. All rights reserved.

(NTSB, Casselton, ND, Railroad Accident Brief, https://www.ntsb.gov/investigations/AccidentReports/Reports/RAB1701.pdf)

The equilibrium phase is reached when, per the HHFT On-Scene Incident Commander Field Guide, the incident has reached a level in which it is no longer growing in scope or size. In the data set evaluated for this report, equilibrium was reached between 3 and 8 hours after the start of the event, whereas the On-Scene Incident Commander Field Guide suggests that equilibrium may not occur for approximately 8 to 12 hours. These timeline milestones are estimates based on various incidents. It is important to consider that these data sets are not all encompassing; for example, in the Mont Carbon, WV derailment the final HIT took place over 10 hours into the incident timeline, reflecting a greater time to equilibrium for that particular incident. Benchmarks of this phase include confined fires, no pressure relief device activations, and an event that is generally two-dimensional in nature[2]. During the equilibrium phase the event is considered 'in control' and offensive efforts may be considered and started. Depending on response decision and priorities of first responders, HHFT events including emergency response and recovery operations have the potential to last for days. The HHFT derailments in this particular data set lasted anywhere from 28 hours all the way up to 72 hours in duration.

2.3. Current Best Practice Resources

NFPA 11, the Standard for Low-, Medium-, and High-Expansion Foam[1], is currently a best practice resource for calculating for the amount of foam concentrate needed for a flammable liquid pool fire. Table 5.8.1.2 of NFPA 11 outlines minimum application rates and discharge times for non-diked spill fire protection – however for alcohol-resistant foams (AR-AFFFs), the standard instructs to consult foam manufacturers for specific product listings. The values determined using NFPA 11 are intended for area-based, two-dimensional pool fires (often in a fixed facility, such as a tank farm) and may not be accurate when considering the three-dimensional, complex, and highly obstructed nature of an HHFT fire.

The publication "High-Hazard Flammable Train (HHFT) On-Scene Incident Commander Field Guide" written by Noll and Hildebrand[2] for the NFPA Research Foundation is a report which provides information for planning and training purposes for first responders to HHFT events. The guide serves as an excellent resource for risk-based response planning for incident commanders. Critical information about HHFT incidents is covered including but not limited to: detail on fuel types; tank and car design and construction; a collection of tactical considerations; and incident timeline.

The most applicable pieces in regards to foam application from the On-Scene Incident Commander Field Guide largely involve key information for first responders to be familiar with so that informed decision making may occur as early as possible in an event. It is vital for first responders to be able to determine when in the event timeline it is appropriate and inappropriate for foam application. The following summarized information is among the most beneficial to have an understanding of:

- The process of incident growth generally includes the following: thermal stress from initial fires; subsequent activation of tank car pressure relief devices; continued thermal stress on adjoining cars; increasing probability of failures through heat induced tears; and subsequent fire and radiation exposures.
- Indicators for rapid incident growth may include running or unconfined spill fires and releases, direct flame impingement on railcars, heat induced blisters on tank shells, and activation of pressure relief devices.

- Acknowledgment that there is an extremely limited early window for offensive response and a high probability of defensive strategies. For example, the guide describes that as of the date of publish (July 2016), no HHFT scenarios have been controlled or extinguished in the early phases of the incident timeline.
- A rough estimate of necessary foam – once equilibrium has been achieved and tank car metals cooled, individual cars have been extinguished with as little as 8 to 10 gallons of Class B foam per tank car. Actual quantity of Class B foam for control and extinguishment in later phases have been substantially less than the 'area based' planning values based on NFPA 11 parameters.
- The success of an offensive operation will rely heavily on having proper amounts of foam and water, the necessary equipment, and responders with appropriate knowledge and experience.

3. LITERATURE REVIEW

A literature review was conducted on foam application during HHFT events and focused on incident reports, professional articles, and academic publications. This review sought to collect available information regarding foam agent application totals, as well as techniques and procedures used to control, suppress, and extinguish these fires. The findings are summarized as follows.

3.1. FRA and NTSB Reporting

The Federal Railroad Administration (FRA)'s Security, Preparedness, and Accident Analysis Division continuously monitors the occurrence of train incidents throughout the United States. Detailed accident reports are generated for all types of incidents and accidents and include comprehensive information on the train, as well as a narrative and timeline of the incident. Although these reports record a great deal of information, minimal information on emergency response considerations, including incident management, fire control and spill control, is typically provided. This lack of information can largely be attributed to the main goals of the FRA as an agency; the FRA's main efforts focus on determining how and why a train incident occurred for future safety purposes as opposed to the firefighting methods and tactics used to end the event.

The National Transportation Safety Board (NTSB), an independent Federal agency, also reports on and investigates the causes of transportation incidents occurring in the United States. NTSB has reported on multiple HHFT derailments in the past decade, and as with the FRA's reports discussed above, the NTSB focuses on the cause of events to analyze metrics of railroad safety, rather than details of the methods used to extinguish the event.

3.2. Ethanol Tank Train Emergencies: Observations from 11 Tank Train Derailments and Case Studies

A publication prepared by Hildebrand Noll Associates, "Ethanol Tank Train Emergencies: Observations from 11 Tank Train Derailments and Case Studies"[10], reviews a series of derailments involving tank trains transporting ethanol. Critical observations regarding ethanol train derailments are noted and act as a beneficial guide for first responders and response planners regarding what to expect from an ethanol train derailment. Observations cover derailed cars vs. cars breached, subsequent fires caused, total gallons of ethanol released, and train speed's effect on derailments. Minimal mention of foam use is made within discussion of the eleven events analyzed although foam was eventually used on several. As it was not the main focus of the paper, no detail or quantifiable information on foam application is provided.

3.3. Other

A variety of other sources including state and local reporting were consulted and reviewed during the literature review process. While a wealth of information exists about the occurrence of HHFT events, little to no data about actual foam usage exists, and findings identified that no fidelity on foam usage during HHFT events can be found in the literature.

Aircraft rescue and firefighting (ARFF) was examined as a possible source of information and data. However, it was concluded that while both aircraft and HHFT events involve high hazard fuel fires, the metrics surrounding these types of events are too dissimilar to allow for use of corresponding ARFF data. For example, most major airfields possess dedicated equipment involving a fleet of response vehicles equipped with foam concentrates, dry chemical products, and necessary equipment. ARFF responses are limited to a small area and have the opportunity to respond early to more confined incidents that are easily accessible; typically ARFF foam operations are completed in a matter of minutes. This is in direct opposition to HHFT events in which an incident may occur anywhere along a railroad, far from dedicated equipment and response teams, and in difficult access areas. In addition to access, other main drivers are the differences in types of fires, response time, and resupply logistics and challenges. These differentiators between aircraft and HHFT incidents; making the quantified resources used for ARFF inapplicable to HHFT research.

3.4. Path Forward

On completion of the literature review, it was determined that there was insufficient data regarding foam usage during HHFT events to develop guidance for first responders, and thus an alternate approach was required. Specialized Response Solutions (SRS) in Fort Worth, Texas had significant experience in combatting these incidents and was identified as a resource for data on foam usage and overall guidance in best practices for foam application in HHFT events. As a reference, SRS provides emergency response services for hazardous materials incidents and has responded to, and has a great deal of experience in extinguishing many HHFT rail cars in derailments.

SRS was hired by JENSEN HUGHES to review their database and provide detailed descriptions and foam usage values for 12 representative HHFT incidents. Bobby Breed of SRS was the lead on the data preparation and has been included as a co-author to this document.

4. DATA COLLECTION

4.1. Scenario Development

To provide an understanding of the foam usage at the various stages of the fire (and the variables affecting each stage), JH and SRS developed a timeline to define the typical progression of the fire and various mitigation steps during the progression. This timeline is based on SRS best practices developed during years of experience combatting these incidents and foam usage observed during mitigation by less experienced organizations. This timeline will ultimately serve as the basis for collecting the foam usage data during the next stage of this program.

Upon arrival at the scene (Early Incident phase in Figure 5), the on-scene incident commander needs to quickly assess the situation and the ramifications/potential for success of conducting an offensive attack. Given the rapid escalation of the fire and incident conditions, foam operations in the early incident phase have a low probability of success. Application of a risk-based response process will be a critical element in assessing the effectiveness of both cooling and foam operations. In only a very limited number of instances is an offensive attack successful immediately upon arrival.

SRS's internal procedure entails cooling (using water only) as the first tactical approach upon arrival, regardless of the stage of the event. Cooling is used to establish boundaries for the event ("bookends" as referred to by SRS). This tactic serves to bracket the edges of an HHFT event and prevent any further spread of fire to railcars which are not breached or burning. Only in a small percentage of situations is cooling not a desirable first action; for example, during extreme cold weather in which cooling water streams freeze on contact. When implementing cooling strategies, water streams should be directed away from the interiors of burning cars and pools of fuel to prevent water from overflowing the tank car and/or mixing with miscible fuels and increasing the overall fire size. Cooling streams are most effective when directed at the exterior of tank cars to absorb as much heat as possible from heated surfaces and reduce the overall heat of the fire.

The next stage of the fire can be considered a "controlled burn" in which the fire burns unabated within the established boundaries (Incident Growth phase in Figure 5). During most incidents, the most severe burning (i.e., peak fuel consumption and peak heat release rate) occurs during this period. The intent of this phase is to allow the fire to grow and consume fuel ultimately reducing the size of the fire due to fuel consumption. This will also provide time for flowing fuel fires to empty breached cars leading to fires that can be extinguished with foam (i.e., foam has only limited capabilities against three-dimensional flowing fuel fires).

Foam is effectively used during this stage to extinguish spills/pool fires that encroach on the incident boundaries, pose a threat to adjacent cars, and/or pose a threat to the environment. Ineffective use of foam includes using foam to cool surfaces, discharging foam into breached cars that have no possibility of being extinguished at the time, and trying to extinguish flowing fuel fires.

Once all immediate threats to life and exposures have been addressed, the boundaries of the event have been well established and the intensity of the fire has decreased to a manageable level, the focus shifts to collapsing the incident area by working the boundaries inward (Equilibrium phase on Figure 5). At this stage of the event, most of the burning is occurring within breached cars with a limited amount of burning occurring on the ground below.

In order to be successful in reducing the size or footprint of the incident, the tank cars at the perimeter of the area are combatted individually. To do so, it is vital for first responders to be able to determine when a tank car is sufficiently cooled allowing for an offensive attack. Adequate cooling reduces the vaporization rate of the fuel and the potential for re-flash due to exposure of the fuel to superheated metal surfaces. This also prevents heat from the tank car from converting the water in the foam mixture to steam, rendering the foam application ineffective.

When adequately cooled, the metal surface of a tank car will appear wet and there will be visibly less production of steam. This indicates that the steel temperature has been reduced to below 212°F/100°C (i.e., the boiling point of water). These temperatures are now adequate to reduce the vaporization rate of the fuel, and minimize foam degradation caused by the hot surfaces and the potential for re-flash.

Once the perimeter cars are adequately cooled, an offensive attack may be implemented with a higher probability for success. Optimal foam usage occurs during this phase of the event. Responders may have the desire to implement a scenario-wide offensive response, however under most conditions, it is favorable to address each involved railcar individually and have a distinct tactical plan specific to a railcar or area of the derailment. A typical attack consists of applying foam to/within the burning car to extinguish the fire and seal the fuel vapors. Multiple applications and reapplications of foam may be necessary to seal/cool the fuel and suppress vapor production as well as compensate for any degradation of foam blankets. Once the car has been successfully extinguished and cooled, heavy lifting equipment may be used to remove the car from the incident area further widening the buffer zone around the incident and reducing the incident area. This process is repeated until all of the cars/fires have been extinguished and all potential re-ignition sources have been cooled and removed.

Foam is effectively used during this stage to extinguish the fires within the cars. Effective foam use also includes controlling fires adjacent to the area of attack and sealing fuel spills that may occur during removal of cars. Ineffective use of foam includes using foam to cool surfaces and over-zealous discharge of foam during the offensive attack on the fire.

4.2. Data Collection and Assembly

The timeline described in the previous section was used to develop the individual data sheets for documenting each event. A sample data sheet is provided in Appendix A. The variables listed on the data sheets are defined as follows:

Control: foam used for sealing pools beneath non-holed, closed vessels to prevent pressure venting and/or heat-induced tears, and/or other methods for the purpose of gaining control of the HHFT event.

Suppression: foam used for suppression efforts such as on pool fires, on the interior of breached tank cars, and/or foam used to affect eventual complete extinguishment.

Extinguishment: foam used for final extinguishment.

Overhaul: foam used during the removal of wreckage, bulldozing, and/or other overhaul methods for the purpose of preventing re-flashing, removing unaffected railcars, and/or for the safety of first responders.

Indiscriminate: foam applications which have limited to no effectiveness in meeting fire control and extinguishment objectives (e.g., applying foam on tank car exterior for cooling).

Variables were then assigned to each of the three phases (early incident, incident growth, and equilibrium) to better define the potential foam usage throughout the incident timeline.

During the early incident phase, only a very limited number of events are likely to be extinguished. Thus, foam is only effectively used during this phase to control the fire and establish the boundaries of the event, ($x_{control,1}$). Conducting an aggressive attack on the fire upon arrival to the scene typically has little or no effect on the fire and is considered to be an indiscriminate use of foam ($x_{indiscriminate,1}$). The following equation was used to capture early incident foam use:

$$x_{control,1} + x_{indiscriminate,1} = x_{early\ incident} \qquad \text{Eq. (1)}$$

During the incident growth phase, foam may be used effectively to control the fire and maintain the previously established boundaries ($x_{control,2}$). For example, control foam may be used on a pool fire beneath a non-holed tank car to prevent pressure relief venting or heat induced tears. Foam also may be used for the early stages of overhaul ($x_{overhaul,2}$) for the life safety of responders while sections of the train are being removed. Foam used to conduct an aggressive attack on the fire during the incident growth phase is considered to be an indiscriminate use of foam ($x_{indiscriminate,2}$) due to its low probability of success. Indiscriminate foam use in the incident growth phase also includes foam used to cool surfaces, since water is the preferred agent. The following equation was used to capture incident growth foam use:

$$x_{control,2} + x_{indiscriminate,2} + x_{overhaul,2} = x_{incident\ growth} \qquad \text{Eq. (2)}$$

During the equilibrium phase, the overall HHFT incident is considered to be ‘under control’ and offensive efforts are likely to succeed if implemented properly. The largest amount of foam is discharged during this phase of the incident. A large portion of the foam used during the equilibrium phase will be used for suppression and extinguishment, $x_{suppression,3}$ and $x_{extinguishment,3}$, in which foam is used to reduce the fire size, blanket two-dimensional pool fires and interiors of tank cars, and for sealing pool fires to quench remaining flames. Foam may be effectively used for overhaul efforts ($x_{overhaul,3}$). As with the early incident and incident growth phases, foam may still be applied indiscriminately during equilibrium ($x_{indiscriminate,3}$). The following equation was used to capture the foam use during the equilibrium phase:

$$x_{suppression,3} + x_{overhaul,3} + x_{extinguishment,3} + x_{indiscriminate,3} = x_{equilibrium} \qquad \text{Eq. (3)}$$

The total foam used is the summation of early incident phase foam use, incident growth phase foam use, and equilibrium phase foam use.

$$x_{early\ incident} + x_{incident\ growth} + x_{equilibrium} = x_{total} \qquad \text{Eq. (4)}$$

In addition to foam usage, information was also collected about the location, train information, a general timeline, water usage, weather conditions, and any other defining variables in order to identify potential trends.

5. RESULTS

The complete SRS data package is provided in Appendix B. The package includes detailed information on the following twelve representative HHFT derailment incidents:

1. New Brighton, PA, 10/20/2006
2. Painesville, OH, 10/10/2007
3. Luther, OK, 8/22/2008
4. Cherry Valley, IL, 6/19/2009
5. Tiskilwa, IL, 10/7/2011

6. Plevna, MT, 8/5/2012
7. Casselton, ND, 12/30/2013
8. Plaster Rock, NB, 1/7/2014
9. Gogama, Ontario, 2/14/2015
10. Galena, IL, 3/5/2015
11. Gogama, Ontario, 3/7/2015
12. Heimdal, ND, 5/6/2015

The data includes incidents involving ethanol, crude oil, petroleum, denatured alcohol, and/or a combination of fuels. During these incidents, between 7 to 39 cars derailed. The incidents cover a range of weather conditions from severe cold weather to extreme heat. The foam concentrate usage ranged from 0 to 2,520 gallons. The water usage ranged from 0 to 2,200,000 gallons.

There were two incidents (Casselton, ND and Cherry Valley, IL) that are outliers in the data package (highlighted in yellow above). These outliers illustrate extremes with respect to foam usage and approaches. During the Casselton incident, first responders made the decision to not fight the fire due to the remote location and extreme cold. Thus, no foam or water was used during this incident. Opposite to this, during the Cherry Valley incident, a total of 2,520 gallons of foam concentrate and 2.2 million gallons of water were used around the derailment See Table 1 on the following page for select data from the SRS data package.

Table 1 – Select SRS Data for Foam and Water Use for Twelve HHFT Derailments

	New Brighton, PA	**Painesville, OH**	**Luther, OK**	**Cherry Valley, IL**	**Tiskilwa, IL**	**Plevna, MT**	**Casselton, ND**	**Plaster Rock, NB**	**Gogama, ALB 1**	**Gogama, ALB 2**	**Galena, IL**	**Heimdal, ND**
Date	10/10/2007	10/10/2007	8/22/2008	6/19/2009	10/7/2011	8/5/2012	12/30/2013	1/7/2014	2/14/2015	3/7/2015	3/5/2015	5/6/2015
Time	9:41 PM	12:02 PM	2:37 PM	8:36 PM	2:14 AM	4:30 PM	2:10 PM	?	11:50 PM	2:42 AM	1:20 PM	7:30 AM
Railcars Derailed	23	30	13	19	26	18	20		29	39	21	7
Fuel	Ethanol	Ethanol, Phthalic anhydride	Crude Oil	Ethanol	Ethanol	Denatured Alcohol	Crude Oil	Crude Oil and LPG	Crude Oil and Petroleum	Crude Oil	Crude Oil	Crude Oil
Time to End of Event	30 hrs	28 hrs	28 - 30 hrs	36 hrs	44 hrs	40 hrs	55 hrs	36 hrs	72 hrs	70+ hrs	70+ hrs	60 hrs
Equilibrium Foam Use (gallons)												
Indiscriminate	0	5	0	0	0	35	0	0	25	30	0	0
Overhaul	0	10	25	140	160	75	0	0	50	45	10	10
Suppression	20	30	125	130	70	122	0	35	165	180	40	45
Extinguishment	0	5	0	0	0	65	0	0	35	55	0	5
Total Equilibrium Foam Used	**20**	**50**	**150**	**270**	**230**	**297**	**0**	**35**	**275**	**310**	**50**	**60**
Water Use (gallons)												
Cooling Water Used	299,000	2,000,000+	18,000	2,180,000	390,000	130,000	-	8,000	110,000	560,000+	25,000	123,000
Foam Application Water	1,000	3,000	2,000	20,000	10,000	12,000	-	2,000	10,000	10,000	5,000	2,000
Total Water Estimate	**300,000**	**2,000,000+**	**20,000**	**2,200,000**	**400,000**	**150,000**	**-**	**10,000**	**120,000**	**600,000+**	**30,000**	**125,000**

6. FINDINGS

6.1. Foam Usage

6.1.1. Incident Data

Within the ten representative incidents in the database, effective foam usage only occurred during the equilibrium phase. During 50% of these incidents, less than 100 gallons of foam concentrate was used (equating to ~3300 gallons of foam solution); while during the remaining 50%, approximately 300 gallons of foam concentrate was used (equating to ~10,000 gallons of foam solution). An analysis of the data provided no definitive distinction between the variables associated with these two groups of data. With this said, the fuel consumption during the growth phase may have been the primary contributor. Specifically, a majority of the fuel released/exposed during the lower foam use incidents may have been consumed during the growth phase of the incident, significantly reducing the fire size prior to an aggressive attack on the fire.

On average, about 50% of the foam discharged during the equilibrium phase was applied directly into the burning cars to suppress and extinguish the fires within. A range of 8 to 25 gallons of foam concentrate per car were used, averaging 14 gallons per car (average taken from five of the incidents which had that level of detail). Overall, values in data set may be understated for the 10 main incidents due to the experience level of responders.

6.1.2. Analytical Values

Table 5.8.1.2 of NFPA 11[1] outlines minimum application rates and discharge times for non-diked spill fire protection. The minimum application rate for an AR-AFFF used on a hydrocarbon product spill is 0.10 gpm/ft^2, however for alcohol-resistant foams used on flammable and combustible liquids, the standard instructs to consult foam manufacturers for specific product listings. Manufacturers such as Ansul and Buckeye recommend a minimum application rate of 0.15 gpm/ft^2 on polar solvent type fuels. Using this application rate, NFPA 11 calculation methods can be applied. An average tank car at its widest midpoint has approximate dimensions of 100 ft long by 10 ft wide, or a maximum pool surface area of 1000 ft^2 within a tank car. Considering a 3% AR-AFFF foam and using the NFPA minimum discharge time of 15 minutes, the following amount of foam concentrate required for a railcar can be calculated:

$$1000\, ft^2 * 0.15 \frac{gpm}{ft^2} * 0.03 * 15\, minutes = 67.5\, gallons\ of\ foam\ concentrate$$

Considering approximately 67.5 gallons of foam concentrate per car as directed by NFPA, Table 2 compares the incidents which SRS had specific data as to the amount of cars foam was applied to and the amount of foam used for suppression versus the amount of foam concentrate that would be required per NFPA 11 (i.e., 67.5 gallons concentrate per car). It should be recalled that while these calculations account for a 3x3 AR-AFF, there is a great deal of 3x6 AR-AFF foam in the field. As HHFT incidents can occur anywhere and foam will be marshalled from the proximity, attention should be paid to whether the foam is a 3x3 or 3x6 foam concentrate. If ethanol or other polar solvent fuels are involved in the incident and a 3x6 foam is used, twice the number of gallons will be required.

Table 2 compares the approximate amount of foam used per the SRS data set to the amount of foam needed per NFPA 11 calculations. The calculated amounts of foam are about 3 to 9 times larger than the amounts used for suppression in the SRS data set. This agrees with other sources such as the On-Scene Incident Commander Guide which concludes that the actual quantities of Class B foam have been substantially less than that of the area based values determined from NFPA 11 methods.

Table 2 – Gallons of Foam per Car: SRS Data Set vs. NFPA 11 Calculation Amounts

Incident	**New Brighton, PA**	**Painesville, OH**	**Luther, OK**	**Cherry Valley, IL**	**Tiskilwa, IL**
SRS DATA					
# Cars Foam Applied To	2	2	5	11	9
Approximate Gallons Foam Per Car	10	15	25	11.8	7.8
Total Gallons Foam Used For Suppression	**20**	**30**	**125**	**130**	**70**
NFPA 11 Calculated Foam Requirement					
Gallons Foam Per Car	67.5	67.5	67.5	67.5	67.5
Total Approximate Gallons Foam for Suppression Required	**135**	**135**	**337.5**	**742.5**	**607.5**

6.2. Water Usage

Based on the incident data, water usage (for cooling) is equally important as foam usage when mitigating these types of incidents. The amount of water used during these scenarios is typically on the order of hundreds of thousands of gallons and in many scenarios, can well exceed a million gallons. Typical water usage values are approximately two orders of magnitude greater than the amount foam solution discharged during the incident.

Of the ten representative incidents, three incidents required less than one hundred thousand gallons of water (10K-30K range), six were measured in the hundred thousand range (120K- 600K gallon range) and one exceeded one million gallons (over 2M gallons).

6.3. Incident Variables Effecting Foam Use

In addition to water and foam usage, information was also gathered and assessed on such variables as arrival time, fuel type, railroad substrate, weather, railcar construction (i.e., jacket tank cars) and first responder tactics.

Arrival time does not appear to play a key role in foam usage but does have an impact on total water usage and how quickly cooling can be accomplished. More relevant is the incipient size of the fire upon arrival as well as the knowledge and training of the first responders.

Fuel type was found to have little to no effect on foam usage. Specifically, fuel type did not appear to alter the tactics of combatting these fires and AR-AFFFs have good/similar capabilities against fuels (hydrocarbons such as crude oil and polar solvents such as ethanol) typically transported by rail. Synthetic crude may be an exception to this since it tends to form a crust on the fuel surface as it burns impacting the ability of foam to spread, blanket, and seal the fuel surface. This information was provided as an observation by SRS and is not supported in the data collected during this program (i.e., there are no fires involving synthetic crude included in the database).

Railroad substrate was also shown to have a minimal effect on foam usage. Substrate may become a variable if it allows the spilled fuel to form a pool on the surface. Most railroad substrates are loosely packed aggregate or raised track which tend to inhibit the formation of large pool fires and facilitate the spread of flammable liquids into ditches or nearby bodies of water.

Extreme weather can play a role in foam use during an HHFT incident, particularly for foam used for vapor suppression or any foam usage outside of a railcar. In extreme sub-freezing temperatures, not only is foam generation difficult, if not impossible, but it also tends to freeze on contact reducing its effectiveness for suppressing vapors during control and overhaul activities. Foam used on the interiors of burning cars will not be affected by exterior temperatures if the foam can be effectively generated and applied to the car.

Jacketed tank cars (e.g. DOT 117 cars, legacy DOT 111 cars retrofitted with jackets, some CPC 1232 cars with head shields) provide some degree of additional puncture and heat resistance. The jacket is inconsequential to foam usage during HHFT incidents but can play a role in water usage and the tactics used for cooling. Specifically, the outer jacket tends to shield the inner shell from the effects of cooling water during the cooling process. Thus, additional cooling of the interstitial space and internal shell may be required prior to conducting an effective offensive attack of the fuel burning within the car.

Training of first responders is one of the most important variables effecting foam usage during an HHFT incident. First responders should be aware and trained on the risks and potential severity of HHFT incidents, as well as when to attack and how to respond, suppress, and extinguish fires involved with the event. Resources such as the On-Scene Incident Commander Field Guide[1] and Transport Canada's Competency Guidelines for Responders to Incidents of Flammable Liquids in Transport, High-Hazard Flammable Trains[11] provide crucial knowledge and assist responders in making appropriate response decisions. The On-Scene Incident Commander Guide details fundamental information regarding HHFT derailments including but not limited to product information, tank car design and construction, incident management considerations, and tactical considerations. Canada's Competency Guidelines, developed in conjunction with NFPA, outlines key competencies for multiple levels of response training. Levels of response are broken down into an awareness level, operations level, incident command level, specialist employee C, specialist employee B, and specialist employee A level response. Response levels such as these can be utilized to understand if first responders within specific geographic areas near railroad tracks have the amount of training desired and needed to handle an HHFT incident. Knowledge of first responders will dictate how quickly the momentum of the incident shifts from stabilization to extinguishment.

7. KNOWLEDGE GAPS

7.1. Incident Documentation

The primary knowledge gap is associated with the lack of documentation of the conditions that occur and actions taken during these incidents. The current documentation is focused on the cause and prevention of HHFT incidents. This needs to be expanded to include a detailed description of the actions taken and the equipment used to mitigate the incident. The timeline and data sheets developed during this program can be converted into incident templates used to document the incident. The collected information can be used to refine tactics and approaches to combatting these fires as well as to identify the desired equipment and agent and water requirements.

7.2. Water Requirements

The information collected during this program illustrates the need for large quantities of water to effectively mitigate HHFT fire scenarios; including both water for cooling as well as for foam application tactics. This information needs to be included in the guidance provided to the first responder community. In addition, for incidents that occur in areas where the availability of foam is limited, but water is abundant, effective tactical procedures can be implemented that minimize the use of foam while producing similar outcomes. Specifically, defensive strategies using foam to establish the incident boundaries and allowing the fire to decay significantly until reaching the equilibrium phase (to consume most of the fuel) prior to conducting an offensive attack is a viable approach.

7.3. Alternative Fire Suppression Options

Although firefighting foams are the industry standard for combatting Class B fires, they have only limited capabilities against three-dimensional flowing fuel fires. Dry chemical extinguishing agents, such as Purple K, have good capabilities against flowing fuel and spray fires but provide no cooling or vapor suppression. Aircraft rescue and firefighting (ARFF) use of a twin agent attack has been suggested for application in an HHFT derailment. However, the two scenario types, while both involving flammable liquids, differ based on the arrival times of the first responders. ARFF responses have a significant geographic advantage for firefighting since they are typically located near the incident. The quick response time for aircraft accidents and limited amount of flammable fuel available for the fire are the main reasons why twin agent response is often effective. Whereas with HHFT incidents, remote locations, slower time to firefighting response decisions, and larger fuel loading often eliminate early incident phase twin agent responses from a first responder’s options.

7.4. Alternative Cooling Options

Since water usage for cooling purposes is equally important as foam usage when mitigating these types of events, optimized cooling agents and techniques may be worth considering. There has been extensive research into using medium to high expansion foam applications to protect dwellings and structures during wildfire events. In addition, silicon-based additives have been used to change the adhesion characteristics of water to increase the contact duration and allow the water to "stick" to the surface being cooled and/or shielded. These alternatives have the potential to reduce water requirements in areas of limited water supplies/availability. Consideration must be given with these agents that rapid dehydration upon contact with super-heated steel may create solid and semi-solid build up that will negatively affect the application of cooling water after the product has dehydrated.

8. SUMMARY AND CONCLUSIONS

There has been rising number of large-scale fires involving high-hazard flammable trains (HHFTs), some with catastrophic consequences. Class B firefighting foams (i.e., AR-AFFFs), are the industry standard for mitigating and combatting flammable liquid pool fire-type hazards. First responders may default to using an area-based method defined in NFPA 11, the Standard for Low-, Medium-, and High-Expansion Foam, for calculating foam application rates and quantities needed to fight HHFT fires. The values determined using NFPA 11 may not be accurate when considering the complex, three-dimensional, and potentially highly obstructed and limited access nature of these fires. The Fire Protection Research Foundation (RF) initiated this program to develop a database and the associated understanding of the foam application rates and total foam quantities needed to effectively mitigate HHFT fire incidents. The information was gathered for the responder community to clarify the requirements and will be ultimately be used for planning purposes and guidance for combating these fires.

To begin the data collection process, a literature review was conducted on foam application during HHFT incidents and focused on reports, professional articles, and academic publications. This review sought to collect available information regarding foam agent application totals, as well as techniques and procedures used to control, suppress, and extinguish these fires. During the review, it became apparent that the primary focus of the incident reports was to identify the cause of events to analyze metrics of railroad safety, rather than details of the tactics and agent quantities used to extinguish the fire. It was determined that there was insufficient data regarding foam usage during HHFT incidents to develop guidance for first responders requiring an alternate approach.

During the various meetings and conference calls conducted during this program, it was determined Specialized Response Solutions (SRS) in Fort Worth, Texas had significant experience in combatting these incidents and was identified as a resource for data on foam usage and overall guidance in best practices for foam application in HHFT events. As a reference, SRS provides emergency response services for hazardous materials incidents and has responded to, and extinguished many HHFT derailments. As a way forward, SRS was hired to review their database and provide detailed descriptions and foam usage values for 12 representative HHFT incidents.

To provide an understanding of the foam usage at the various stages of the fire (and the variables affecting each stage), a timeline was developed to generically describe a typical HHFT fire scenario and various mitigation steps during the progression. This timeline was based on SRS best practices developed during years of experience combatting these incidents and foam usage observed during mitigation by less experienced organizations. This timeline ultimately served as the basis for collecting, organizing and analyzing the foam usage data during this program.

Based on the incident data, cooling water requirements are equally important as foam usage when mitigating these types of events. The amount of water used during these scenarios is typically on the order of hundreds of thousands of gallons and in many scenarios, can well exceed a million gallons. Typical water usage values are approximately two orders of magnitude greater than the amount foam solution discharged during the event.

The assembled data package includes detailed information on twelve representative HHFT derailment incidents. The data includes incidents involving ethanol, crude oil, petroleum, denatured alcohol, and/or a combination of fuels. During these incidents, between 7 to 39 cars derailed. The incidents cover a range of weather conditions from severe cold weather to extreme heat.

Two incidents in the package are obvious outliers. During one incident, first responders made the decision to allow the fire to burn, unmitigated, due to the remote location and extreme cold. Thus, no foam or water was used during this incident. During the other incident, excess amounts of foam were applied indiscriminately around the derailment. During this incident, a total of 2,520 gallons of foam concentrate and 2.2 million gallons of water were used. This incident provides an extreme example of excess foam use resulting from a lack of understanding on how to effectively mitigate this type of incident. The indiscriminate use of foam is discouraged, not only to limit the costs but to minimize the unnecessary release of foam into waterways and wells.

During the ten representative incidents, effective foam usage only occurred during the equilibrium phase. During 50% of these incidents, less than 100 gallons of foam concentrate was used (equates to ~3300 gallons of foam solution). During the remaining 50%, approximately 300 gallons of foam concentrate was used (equates to ~10,000 gallons of foam solution). On average, about 50% of the foam discharged during the equilibrium phase was applied directly into the burning cars (~ 14 gallons per car on average) to suppress and extinguish the fires within the car. The remainder was used to extinguish pool/spill fires and to seal fuel vapors during overhaul.

The foam use values from the incident data were then compared to the analytical values (area method) determined using NFPA 11. The analytical values were typically about five times that actually used during the event. With this said, the empirical values may be skewed toward the lower end of the range due to the extensive experience of the first responders.

The data illustrated that water usage (for cooling) is equally important as foam usage when mitigating these types of incidents. The amount of water used during these scenarios was typically on the order of hundreds of thousands of gallons and approximately two orders of magnitude greater than the amount foam solution (foam concentrate/water solution) discharged during the event.

In addition to water and foam usage, information was also gathered and assessed on variables such as arrival time, fuel type, railroad substrate, weather, railcar construction (i.e., jacket tank cars) and first responder tactics. In general, arrival time, fuel type, railroad substrate, weather and railcar construction all had minimal effects on the incident. However, tactics were shown to play a major role in the outcome.

Inexperienced first responders tend to use foam ineffectively and can prolong the overall duration of the incident. Resources such as the On-Scene Incident Commander Field Guide and Transport Canada's Competency Guidelines for Responders to Incidents of Flammable Liquids in Transport, High-Hazard Flammable Trains provide crucial knowledge and assist responders in making appropriate response decisions. The timeline and associated variables developed during this program provides a good high-level overview of the recommended tactics for combatting HHFT fires.

Since water usage for cooling purposes is equally as important as foam usage when mitigating these types of events, optimized cooling agents and techniques may be worth considering in areas of limited water supply/availability.

The information documented during this program helps to bracket the overall amount of foam concentrate needed to respond to an HHFT incident. During the 10 incidents documented in this report, approximately 300 gallons of foam concentrate or less was sufficient to suppress and extinguish these fires. This was the quantity used by a group of well trained, experienced firefighters and may need to be adjusted based on the expected level of training/experience of first responders. The main lessoned learned from the review of data and discussions with SRS centers around using foam only after railcars have been properly cooled and after a car can be responded to with an individual tactical plan. Parallel to foam application, the use of cooling water serves as a vital preemptive step to any offensive response. Increased knowledge more than any amount of available foam concentrate will affect the overall outcome, duration, and severity of an HHFT incident. With proper knowledge of HHFT derailments and the accompanied training, first responders in areas near railroads carrying high-hazard flammable liquids will be more prepared and able to respond to an accident should it occur.

9. REFERENCES

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APPENDIX A: DATA COLLECTION SHEETS

Location of HHFT Event	

GENERAL INFORMATION

Date		Time	
Rural/Well Populated Area?			
Train Information (e.g. total cars derailed, total cars involved in fire, total cars breached, any other pertinent details)			

EVENT DETAILS

Based on explanatory infromation on attached sheets, which event type did this incident match most closely? (Event Type A, B, or C?)	

Timeline: enter approximate time of important points during the HHFT event		Supplemental Information
Time of first responder arrival:		First responder affiliation? Were additional agencies contacted, when?
Time of first strategy decision:		What decisions were made? What factors effected these decisions? Offensive/Defensive/Non-Intervention?
Time Period of Incident Growth:		Describe any sequential thermal stress on containers, pressure relief venting, heat induced tears, and fire/radiant heat exposures that occurred. Describe defensive strategy, if any, that was implemented.
Time Equilibrium was reached:		Describe the state of the HHFT event at the approximate time of equilibrium. Describe the offensive strategy, if any, that was implemented.
Time of end of HHFT event		

FOAM USAGE		
Based on explanatory information on attached sheets, enter foam usage during specific portions of the HHFT event. If specific numbers for suppression, control, overhaul, and wasted foam are unknown, then only approximate an amount of for the overall phase. Enter in terms of estimated gallons of foam concentrate utilized.		
Phase of HHFT Event	(gallons)	Provide detail/supplemental information about foam use where deemed important. Factors that a critical and should be mentioned next to values of foam concentrate used may include: training or lack thereof of responders; weather at time of application; wind at time of application; railroad type (i.e. elevated fill, valley, bridge); other factors that may have affected amount of foam used at any point in the HHFT event.
(1) Early Incident		
x control,1 =		
x wasted,1 =		
(total gallons foam concentrate in early incident) x,1 =		
(2) Incident Growth		
x control,2 =		
x wasted,2 =		
x overhaul,2 =		
(total gallons foam concentrate in incident growth) x,2 =		
(3) Equilibrium		
x wasted,3 =		
x overhaul,3 =		
x suppression,3 =		
x extinguish,3 =		
(total gallons foam concentrate in equilibrium) x,3 =		
Total gallons of foam concentrate used for the HHFT event		

WATER USAGE		
Water Use (gallons)		Supplemental Information
Cooling Water Used		
Cooling Water Recycled?		
Foam Application Water Used		
Foam App. Water Recycled?		
Total Water Estimate		
Fire Deparment Water Use		

APPENDIX B: SRS DATA SET

	New Brighton, PA	Painsville, OH	Luther, OK	Cherry Valley, IL	Tiskilwa, IL	Plevna, MT	Casselton, ND	Plaster Rock, NB	Gogama, ONT	Gogama, ONT	Galena, IL	Heimdal, ND
Key Identifying Words	Rural Unit Train Quick response Defensive Geographic restrictions Bridge/River Holes Tears Cooling Interior foam application Pool fires	Rural Mixed Freight Train Quick response Large amount of water Holes Interior foam application	Rural Hot Weather (92 F) Slow response Interior foam application Holes Defensive Tears Cooling Difficult site access	Well Populated Unit Train Wasted foam Interior foam application Holes Defensive Cooling Pool fires Large amount of foam Buried gas line extended event	Rural Mixed Freight Train Defensive Cooling Tears Pool fires	Rural Unit Train Slow response Offensive Defensive Tears Pool fires Pressure venting/explosions	Rural Cold Weather (-50 F) Unit Train Tears Defensive Pool fires Pressure venting/explosions Minimal water supply No foam	Rural Mixed Freight Train DOT-111 Cars Holes Tears Defensive Pressure venting/explosions Large release of car contents	Rural Mixed Freight Train Cold Weather Holes Defensive	Rural CPC-1232 Cars Unit Train Holes Defensive Pool fires	Rural CPC-1232 Cars Unit Train Cold Weather Holes First responder lack of knowledge Tears	Rural CPC-1232 Cars Unit Train Rainy Weather Elevated track bed Marsh area Holes Defensive
BASIC INFO												
Date	10/10/2007	10/10/2007	8/22/2008	6/19/2009	10/7/2011	8/5/2012	12/30/2013	1/7/2014	2/14/2015	3/7/2015	3/5/2015	5/6/2015
Time	9:41 PM	12:02 PM	2:37 PM	8:36 PM	2:14 AM	4:30 PM	2:10 PM	-	11:50 PM	2:42 AM	1:20 PM	7:30 AM
Cars Derailed	23	30	13	19	26	18	20	-	29	39	21	7
Cars Released / on Fire	20		8	13	9	17 / 6	18	-	21	20	10	5
Fuel	Ethanol	Ethanol, Phthalic anhydride	Crude Oil	Ethanol	Ethanol	Denatured Alcohol	Crude Oil	Crude Oil and LPG	Crude Oil and Petroleum	Crude Oil	Crude Oil	Crude Oil
TIMELINE												
Time of First Responder Arrival	10 min	Minutes	30 min	Minutes	10 min	20 min	Minutes	15 - 25 min	Unknown	Unknown	15 min	Minutes
Time of First Strategy Decision	20 min	15 - 30 min	3.25 hrs	1.5 hrs	30 min - 1 hr	30 min	15 - 20 min	30 min	30 min	Early	Early	Early
Time Period of Incident Growth	30 min - 2.5 hrs	30 min - 2.5 hrs	30 min - 2.5 hrs	up to 2.5 hrs	30 min - 5.5 hrs	30 min - 1 hr	30 min - 1.5 hrs	Initial - 1 hr	30 min - 3.5 hrs	30 min - 3.5 hrs	30 min - 3.5 hrs	30 min - 3.5 hrs
Time Equilibrium was Reached	3 - 4 hours	4 - 5 hrs	6 - 8 hrs	4.5 - 6 hours	5.5 - 6 hrs	2.5 - 4 hrs	3 - 5 hrs	30 min - 1 hr	3.5 hrs	3.5 hrs	3.5 hrs	3.5 hrs
Time to End of Event	30 hrs	28 hrs	28 - 30 hrs	36 hrs	44 hrs	40 hrs	55 hrs	36 hrs	72 hrs	70+ hrs	70+ hrs	60 hrs

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FOAM (gallons)												
Early Incident Phase (gallons)												
Control	0	0	0	200	0	0	0	0	0	0	0	0
Indiscriminant	0	0	0	2000	0	0	0	0	0	0	0	0
Total Early Incident Foam Use	**0**	**0**	**0**	**2200**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Early Incident Foam Use Detail				**Control:** used effectively on pool fires and rescue ops. **Indiscriminant**: delivered indiscriminently to areas on both sides of derailment.								
Incident Growth Phase (gallons)												
Control	0	0	0	0	0	0	0	0	0	0	0	0
Indiscriminant	0	0	0	50	0	0	0	0	0	0	0	0
Overhaul	0	0	0	0	0	0	0	0	0	0	0	0
Total Incident Growth Foam Use	**0**	**0**	**0**	**50**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Incident Growth Foam Use Detail				**Indiscriminant:** estimated based on fire department use on small pool fire applications.								

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Equilibrium Phase (gallons)												
Indiscriminant	0	5	0	0	0	35	0	0	25	30	0	0
Overhaul	0	10	25	140	160	75	0	0	50	45	10	10
Suppression	20	30	125	130	70	122	0	35	165	180	40	45
Extinguishment	0	5	0	0	0	65	0	0	35	55	0	5
Total Equilibrium Foam Use	**20**	**50**	**150**	**270**	**230**	**297**	**0**	**35**	**275**	**310**	**50**	**60**
Equilibrium Foam Use Detail	**Suppression:** cooling of cars continued until small foam applications were made on two cars.	**Indiscriminant:** foam used as wetting agent to help with. **Overhaul:** small pool fires around ETOH cars, and grain piles. **Suppression:** final interior application on alcohol and phthalic car.	**Suppression:** five cars had foam applied to combat internal fires.	**Suppression:** eleven cars were foamed for vapor suppression and final exting. Applied by SRS.		**Indiscriminant:** running pool fire from leaking SRV, minimal effectiveness. **Overhaul:** protection of wreckers, and equipment. **Extinguishment:** one car had limited openings and a long burning fire, difficult to get enough foam in to the car at one time to extinguish, several applications were made.			**Indiscriminant:** frozen substrate, and sub zero temperatures. **Suppression:** multiple application necessary due ot Syn Crude crust over, and temperature extremes.	**Suppression:** multiple applications to cars were required due to freezing temperatures.	**Suppression:** freezing temperatures complicated the foam applications, and stay time of blankets	**Suppression:** multiple applications to cars were required due to rain events and terrain. Elevated track bed, and marsh area
Total Gallons Foam Concentrate Used During Event	**20**	**50**	**150**	**2520**	**230**	**297**	**0**	**35**	**275**	**310**	**50**	**60**

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WATER (gallons)												
Water for Cooling	299,000	2,000,000+	18,000	2,180,000	390,000	130,000	0	8,000	110,000	560,000+	25,000	123,000
Cooling Water Recycled?	No	No	Yes	No	No	No	No	No	No	No	No	No
Water for Foam Application	1,000	3,000	2,000	20,000	10,000	12,000	0	2,000	10,000	10,000	5,000	2,000
Foam Water Recycled?	No	No	Yes	No	No	No	No	No	No	No	No	No
Total Water Used Estimate	300,000	2,000,000+	20,000	2,200,000	400,000	142,000	0	10,000	120,000	600,000+	30,000	125,000
Fire Department Water Used	300,000	2,000,000+	-	2,180,000	390,000	0	0	10,000	0	0	0	0
EVENT DETAILS												
General Info	Rural edge of Town. 80 car unit train of ethanol, 23 cars derailed, 20 cars released and on fire, several cars on bridge, several in river, and several on dry ground.	Rural edge of town. 112 car mixed freight train, 30 cars derailed, 7 ethanol cars, 1 LPG, and several other chemical cars and general freight cars.	Rural, very remote. 77 car train and 3 locomotives, train speed- 19MPH, 92 F temperature, clear day. Derailment occurred 30 cars from front, and derailed 13 Crude cars, 8 of which opened and were on fire.	Well Populated. 114 car unit train of ethanol, travling at 36 MPH, derailed at a road crossing where a wash out occurred, from torrential rains in the area. 19 cars derailed and 13 cars were holed and on fire very shortly after the event.	Rural, edge of small town, in plowed field. 26 cars from a general freight train derailed, included 10 ethanol cars, 9 of which released product and/or were on fire. The resulting fire ignited threee corn mash cars that complicated the fire efforts later in the event.	Rural, plains area. 88 car unit train of Denatured alcohol, 18 car derailed and 17 released product and 6 were on fire, 3 cars had heat induced tears and ruptures.	Rural. Crude oil unit train collided with another derailed train, 20 cars were derailed and 18 cars were breached and burning, several cars had heat induced tears early in the derailment. Temperature ranged from -10 F to -50 F.	Rural. 122 car mixed freight train, 19 cars and a locomotive derailed. 5 crude oil cars, three LPG cars and several other freight cars. 2 DOT 111 crude cars were breached and leaked product and were on fire, a third crude car was affected by the fire and released a small amount of product form the bottom outlet. Two LPG cars were severly damaged adn were burning uncontorlled form sheared off valves in the protective housings.	Rural. 100 car key train with crude and petroleum distialtes, 29 crude oil cars derailed, initally 7 cars of crude were holed and burning and this led to the fire impact of 14 additional cars. 21 cars total in the fire.	Rural. 111 car unit train of crude oil, 39 cars derailed and more than 20 cars were holed, breached and on fire, cars were all CPC-1232 cars.	Rural. 105 car unit train of crude oil, 21 cars derailed and 10 cars were holed, breached and on fire, cars were all CPC-1232 cars.	Rural. 109 car unit train of crude oil, 7 cars derailed and more than 5 cars were holed, breached and on fire, cars were all CPC-1232 cars.

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First responder affiliation? Were additional agencies contacted, when?	Very quick local response, calls came in immediately to 911.	Very quick initial response by local units.	Rural fire department response and several mutual aid departments, all volunteer departments, with support from local and state Law Enforcement. Slow repsponse, 30 min after event, due to response distance and bad access.	CVFD and several mutual aid departments.	Local resources arrived on scene quickly and began setting up water shuttle ops to combat grass fires and keep the ground fires form spreading. Most of the resources were assigined to perimeter security and initial grass fire control operations.	First responders attended to the grass fire first, while assessing the derailemnt form a distance, Several explosions occurred and the FD stayed in a defensive mode.	Local fire station was less than 10 minutes away.	Several local mutual aid departments responded.	Un known on initial responders.	Un known on initial responders.	Initial responders arrived while fire was very small, lack of understanding about foam sources needed and use of other extinguishing media, prevented first in companies form attempting and fire figth, while the fire was small.	Defensive from the start.
What decisions were made? What factors effected these decisions? Offensive/Defensive/Non-Intervention?	Defensive position due to geographic restrictions and violent fire behavior.	Several mutual aid departments and lots of fire units called ot the scene. Early fire stratedgy was large flow water appliance, unmanned and surrounding the scene.	Defensive fire suppression for derailment, attempted fire suppression of grass and brush fire, focused on evacuations and scene access control.	Early defensive fire approach, victim rescue accelerated the fire resources needed early, defensive cooling streams set up and several foam application occurred early with no effectiveness.	9 of the 10 ethanol cars appeared to be leaking and on fire, very shortly after the initial event, several of the cars SRV's functioned and at least three cars had heat induced tears, or blisters. This occurences helped the FD with the decision to let things burn.	An offensive attack on range fire, and defensive approach to derailment.	Defensive decision early in the incident.	Defensive tactics were employed, due to size of pool fires, initial explosion, and commodities on the consist.	Defensive, let it burn decision was made early on in the incident.	Due to location and resources, and defensive plan was implemented.	Due to location and resources, and defensive plan was implemented.	Due to location and resources, and defensive plan was implemented.

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Describe any sequential thermal stress on containers, pressure relief venting, heat induced tears, and fire/radiant heat exposures that occurred. Describe defensive strategy, if any, that was implemented.	Holed car on bridge, from physical impact released 80% of car volume and fed large pool fire near bridge abuttment. Large holes in car that landed in river caused significant release and fire on and near waters edge, weep holes in bridge abuttment leaked fuel for hours a feed pool fires near pile of cars	Small flammable liquid fires, ignited combustible grains and wood products. In the derailment a car of Phthalic anhydride was holed and ignited. In the wreck was (1) car of LPG that was derailed but not near or on fire.	Several cars were involved in a pool fire and several heat enduced tears created significant heat. Defensive operations were focused on water shuttle and H2O capacity to start an offensive fire approach during equilibrium phase. Burning oil well affected process as well.	Due to confusion in the beginning as to lading, the FD delayed setting fire fighting goals until several hours in to the event and when the train crew confirmed the lading. Large pool fires were buring in and around the cars, several SRV had/or were operating, and at least two cars were holed and burning freely. Cooling and protection lines were used in the attepted rescue of people on site, and unmanned cooling streams were set up and operated by midnight, the day of the event. .	Very similar as above: 9 of the 10 ethanol cars appeared to be leaking and on fire, very shortly after the initial event, several of the cars SRV's functioned and at least three cars had heat induced tears, or blisters. This occurences helped the FD with the decision to let things burn.	Catastrophic failure of one car , resulted in a pressurized total failure of one car, the car was in a pool fire and was completely upside down, the relief valve was prevented form operatinig, due to the car orientation and the pile of cars surrunding it.	Large pool fire very early in the incident, several tank car failures within the first 120 minutes, water was in scarce supply due to ambient temperature			Large pile of cars, large pool fire and several releases accurred during the ealry part of the fire event.	Large pile of cars, large pool fire and several HIT releases accurred during the ealry part of the fire event.	Large pile of cars, large pool fire and several releases accurred during the ealry part of the fire event.

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Describe the state of the HHFT event at the approximate time of equilibrium. Describe the offensive strategy, if any, that was implemented.	Large pool fires had begun to slow, cars burned freely from holes that were opened in the cars from physical damage and two cars that had tears or blisters open up to allow free buring of product.	Alcohol fire was consideralbly small and contained near the leaking cars and was declared under control by the fire chief at 1800 hrs day of the derailment. Several cars, including the phthalic anhydride continued to burn over night.	Cars were allowed to burn overnight. Observation and water resourcing took place all night to prepare for offensive car extinguishment. Water retention and reuse pits were dug to re-use fire/cooling water mulitple times.	Hard to quantify on this event, the derailed cars were spread out and on one side of the street, unmanned streams were applied to "piles" of cars and this resulted in spreading the pool fires to areas not previously impacted by fire. As one car of product was diluted with fire water, the ensuing mixture of flammable liquid was spilled from a buring tank that had begun to reach equilibrium. As streams were applied to the buring cars, the resulting spillage from the buring cars, created new high heat events.	As day broke the next morning, the pool fires had relaxed substantially, and the internal fires in inside the ethanol cars, were burning at combustion equilibrium respectively to each hole size and car orientation.	After the heat induced tears and the one car complete failure, the pool fires burned at a relaxed rate, and continued to burn freely.	Several small blisters and heat tears occurred for the first 1-5 hours.	Initial release was two holed cars of oil and and two burning LPG cars. Large vapor release of LPG fed initial fire behavior along with thousands of gallons of crude on the cround.				

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End of HHFT event	Fire plan started in the early morning hours of the next day and included defensive, unmanned cooling streams from the track bed adjaccent to the last car on th etracks. This operation was for remote cooling and safety of crews removing other cars and preparring to off load damaged cars. Cooling of cars continued until small foam applications werre made on two cars.	Very short fire extinguishment of residual product in cars, large amounts of water were applied by FD, prior to internal fires in cars being extinguished.	Offensive fire ops began at 0700 hrs, morning after and all cars and pool fires were out at 1800 hrs. Cooling water was applied for an additional 10 hrs to cool product for recovery.	Event would have been over sooner if the accident did not affect a burieed high pressure gas line, that needed to be excavated and repaired from damage received during th ewash out and derailment.	Total time from initial incident to track restoration and FD being released form the site. Continued several days for clean-up	Non response form locals, and delayed response form RR due to distance traveled.	Distance of responder travel and lack of water resources affected early decisions for fire tactics as well as several interuptions due to investigative priority delayed response activities	HHFT issues were over after extinguishment of crude cars and removal form the site, the LPG vent and burn operation continued for an additional 24 hours		Length of travel to site, remote access, and weather affected response objectives.	Length of travel to site, remote access, and weather affected response objectives.	Length of travel to site, remote access, and weather affected response objectives.