HIGH HAZARD FLAMMABLE LIQUID TRAIN (HHFT) INCIDENTS: MYTHS, FACTS AND OBSERVATIONS

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INTRODUCTION

Changes in the North American energy sector have brought new challenges to the emergency response community, especially in many geographic areas where there has not historically been a large energy sector footprint. These changes have involved oil and gas exploration, production and manufacturing facilities, as well as the expansion of transportation modes, corridors and operations to meet the needs of the emerging marketplace.

This background paper will focus on flammable liquid unit trains, primarily those transporting crude oil and ethanol. The U.S. Department of Transportation – Pipeline and Hazardous Materials Safety Administration (DOT / PHMSA) defines High Hazard Flammable Liquid Trains (HHFT) as trains that have a continuous block of twenty (20) or more tank cars loaded with a flammable liquid or thirty-five (35) or more cars loaded with a flammable liquid dispersed through a train.

The objectives of this paper are to assist emergency planning and response personnel in preparing for HHFT incident scenarios. The information is based upon an analysis of previous HHFT incidents that have occurred, the lessons learned, and the input and experiences of approximately fifteen emergency response peers representing the railroad and petroleum industries, emergency response contractors, and the public safety emergency response community. See the Annex for the list of emergency response peers who participated in this process.

The information provided in this paper is intended to supplement HHFT planning and training information already being used within the emergency response community, such as the *DOT / PHMSA Petroleum Crude Oil Commodity Preparedness and Incident Management Reference Sheet* (September 2014). The issues outlined in this paper focus upon "What do we know about HHFT emergency response and incident management operations that is considered to be either factual or has been validated through science or engineering?" and "What have we repeatedly observed at HHFT scenarios but has not yet been validated by either science or testing?"

RISK-BASED RESPONSE

The application and use of a risk-based response (RBR) methodology is critical for incidents involving HHFT's. As background, RBR is defined by *NFPA 472 – Standard for the Competence of Responders to HM/WMD Incidents* as a systematic process by which responders analyze a problem involving hazardous materials, assess the hazards, evaluate the potential consequences, and determine appropriate response actions based upon facts, science, and the circumstances of the incident. Knowledge of the behavior of both the container involved and its contents are critical elements in determining whether responders should and can intervene.

Most fire departments have a fundamental understanding and familiarity with flammable and combustible liquids, as they represent the most common class of hazardous materials encountered. The size, scope and complexity of the problems posed by a HHFT incident will challenge virtually all emergency response organizations, and have a direct influence upon the possible strategies and tactics that may be employed by the Incident Commander and Unified Command.

The HHFT lessons learned (i.e., facts and observations) outlined in this paper will be broken into the following five categories: Planning, The Products, The Containers, Incident Management, and Tactical Considerations.

I. PLANNING CONSIDERATIONS

The following general observations can be made as it pertains to local-level planning for HHFT incidents.

- Future HHFT movements will be influenced by economics, market forces and political decisions. While there will be some variation in the total number of tank car movements, the HHFT issue will likely challenge communities well into the future. Even as new transmission pipelines are approved and constructed, the continued movement of both crude oil and ethanol HHFT's from their source to refineries and the marketplace is likely to continue.

- The number of tank cars involved in a HHFT derailment scenario will be dependent upon a number of factors, including train speed, train make-up and track configuration (e.g., curve, grade).

- Pre-incident relationships between emergency responders and their railroad points-of-contact is a critical element in establishing the trust and credibility needed during a major response. By reviewing commodity flow studies, transportation corridor assessments and operational capability assessments, responders can determine and prioritize the overall risks posed by different scenarios to their community.

- The basic approach for managing HHFT incidents is not much different than other hazmat response scenarios – do not under-estimate the need or the value of basic HM-101 skills. Knowledge of the product, its container and the environment will be critical in evaluating response options using a risk-based response process. Response challenges will primarily focus on the location of the incident, the amount of product involved, the size of the initial problem, and the amount, type and nature of resources necessary for fire control, spill control, clean-up and recovery.

II. THE PRODUCTS

The following facts can be identified with respect to crude oils and ethanol as found in HHFT scenarios:

- When removed from the ground, crude oil is often a mixture of oil, gas, water and impurities (e.g., sulfur). The viscosity of the crude oil and its composition will vary based upon the oil reservoir from which it is drawn, well site processing, and residence time in storage tanks.

When transferred into a storage tank or a railroad tank car, it is often a mixture of crude oil and related constituents drawn from various locations and even different producing formations.

It is impossible to determine from which well site any one individual rail car load has originated. Shipments of crude oil are analyzed at the loading location and will have a certification of analysis for the mixture that is loaded on the train. While primarily used for refinery engineering purposes the certificate of analysis includes a characterization of the crude oil and its fractions, and can provide critical information on how the crude oil will behave in a water-borne spill scenario.

- Emergency responders must have a basic understanding of the physical properties (i.e., how it will behave) and chemical properties (i.e., how it will harm) of the materials involved. Considerations should include (a) whether the crude oil is a light or heavy crude oil (in terms of viscosity), and (b) if the crude is a sweet or sour crude oil. **Table 1** (see pages 4-5) provides an overview of the common types of crude oils currently being encountered in HHFT incidents.

The viscosity of petroleum liquids is often expressed in terms of American Petroleum Institute or API gravity, which is a measure of how heavy or how light a petroleum liquid is as compared to water. Water has an API gravity of 10: if the gravity is greater than 10 the petroleum product is lighter and will float on water; if less than 10 it is heavier and will sink. Crude oils are classified by the petroleum industry into the following general categories based upon their API gravity:

Viscosity	API Gravity
Light	> 31°;
Medium	22 to 31°
Heavy	< 22°
Extra Heavy	< 10°

Sour crude oil is a crude oil containing a large amount of sulfur (greater than 0.5% hydrogen sulfide concentrations) and may pose a toxic inhalation hazard. Hydrogen sulfide levels can be an issue in a spill scenario, with higher concentrations typically been found within the container or directly outside of a tank car opening.

Shale crude oils tend to be a light sweet crude oil with a low viscosity, low flashpoint, and benzene content. Shale crudes may also have the possibility of producing significant amount of C_6 - hexane in some locations. In contrast, oil sands crude oils (e.g., Alberta Tar Sands, bitumen) tend to be a heavier crude oil with an API gravity of approximately 8°. Canadian tar sand crudes also tend to be sour unless they have been partially refined before being loaded onto tank cars.

TABLE 1	LIGHT SWEET CRUDE OIL	DILBIT/SYNBIT (BITUMEN WITH DILUENT*)	BITUMEN (OIL SANDS)	DILUENT
TRANSPORTED AS HAZMAT	Yes - DOT Class 3, UN1267 (ERG Guide No. 128)	Yes - DOT Class 3, UN1267 (ERG Guide No. 128)	Maybe - DOT Class 9, UN3257 (ERG Guide No. 128) If shipped above 212 °F and below its flash point	Yes - DOT Class 3, UN1268 or UN 3295
FLASH POINT	Varies: -30° F - 104° F	Range: 0.4° F (dilbit) - 68° F (synbit)	330° F	<-30° to -4F° F
BOILING POINT	Varies: PGI = <95° F, PGII = >95° F	95° F - >500° F	554° F	100 - 118°F
REID VAPOR PRESSURE	8 - 14 psi	11 psi	4 psi	8 - 14 psi
VISCOSITY** IN CENTIPOISE (CPS) @ ~75 °F:	6-8 (Low - Flowable)	60-70 (Low - Flowable)	100,000-1,000,000 (very high - semi solid when cold)	6-8 (Low - Flowable)
API GRAVITY	Bakken 40° - 43°	Will vary based on amount of diluent; approximately 20°	Approximately 8°	
SPECIFIC GRAVITY	0.80 - 0.8 (Floats on water)	0.90-0.98 Initially (Floats then sinks as light ends volatilize)	0.95 - 1.05 (Will sink in Salt Water; Likely to sink in Fresh Water)	0.480-0.75 (Floats on water)
VAPOR DENSITY	1.0 - 3.9 (Heavier than Air)	>1 (Heavier than Air)	>1 (Heavier than Air)	1.0 - 3.9 (Heavier than Air)
HYDROGEN SULFIDE	0.00001% (potential to accumulate as H_2S in head space of vessels)	<0.1% (potential to accumulate as H_2S in head space of vessels)	Negligible (contains bonded sulfur, generally not available as H_2S)	<0.5
BENZENE	Generally <1.0%	0% - 5%	Negligible (Monitor, however it should not be a concern)	0% - 5%

TABLE 1 (continued)	LIGHT SWEET CRUDE OIL	DILBIT/SYNBIT (BITUMEN WITH DILUENT*)	BITUMEN (OIL SANDS)	DILUENT
EVAPORATION RATE (TEMPERATURE DEPENDENT)	>1 (High Evaporation Rate)	Diluent will evaporate quickly, Bitumen will not evaporate	None	>1 (High Evaporation Rate)
SOLUBILITY	Low to Moderate	Moderate	Extremely Low	Slightly Soluble
WEATHERING	Quickly	Diluent weathers fairly quickly, will then form Tar Balls	Very Slow - Like Asphalt	Quickly
RESIDUES	Films and Penetrates	Films and Penetrates - residue is very persistent	Heavy Surface contamination - very Persistent	Films and Penetrates
AIR MONITORING	**LEL** (combustible gas indicator), **Benzene** (direct read or tubes), **H_2S** (direct read or tubes)	**LEL** (combustible gas indicator), **Benzene** (direct read or tubes), **H_2S** (direct read or tubes)	**LEL** (combustible gas indicator), **Benzene** (direct read or tubes), **H_2S** (direct read or tubes)	**LEL** (combustible gas indicator), **Benzene** (direct read or tubes), **H_2S** (direct read or tubes)
RECOMMENDED RESPONDER PPE	Clothing: Turnout Gear/Nomex Coveralls (subject to task and air monitoring) Respiratory Protection: SCBA/APR/Nothing (subject to Task & benzene, H_2S & particulate concentrations)	Clothing: Turnout Gear/Nomex Coveralls (subject to task and air monitoring) Respiratory Protection: SCBA/APR/Nothing (subject to Task & benzene, H_2S & particulate concentrations)	Clothing: Thermal Protection (if hot)/Nomex Coveralls (subject to task and air monitoring) Respiratory Protection: SCBA/APR/Nothing (subject to Task & benzene, H_2S & particulate concentrations)	Clothing: Turnout Gear/Nomex Coveralls (subject to task and air monitoring) Respiratory Protection: SCBA/APR/Nothing (subject to Task & benzene, H_2S & particulate concentrations)
COMMUNITY, WORKER & RESPONDER SAFETY	Flammability, Benzene, LEL, H_2S	Flammability, Benzene, LEL, H_2S, PAH's (poly-aromatic hydrocarbons)	H_2S, PAH's (poly-aromatic hydrocarbons)	Flammability, Benzene, LEL, H_2S

- Bitumen is a tar-like material that is extracted from tar sands. It is highly viscous and must be heated to make it flow. The majority of bitumen being extracted in North America originates in Alberta, Canada.

  In order to transport bitumen, a diluent is usually added to decrease the viscosity and density of the crude oil. The most commonly used diluent is natural gas condensate (liquid byproduct of natural gas processing). Typically these mixtures are 70% bitumen and 30% diluent, resulting in a API gravity of less than 22°. A second type of diluent is synthetic crude oil, which results in a bitumen (50%) / synthetic crude oil (50%) mixture called "synbit." At a 2010 pipeline incident in Michigan involving bitumen, responders reported the presence of floating oil, submerged oil, and sunken oil. Incident experience has noted that the behavior of bitumen oils in water will ultimately depend upon the density of the oil, weathering, and the turbulence of the water.

- Responders will likely have environmental challenges for water-borne spill scenarios involving crude oil and ethanol, especially if the incident impacts a navigable waterway. Ethanol has a very low persistence and will evaporate or dissolve into the water column. In contrast, crude oil will weather and leave a very persistent heavy residue. These differences will require different spill response tactics.

- In analyzing previous incidents involving fire, crude oil and ethanol data points have essentially matched each other in terms of container behavior, container failures, and response experiences.

- Air monitoring results at both incidents and test fires have shown that the products of combustion (i.e., soot and particulates) from crude oil and ethanol fires have not been significantly different than those seen at fires involving Class A materials.[1]

- Considerable research and experience exists on crude oil firefighting, especially as it pertains to crude oil storage tank firefighting and the behavioral concepts of frothover, slopover and boilover.

  Frothovers and slopovers can be a safety issue when applying extinguishing agents, especially in the later stages of a crude oil tank car fire. Application of foam and water in the later stages of a crude oil tank car fire can result in some of the tank car contents spewing out of tank car openings.

  In contrast, the risk of a boilover at a crude oil derailment scenario remains subject to debate. Questions exist on whether the findings seen in crude oil storage tank firefighting can be directly extrapolated to HHFT scenarios. As background, in order for a boilover to occur in a storage tank scenario, three criteria are needed:

  - The oil must have a range of light ends and heavy ends capable of generating a heat wave;
  - The roof must be off of the tank (i.e., full surface fire); and
  - A water bottom (i.e., water at the bottom of the tank) necessary for the conversion of the water to steam (1,700:1).

As the oil burns, the light ends burn off and a heat wave consisting of the heavier oil elements is created. When this heat wave reaches the water bottom, the water rapidly flashes over to steam at an expansion ratio of 1,700:1 and forces the ejection of the crude oil upward and out of the tank.

While always possible, the conditions needed for a boilover appear to lower the probability of a boilover occurring in a tank car derailment scenario as compared to a crude oil storage tank scenario.

A key factor in assessing the probability of a boilover is the amount of water in the container. Based upon observations at a number of refineries, shale oil tank cars are typically arriving at refineries with <1% water. Mechanical agitation from the transportation of crude oil in a tank car keeps the water content in suspension. In addition, crudes in rail transport do not have the same residence time for the water to accumulate at the bottom of a moving tank car as it does in a static fixed storage tank. It is difficult to achieve all of the conditions needed for a boilover to occur in this scenario. However, the indiscriminate application of large water streams into a pile of burning tank cars that result in water getting inside of a tank car may increase the risk of a boilover later in the incident.

The following observations have been noted with respect to crude oils and ethanol as found in HHFT scenarios:

- Incidents involving crude oil products with varying percentages of dissolved gases have not generated significant emergency response issues in terms of fire behavior once ignition occurs. Dissolved gases and light ends may facilitate easier ignition of the released product when the initial tank car stress / breach / release events take place. There does not appear to be significant differences in fire behavior once ignition occurs. Once light ends burn off, a heavier, more viscous crude oil product will often remain.

  In non-fire spill scenarios, vapor concentrations have been confirmed via air monitoring. Air monitoring at non-fire events has also shown that the light ends will boil off within several hours. Obtaining the Certificate of Analysis (or comparable information) from the shipper may provide key information on the crude oil viscosity and make-up for assessing potential spill behavior in water.

- Incident experience has shown that very seldom does the fire completely consume all of the product within a tank car. Responders have noted that once the light ends have burned off and the intensity of a crude oil tank car fire levels off to a steady state fire, the heavier ends continue to burn similar to a “smudge pot.”

III. THE CONTAINERS

At the present time, crude oil and ethanol are transported in DOT-111 or CPC-1232 tank cars. On May 8, 2015, the US DOT/PHMSA issued a final rule (HM-251) that provided risk-based regulations pertaining to HHFT operations and new tank car standards for HHFT’s. As specified in the final rule, during the period of 2017 through 2025 DOT-111 and CPC-1232 tank cars used for the shipment of flammable liquids in HHFT service will be either removed from service, retrofit to meet a new DOT-117R standard, or replaced by the new DOT-117 tank car. New tank cars constructed after October 1, 2015 must meet the DOT-117 design or performance criteria.

On December 4, 2015, the Fixing America's Surface Transportation (FAST) Act was signed into law and revised the May 8, 2015 rulemaking to now apply to all flammable liquids transported by rail. See Table 2 for a comparison of the U.S. and Canadian retrofit schedules.

Table 2
Comparison of Tank Car Phase Out Schedule - U.S. vs. Canada

Tank Car Spec / Service	U.S. FAST Retrofit Timeline	Tank Car Spec / Service	Canadian Retrofit Timeline
Non-Jacketed DOT-111 in PG I Service	Crude Oil – 1/1/18 Other – 5/1/25	Non-Jacketed DOT-111 – Crude Oil	5/1/17
Jacketed DOT-111 in PG I Service	Crude Oil – 3/1/18 Other – 5/1/15	Jacketed DOT-111 - Crude Oil	3/1/18
Non- Jacketed CPC-1232 in PG I Service	Crude Oil - 4/1/20 Other - May 1, 2025	Non-Jacketed CPC-1232 - Crude Oil	4/1/20
Non-Jacketed DOT-111 in PG II Service	Crude Oil – 1/1/18 Ethanol – 5/1/23 Other – 5/1/29	Non-Jacketed DOT-111 - Ethanol	5/1/23
Jacketed DOT-111 in PG II Service	Crude Oil – 3/1/18 Ethanol – 5/1/23 Other – 5/1/29	Jacketed DOT-111 - Ethanol	5/1/23
Non-Jacketed CPC-1232 in PG II Service	Crude Oil – 4/1/20 Ethanol – 7/1/23 Other – 5/1/29	Non-Jacketed CPC-1232 - Ethanol	7/1/23
Jacketed CPC-1232 in PG I and II Service and All Remaining TC's in PG III Service	Crude Oil – 5/1/25 Ethanol – 5/1/25 Other PG I – 5/1/25 Other PG II & III – 5/1/29	Jacketed CPC-1232 in PG I and II & All Remaining TC's in Other Flammable Liquid Service	5/1/25

From a risk-based response perspective, the enhanced DOT-117R and DOT-117 tank cars will have most of the same construction features currently found on high-pressure tank cars used for the transportation of liquefied gases (e.g., LPG, anhydrous ammonia, etc.). These features will include full-height 1-2-inch thick head shields, jacketing, thermal protection, increased shell thickness (DOT-117), top fitting protection, and either removal or redesign of the bottom outlet handle.

The following facts can be noted with respect to the behavior of the railroad tank cars in a HHFT scenario:

- Tank cars equipped with jacketing and thermal protection have performed better than the legacy DOT-111 and non-jacketed CPC-1232 (i.e., Interim DOT-111) tank cars in derailment scenarios involving fire.

Observations show that the number of tank cars that breach or fail is dependent on the type of tank car involved (e.g., DOT-111, CPC-1232 jacketed vs. non-jacketed tank car) and the configuration of the derailment (i.e., in-line vs. accordion style). Tank cars that pile up generally sustain greater numbers of car-to-car impacts that result in breaches, or will be susceptible to cascading thermal failures from pool fires. Tank cars that roll over in-line are less susceptible to a container breach, but may leak from damaged valves and fittings.

After the initial mechanical stress associated with a derailment, crude oil and ethanol tank cars may breach based upon a combination of (a) thermal stress from an external fire impinging on the tank car shell, (b) the heat-induced weakening and thinning of the tank car shell metal, and (c) the tank car internal pressure. The hazards posed by the release of flammable liquids include flash fires, pool fires, fireballs from container failure (i.e., radiant heat exposures) and any associated shock wave.

- For example, all of the crude oil tank cars involved in the Mount Carbon, WV derailment were CPC-1232 tank cars with no thermal protection. During the derailment sequence, two tank cars were initially punctured releasing more than 50,000 gallons of crude oil. Of the 27 tank cars that derailed, 19 cars became involved in the pileup and post-accident pool fire. The pool fire caused thermal tank shell failures on 13 tank cars that otherwise survived the initial accident.[2]

  Also of critical importance to responders is the timing of the tank shell failures. Emergency responders at the Mount Carbon, WV incident reported the first thermal failure about 25 minutes after the accident. Within the initial 65 minutes of the incident, at least four tank car failures with large fireball eruptions occurred. The 13th and last thermal failure occurred more than 10 hours after the accident.[3]

- The size of the area potentially impacted by both the fireball and radiant heat as a result of a tank car failure are key elements in a risk-based response process. A review of research literature by the Sandia National Laboratory for U.S. DOT / PHMSA showed that a 100 ton release of a flammable liquid (approximately equivalent to a 30,000 gallon tank car) with a density similar to kerosene or gas oil would produce a fireball diameter of approximately 200 meters (656 feet) and a duration of about 10 – 20 seconds.[4] This information can assist Incident Commanders in determining protective action distances as part of a risk-based response process.

Observations that can be made with respect to the behavior of the railroad tank cars in a HHFT scenario include:

- Derailments resulting in a liquid pool fire scenario can lead to the failure of valve gaskets, which leads to additional tank car leaks and associated issues during derailment clean-up and recovery operations.

- Tank cars that have been breached and involved in fire will usually contain some residual product that will continue to produce internal vapors (i.e., typically a vapor rich environment). There have been instances where tank cars being moved during clean-up and recovery operations have allowed air to enter the tank resulting in a flash fire / jet fire from the container breach. Responders should expect vapor flash fires at any time and in any direction, especially during wreck clearing and clean-up operations.

- Heat induced tears (HIT) have been observed on tank cars containing both crude oil and ethanol. At this time no relationship between the activation of a pressure relief device and the blistering of the tank car shell has been observed. While the majority of heat induced tears (HIT) have occurred during the initial 1-6 hours of an incident, tank car failures can occur at any time. Heat induced tearing has occurred within 20 minutes of the derailment and as long as 10+ hours following the initial derailment.

- There can be significant differences in product behavior (e.g., physical properties, internal pressure), tank car design and construction, and breach-release behaviors between pressure tank cars such as the DOT-105 and DOT-112/114 tank cars, and non-pressure tank cars such as the DOT-111 and CPC-1232. There has been no evidence of runaway linear cracking or separation as historically observed with pressure tank car failures occurring in unit train scenarios involving crude oil.

  Based upon Federal Railroad Administration (FRA) reports, the following container behavior observations have been noted: [5, 6]

  - Container separation has occurred at derailments involving ethanol tank cars in Arcadia, OH and Plevna, MT. A separation occurs when a thermal tear propagates circumferentially from each end of the tear and results in the tank car completely or nearly fragmenting into multiple pieces.
  - The FRA report also noted that some of the "explosions" at these derailments may be the result of either a rapid massive vapor release in a matter of seconds which can cause a blast wave the effects of which are limited to relatively short distances or the misrepresentation of the fire ball type of burning as an "explosion."

  As used within the fire service and defined by the National Fire Protection Association (NFPA), a BLEVE is a major container failure, into two or more pieces, at a moment in time when the contained liquid is at a temperature well above its boiling point at normal atmospheric pressure. DOT-111 and CPC-1232 tank cars transporting crude oil do not appear to be susceptible to the separation / fragmentation of the tank car, similar to that seen with pressurized tank cars. However, as noted above, separation of ethanol tank cars has occurred at two incidents.

- The term "equilibrium" is used at various places within this paper to describe the point in which the fire problem is no longer expanding and has achieved a "steady state" of fire and container behavior. It usually takes place after most of the light ends have burned off and the intensity of the fire is no longer increasing. The following fire behavior and incident characteristics would be indicative of the state of "equilibrium:"

  1. The fire is confined to a specific area with little probability of growth in either size or intensity.
  2. There is low probability of additional heat induced tears or container breaches caused by fire impingement directly upon tank cars.
  3. There are no current pressure relief device (PRD) activations indicating continued heating of tank cars.

IV. INCIDENT MANAGEMENT

Experience has demonstrated that HHFT incidents are large, complex and lengthy response scenarios that will generate numerous response issues beyond those normally seen by most local-level response agencies. In addition to the hazmat issues associated with the response problem, there will be a number of other secondary response issues that will require attention by Incident Command / Unified Command. These will include public protective actions, logistics and resource management, situational awareness, information management, public affairs, and infrastructure restoration. Expanding the ICS organization early to include command and general staff positions will be critical in both recognizing and managing these issues.

Most fire service emergencies are “high intensity, short duration events” terminated in a matter of hours or within a single operational period. In contrast, major environmental incidents such as HHFT derailments are long duration events that will extend over several days. Smaller public safety response organizations may be overwhelmed by the multitude of governmental agencies and related organizations that will ultimately appear on-scene.

Unified command will be critical for the successful management of the incident. Keep in mind that the configuration of unified command during the first operational period will likely look a lot different in subsequent operational periods as the incident transitions and incident objectives change. Initial unified command will primarily consist of local response agencies who routinely work together at the local level (e.g., fire, LE, EMS with an initial railroad representative). As the incident expands and other agencies arrive on-scene, unified command will evolve to the organizational structure outlined in the National Response Framework or Canadian equivalent for oil and hazardous materials scenarios (i.e., Emergency Support Function (ESF- 10). Under ESF-10, unified command will likely consist of the following:

- Local On-Scene Coordinator (most likely the Fire Department during emergency response operations)
- State On-Scene Coordinator (usually designated state environmental agency)
- Federal On-Scene Coordinator (U.S. Environmental Protection Agency (EPA) or U.S. Coast Guard (USCG), based upon the location of the incident and its proximity to navigable waterways.
- Responsible Party or RP (e.g., railroad carrier, shipper)

As the size, scope and complexity of the incident increase, Incident Management Teams (IMT’s) at the regional, state and federal levels can serve as an excellent resource to support unified command activities.

The application and use of risk-based response processes will be critical to the safe and successful management of the incident. All initial decisions should be driven by a risk-based size-up process, based upon product / container(s) behavior, incident location and exposures, and incident potential. A review of firefighter injury and fatality reports since 1970 shows that the greatest risk of responder injuries at hazardous materials emergencies will be First Responder – Operations level personnel operating during Hour 1 of the response.[7].

V. TACTICAL CONSIDERATIONS

Class B Foam Operations. An HHFT incident is a low frequency, high consequence scenario that will likely be the largest flammable liquid incident encountered by most response agencies. Challenges will include the location of the incident, the overall size and scope of the problem, the rapid growth of the fire and spill problem, and the level of resources available at the beginning of the incident. An objective assessment of most fire department Class B fire capabilities would likely show the following:

- Flammable liquids are the most common class of hazardous materials encountered by the fire service.
- Most fire department Class B fire operational capabilities are focused towards smaller flammable liquid scenarios involving vehicles and spills of 100 gallons and smaller.
- Gasoline tank truck emergencies (8,000 to 10,000 gallon capacity) are generally the largest flammable liquid scenario encountered. In most instances, defensive-based strategies to protect exposures and allow the fire to burn itself out are employed.
- Few municipal fire departments have the operational capability during the initial operational period to deal with large bulk flammable liquid scenarios, such as those found in petroleum storage tank emergencies.
- Industrial fire departments, such as those found in the petroleum and petrochemical industries, have Class B agent operational capabilities to acquire, deliver and sustain large Class B foam operations (2,500 gpm and higher) for large flammable liquid scenarios.
- All flammable liquid firefighting and Class B foam operations begin with the need for large water supplies to support cooling operations, exposure protection and fire extinguishment. With few exceptions, most railroad corridors do not have large flow hydrant–based water supplies immediately available. In addition, the use of natural water sources, such as streams and rivers, may not be easily and safely accessible.
- A review of previous HHFT incidents shows that the majority of firefighting operations after the initial response period have been conducted by emergency response contractors contracted by the Responsible Party (RP), with public fire departments in a supporting role.

The intent of presenting this assessment is to convey that initiating large flow foam operations at HHFT scenarios will be a significant operational challenge for many public fire departments. This will be a low frequency / high consequence scenario that will pose significant risks to emergency responders if offensive strategies are employed. In light of these risks, some jurisdictions have developed tactical pre-plans based upon local risk exposures to assess their ability to safely initiate offensive or defensive operations. A critical element of this process is the identification of "go / no go" areas where tactical response operations may not be possible based upon incident location, topography and scene access.

Formulas for calculating Class B foam concentrate requirements are referenced from *NFPA 11 – Standard for Low-, Medium-, and High Expansion Foam*, and are based upon either spill scenarios (i.e., less than 2-inches product depth) or product storage in depth scenarios. In contrast, flammable liquid spills along a railroad right-of-way are a hybrid, multi-dimensional scenario that can consist of surface spills, pooled product, and product absorbed into the railbed, soil, etc. As a result, foam calculations based upon NFPA 11 parameters on the area of involvement may not be accurate for HHFT scenarios.

A review of previous HHFT incidents shows that potential foam operations can fall into two different operational environments: (1) offensive operations to rapidly control or extinguish the fire in the early phases of the incident timeline, and (2) final extinguishment of the fire in the later phases of the incident timeline after the size and intensity of the fire have greatly diminished (i.e., equilibrium has occurred). Observations include the following:

- No HHFT scenarios have been controlled or extinguished in the early phases of the incident.
- The actual quantity of Class B foam concentrate supplies used for the control and extinguishment of HHFT incidents in the later phases of the incident timeline have been substantially less than the "area-based" planning values based upon the NFPA 11 parameters.
- Once "equilibrium" has been achieved and tank car metals cooled, individual tank cars with breaches and internal fires have been extinguished using as little as 8 gallons of Class B foam concentrate per tank car.
- The use of Class B firefighting foams in combination with dry chemical extinguishing agents (e.g., Purple K or potassium bicarbonate) will be critical tools in the controlling and extinguishing pressure fed fire scenarios.

Risk-Based Tactical Considerations. The following observations can be made with respect to tactical considerations at a HHFT scenario:

- Clues and signs that could indicate that the incident is likely to rapidly grow or cascade, include:

    - Running or unconfined spill fires and releases. Spills may flow into storm drains and other underground structures creating secondary spills and fires. In addition, the use of large water streams for cooling may also spread the fire to unintentional areas.
    - Direct flame impingement on tank cars from either a pool fire or torch fire.
    - Presence of heat induced blisters appearing on the tank car shell.
    - Activation of pressure relief devices (PRD).
    - Fire area has grown since emergency responders have arrived on-scene.

  Any tank car that is subject to flame impingement and venting from a PRD is susceptible to container failure and the generation of a large fireball.

- Most emergency response agencies do not have a robust spill control capability, especially if waterways are involved. Most spill control resources (both land and water-based) at HHFT incidents have been provided by Oil Spill Response Organizations (OSRO's) and emergency response contractors retained by the Responsible Party. First responder spill control priorities will primarily be focused towards defensive tactics for non-fire scenarios to either keep the product out of the water or protect downstream water intakes, users and environmentally sensitive areas. Identification of these downstream sites and locations are critical planning elements.

- Based upon a review of 25+ HHFT incidents, once rapid growth of the fire occurs and PRD's begin to activate offensive strategies cannot be safely implemented until the fire problem achieves a "state of equilibrium," which is often 8+ hours into the incident. The following fire behavior and incident characteristics would be indicative of a "state of equilibrium:"

  - The fire is confined to a specific area with little probability of growth.
  - There is low probability of additional heat induced tears or container breaches.
  - There are no current PRD activations indicating continued heating of tank cars.
  - The fire is primarily a two-dimensional fire versus a pressure-fed three-dimensional fire.

- Based upon previous incidents, the following factors can serve as an initial operational baseline for determining if the fire scenario can be controlled:
  - Is the fire confined to a specific area with little likelihood of growth?
  - Is there a low probability of additional heat induced tears or container breaches?
  - Is the fire primarily a two-dimensional fire versus a large number of pressure-fed three-dimensional fires?
  - Are sufficient water supplies available for container cooling BEFORE foam operations are initiated? These cooling operations will be critical to the operational success of post-equilibrium fire attack operations.
  - Are sufficient Class B foam supplies, appliances and personnel competent in foam operations available? Once initiated, can the required foam operations be sustained?

Post-Equilibrium Fire Operations. Before offensive operations can be initiated after the state of equilibrium is achieved, the involved tank cars will likely have to be cooled. Responders should use thermal imagers or look for steam coming off the tank car shell to assess the product temperature. Product temperatures as high as 450° F. (232° C) have been observed in previous derailments. Assessment of the product temperature will be complicated if the tank car is jacketed.

Key elements of offensive strategies that have been employed at HHFT scenarios **after equilibrium** include (1) adopting a "divide and conquer" approach whereby involved tank cars are addressed one at a time; (2) tank cars being cooled to ensure the ability of Class B foams to seal against hot metal surfaces; (3) foam handlines being used to apply foam into breached tank cars; and (4) dry chemical agents, such as Purple K, being used to control any three-dimensional fires.

VI. RISK-BASED RESPONSE: THE HHFT INCIDENT TIMELINE

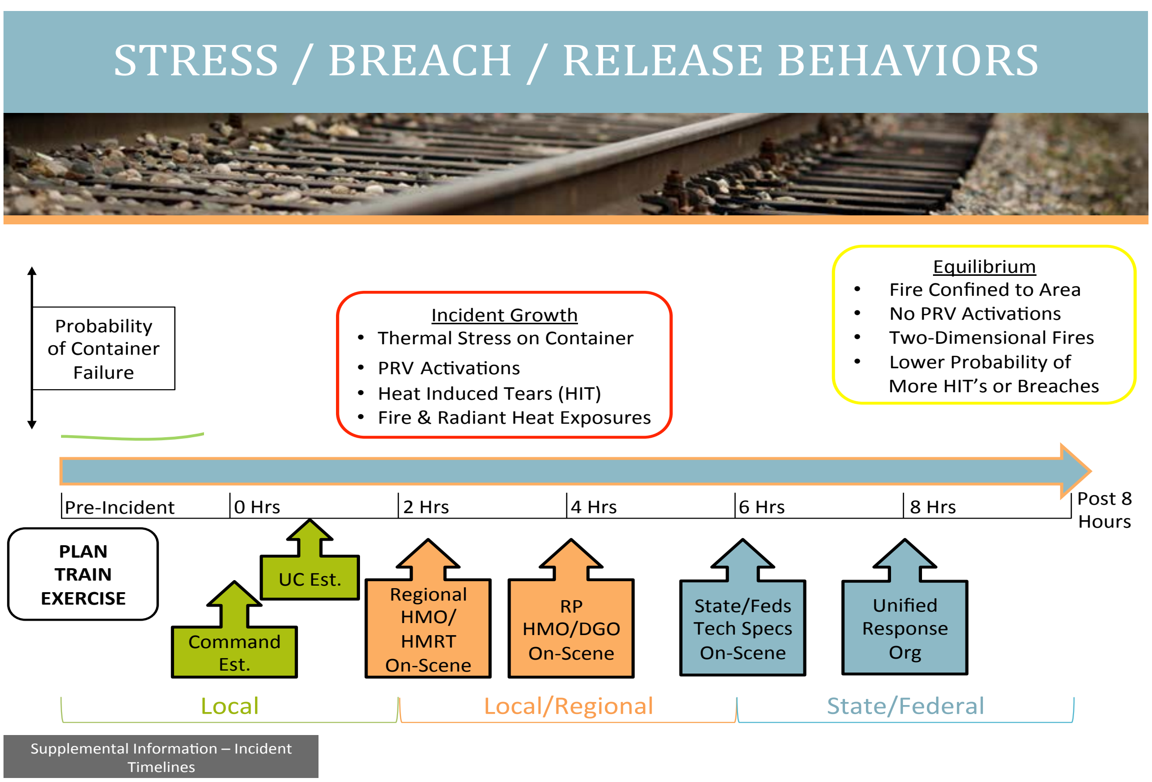
Incident size-up initiates the process of assessing the hazards and evaluating the potential risks at a HHFT scenario. As part of a risk-based response process, understanding the behavior of the container involved, its contents, the location of the incident and surrounding exposures are critical elements in determining whether responders should and can safely intervene.

To assist emergency responders in this process, an HHFT Incident Timeline was developed as a training tool (see pages 16-17). The timeline is designed to show the relationship between (a) the behavior of the tank car(s) and their contents; (b) key incident management benchmarks, and (c) strategic response options. An incident timeline can be an effective training tool. While specific timeline elements will vary based upon incident dynamics, local / regional timelines and operational capabilities, the timeline provides a visual tool that "helps to connect the dots" for incident action planning considerations.

The Incident Timeline consists of three screens. Key points of each screen include the following:

1. Stress / Breach / Release Behaviors

- The timeline focuses upon the first operational period.
- The curve represents the probability of container failures, which leads to a cascading and growing response scenario.
- The properties of the commodities being transported along with the speed of the train and the energy associated with the initial derailment will directly influence the initial container breach, spill / release behavior and ignition potential. After the initial mechanical stress caused by the derailment forces, subsequent container stress / breach / release behaviors will be thermal or fire focused.
- Incident growth will generally follow a process of (a) thermal stress from the initial fire upon the tank cars; (b) activation of tank car pressure relief devices; (c) continued thermal stress on adjoining tank cars from a combination of both pool fires and pressure-fed fires from PRD's; (d) increasing probability of container failures through heat induced tears; and (e) subsequent fire and radiant heat exposures on surrounding exposures when explosive release events occur.
- Fires will continue to burn off the available flammable liquid fuel until such time that it achieves a level of "equilibrium" and is no longer growing in size or scope. **An analysis of historical incidents shows that equilibrium at a major incident may not occur for approximately 8-12 hours.** There is a lower probability of additional heat induced tears or tank car breaches once equilibrium is achieved.
- "Equilibrium" benchmarks would include the fire being confined to a specific area and no longer increasing in size or scope; no PRD activations, and the fire scenario primarily being a two-dimensional scenario, with any three dimensional pressure-fed fires decreasing in intensity.

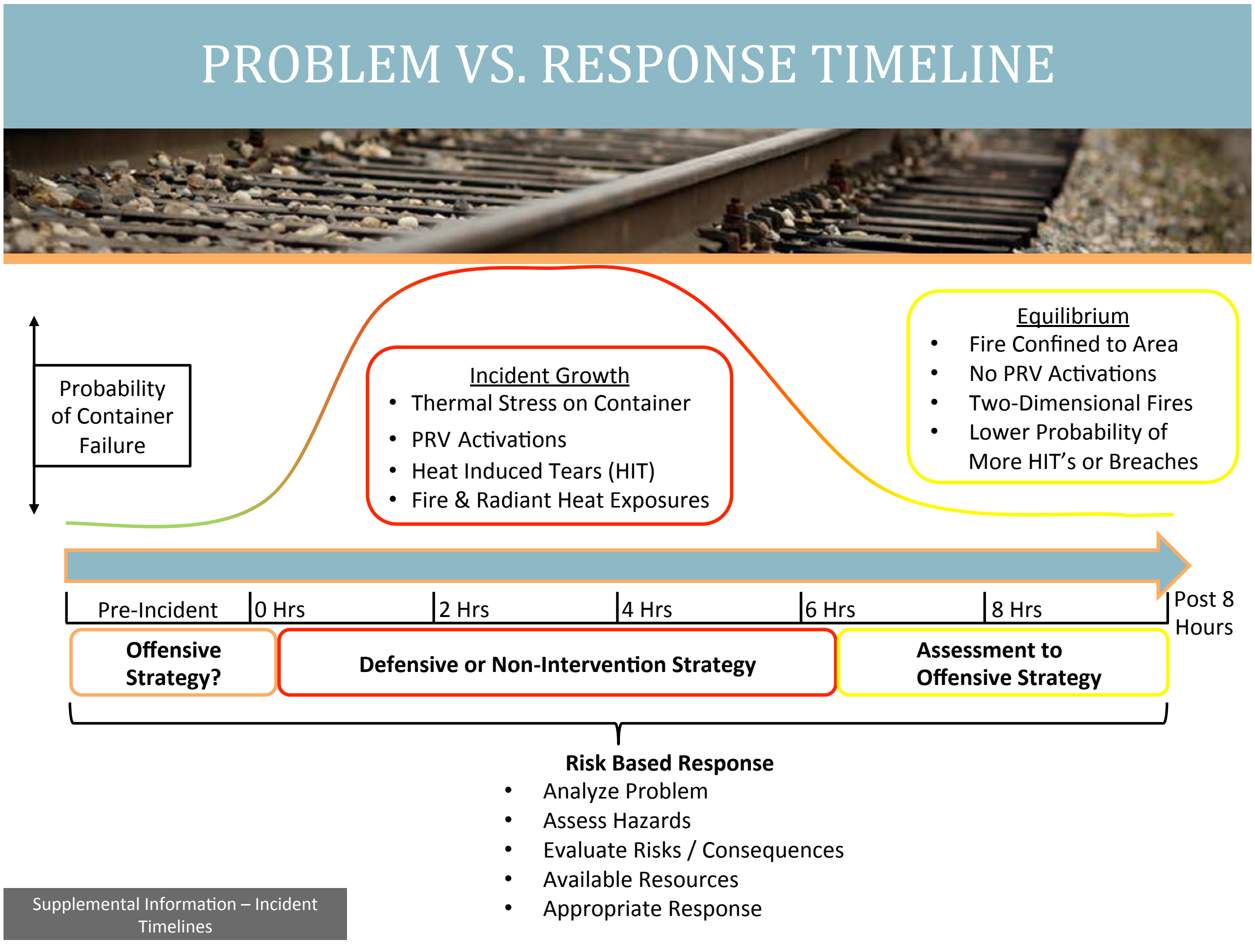


2. Incident Management Benchmarks

- Lessons learned from previous incidents clearly shows that communities that engage in pre-incident planning, training and exercise activities with fellow stakeholders establish the foundation for a safe and effective response. The importance of establishing relationships between all of the key players before the incident cannot be over-emphasized.
- While the exact timeline will vary based upon local / regional resources and response times, key incident management benchmarks within hour 1 will include (a) conducting an incident size-up, identification of critical incident factors, and development of initial incident objectives; (b) establishment of command and an Incident Command Post (ICP) and (c) establishment of a unified command organization. Unified command at this phase of an incident will be local-centric and focus upon the integration of fire / rescue, law enforcement and EMS resources. Railroad personnel will primarily function in a liaison role during this initial window.
- Arrival of resources that can provide technical assistance to Incident Command / Unified Command (IC/UC) within the first several hours of the incident. Based upon local / regional capabilities and response times, this technical assistance may be provided through any combination of Technical Specialists, HazMat Officers, Hazardous Materials Response Teams (HMRT) or HazMat / Dangerous Goods Officers from the Responsible Party (RP).
- Arrival of additional governmental and RP representatives, as well as contractors working on behalf of the RP. Based upon incident location and response times, these elements will likely arrive on-scene in the later half of the first operational period.
- Once all of the players are on-scene, unified command will evolve to an organizational structure that will likely challenge the organizational skills of many response agencies. Unified Command will likely consist of:

    - Local On-Scene Coordinator (most likely the Fire Department during emergency response operations)
    - State On-Scene Coordinator (usually designated state environmental agency)
    - Federal On-Scene Coordinator (U.S. Environmental Protection Agency (EPA) or U.S. Coast Guard (USCG), based upon the location of the incident and its proximity to navigable waterways.
    - Responsible Party or RP (e.g., railroad carrier, shipper)

  Other local, state, federal and non-governmental organizations will work through their respective On-Scene Coordinator or the Liaison Officer to bring their issues to the table.



3. Strategic Response Options

- Once responders understand the relationship between the fire growth curve and the incident timeline, the strategic level options available to control the problem can be better assessed.
- In order to safely and successfully control a HHFT fire scenario, the following criteria must be considered:
  - What is the likely outcome without intervention?
  - What is the status and growth pattern of the fire? Is the fire relatively small and not rapidly growing? Or is the incident rapidly expanding in both its size and scope?
  - What is the probability of heat induced tears or container breaches occurring and preventing responders from safely approaching the incident close enough to apply foam and water streams? Once there is significant thermal stress on tank cars, PRD's start to activate and additional tank car breaches occur, the ability of emergency responders to influence the outcome is not likely.
  - Are sufficient water supplies and water movement capabilities available to support all exposure cooling and fire extinguishment operations?
  - Are sufficient Class B foam supplies and appliances available to support the required flow and concentrate requirements?
  - Are emergency response personnel trained and competent in large volume foam operations, and can they implement and sustain large volume foam operations in a time-constrained scenario?

- Based upon an analysis of approximately 25 HHFT incidents, there is a very limited window of opportunity in the early stages of an incident for implementing offensive fire control strategies. There is a higher probability that response options will be limited to defensive strategies (e.g., exposure protection) to minimize the spread of the problem or non-intervention strategies (i.e., no actions) until equilibrium is achieved. Using a risk-based response process will be critical for this re-assessment process.
- Once the equilibrium phase is achieved, responders may choose to switch to an offensive fire control strategy.

SUMMARY

Changes in the North American energy sector and the increased utilization of High Hazard Flammable Liquid Trains (HHFT) have brought new challenges to the emergency response community. The objectives of this paper are to assist emergency planning and response personnel in preparing for incidents involving an HHFT within their community. . The information provided is based upon an analysis of approximately twenty-five HHFT incidents that have occurred, the lessons learned, and the input and experiences of approximately 15+ emergency response peers representing the railroad and petroleum industries, emergency response contractors, and the public safety emergency response community.

This paper is viewed as a living document, and will be updated to reflect new information, research and lessons learned from future incidents. Questions and comments should be directed to Gregory G. Noll at ggnoll@me.com.

TERMS AND DEFINITIONS

Boiling Liquid, Expanding Vapor Explosion (BLEVE). A major container failure, into two or more pieces, at a moment in time when the contained liquid is at a temperature well above its boiling point at normal atmospheric pressure (NFPA).

Boilover. The expulsion of crude oil (or certain other liquids) from a burning tank. The light fractions of the crude oil burn off producing a heat wave in the residue, which on reaching a water strata, may result in the expulsion of a portion of the contents of the tank in the form of a froth.

Certificate of Analysis. The characterization of the crude oil and its fractions produced by the product shipper. While primarily used for refinery engineering purposes, it can also provide critical information on how the crude oil will behave in a water-borne spill scenario.

Frothover. Can occur when water already present inside a tank comes in contact with a hot viscous oil which is being loaded

Heat Induced Tear. Also referred to as a thermal tear, a longitudinal failure that occurs in the portion of the tank car shell surrounding the vapor space of the tank following exposure to pool fire conditions. Thermal tears have been measured from 2 feet to 16 feet in length.

High Hazard Flammable Liquid Train (HHFT). A train that has a continuous block of twenty (20) or more tank cars loaded with a flammable liquid (i.e., unit train), or thirty-five (35) or more cars loaded with a flammable liquid dispersed through a train (i.e., manifest train with other cargo-type cars interspersed).

Risk Based Response. A systematic process by which responders analyze a problem involving hazardous materials, assess the hazards, evaluate the potential consequences, and determine appropriate response actions based upon facts, science, and the circumstances of the incident (NFPA 472).

Slopover. Can result when a water stream is applied to the hot surface of a burning oil, provided that the oil is viscous and its temperature exceeds the boiling point of water. It can also occur when the heat wave contacts a small amount of water stratified within a crude oil. As with a boilover, when the heat wave contacts the water, the water converts to steam and causes the product to “slop over” the top of the tank.

Unit Train. A train in which all cars carry the same commodity and are shipped from the same origin to the same destination, without being split up or stored en-route.

ENDNOTES

1 Center for Toxicology and Environmental Health, “Bakken Crude Oil Burn Demonstration – Air Monitoring and Sampling Report Prepared for Williams Fire & Hazard Control” (North Little Rock, AR: Center for Toxicology and Environmental Health, January 16, 2014), 12.
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3 Ibid. 8.
4 Sandia National Laboratories, "Literature Survey of Crude Oil Properties Relevant to Handling and Fire Safety in Transport" (Albuquerque, NM: Sandia National Laboratories, March 2015), 78.
5 Alexy, Karl, "Comparative Analysis of Documented Damage to Tank Cars Containing Denatured Alcohol or Crude Oil Exposed to Pool Fire Conditions" (Washington, DC: US DOT / Federal Rail Administration - date unknown), page 4.
6 Raj, Phani K., "Comparison of Magnitude of Hazards Resulting from the Release of Crude Oil and Ethanol from Tank Cars." 8.
7 Noll, Gregory, Survey of firefighter injury and fatality reports during the period of 1970 – 2015. Report sources included NFPA, NIOSH, U.S. Fire Administration and other open sources.

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