WHAT RECENT HHFT DERAILMENT FIRES TELL US

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In July 2016, TRC Environmental Corporation (TRC) and Hildebrand and Noll Associates, Inc. (HNA) were requested to develop planning guidance on train derailments involving large volumes/high concentrations of denatured ethanol for the Massachusetts Emergency Management Agency (MEMA). As part of this project, as well as similar projects conducted by HNA for other clients, TRC and HNA assessed current firefighting strategies for the release of ethanol and/or crude oil from High Hazard Flammable Trains (HHFT) and developed the planning assumptions necessary to prepare for these types of incidents.

For these projects, studies and in-depth analyses of 27 HHFT derailments resulting in tank cars breaches that occurred in the United States and Canada involving denatured ethanol[1] (ethanol) and/or crude oil[2] from 2006 through 2015 were performed. The analyses were primarily based on the information from the National Transportation Safety Board (NTSB), Federal Railroad Administration (FRA), and/or Transport Canada (TC) databases, with supplemental information from news reports in some cases. The objective of these analyses was to identify key planning assumptions that would be used in developing appropriate firefighting strategies by focusing on the number and types of cars derailed, approximate train speeds at the

[1] Denatured ethanol in this paper refers to ethanol which contains approximately 2% to 5%, but as much as 7%, gasoline or other denaturant in order to make it unfit for drinking.

[2] Crude oil refers to shale oil that has a high percentage of volatile constituents (e.g., Bakken crude oil), and meets the USDOT definition of a Class 3 flammable liquid

time of the derailment, number of cars breached, amount of product released, and whether or not the released product caught fire.

Additionally, the studies included obtaining and reviewing information on the properties and characteristics of ethanol, crude oils, and other Class 3 flammable materials, as well as information for railroad tank cars. Insights and understandings gained from these studies were used to further develop the firefighting strategies for HHFT derailment fires.

INTRODUCTION

As the American Association of Railroads (AAR) and the American Short Line and Regional Railroad Association (ASLRRA) stated in their comments on the advanced notice of proposed rulemaking requiring comprehensive oil spill response plans for crude oil trains by the U.S. Department of Transportation – Pipeline and Hazardous Materials Safety Administration (USDOT – PHMSA), "[a]ccording to Federal Railroad Administration (FRA) statistics, since 2000, the rate of train accidents with a release for every thousand carloads of hazardous materials transported has declined 35 percent, from 0.020 to 0.013." In other words, "99.998 percent of hazardous materials cars are transported to destination without a release" (American Association of Railroads, 2014). Although HHFT derailments that result in tank car breaches are low frequency incidents, there were 27 such incidents in the United States and Canada involving ethanol and/or crude oil from 2006 to 2015 that resulted in loss of life, injuries, property damage, and/or environmental impacts.

TRC and HNA assisted MEMA with the development of the Large Volume/High-Concentration Ethanol Incident Response Appendix (the Appendix) (Narin van Court et al., 2016a) to the Hazardous Material Annex of the Commonwealth of Massachusetts Comprehensive Emergency Management Plan and associated guidance documents (Narin van

Court et al., 2016b). The purpose of the Appendix was to promote situational awareness and outline the operational activities for a state response to a significant ethanol incident, such as an ethanol train derailment. The purpose of the guidance documents was to assist local emergency managers and planners develop area-specific response plans for these types of incidents.

In separate but related projects, HNA assisted the National Fire Protection Association (NFPA) and USDOT – PHMSA in developing guidance documents for responding to HHFT derailments and fires involving flammable liquids (Hildebrand and Noll, 2016a; Hildebrand and Noll, 2016b, respectively).

As a result of the work by TRC and HNA, the planning assumptions needed to develop suitable firefighting strategies for HHFT derailment fires were developed and include the following:

- There is a high probability that HHFT derailment scenarios involving DOT-111 or CPC-1232 tank cars will result in multiple container failures; to date, the newer DOT-117 tank cars have not been involved in any HHFT derailment scenarios.
- These incidents present large, complex response scenarios, and will quickly challenge the incident management capabilities of most local response agencies, so consideration should be given to the response of All-Hazard Incident Management Teams (IMT) to provide incident management assistance.
- There is a low probability of offensive fire tactics successfully suppressing fires for scenarios involving multiple tank car failures because these incidents rapidly escalate and grow.

- Expect large volumes of flammable liquids to be released and/or involved in fire. Allowing the material to burn off versus the long term environmental impacts to water or soil should be considered.
- Risks of tank car breach and failure during low speed derailments, such as in an urban area where track speeds may be regulated to 10 or 25 miles per hour, may still be significant.

METHODOLOGY

To develop the planning assumptions for firefighting strategies, HNA and TRC performed an in-depth analysis of 27 HHFT derailments resulting in tank car breaches that occurred in the United States and Canada from 2006 through 2015. These derailments included 11 ethanol HHFT, 15 crude oil HHFT, and one HHFT with both ethanol and crude oil. The details are summarized in Table 1. An HHFT is defined in Title 49 of the Code of Federal Regulations Part 171.8 (49 CFR 171.8) as either a single train transporting 20 or more loaded tank cars of a Class 3 flammable liquid in a continuous block or a single train carrying 35 or more loaded tank cars of a Class 3 flammable liquid throughout the train consist. While other train derailments involving Class 3 flammable liquids trains occurred within the timeframe considered for this analysis, these incidents involved trains that did not meet the definition of HHFT and, therefore, were not included in the analyses. The information on the 27 HHFT derailments was generally obtained from the NTSB, FRA, and/or TC databases, with supplemental information from news reports in some cases.

The analysis focused on four key factors to guide emergency response planners developing planning scenarios and response strategies and tactics:

1. *Number of cars derailed vs. number of cars breached:* to provide an understanding of the average number of tank cars involved in a derailment, as well as the relationship of cars derailed to cars breached.
2. *Derailments that resulted in tank car fires:* to provide an understanding of the number of incidents that resulted in tank cars breaching with subsequent fires.
3. *Quantities of product released:* to provide an understanding of the size of potential product releases and the size of the potential spills and fires that may occur.
4. *Train speed at time of derailment:* to provide a useful perspective for estimating the number of cars that may derail and the probability of breaching.

FINDINGS / OBSERVATIONS

Based on our analysis, we developed the findings and observations that are described in the following sections.

Before each of the four key factors are discussed in more detail, it is important to note that for the derailments included in this study the tank cars transporting ethanol or crude oil were legacy DOT-111 and CPC-1232 tank cars. Each tank car typically has a capacity in the range of 24,000 to 32,000 gallons, which is equivalent to three to four DOT-406 cargo tank trucks (i.e., tractor-trailer tanker transports) used for on-road transportation of these materials. In the first quarter of 2015, CPC-1232 tank cars (both non-jacketed and jacketed types) were the most common type of tank cars used to transport crude oil (84% of the total: i.e., 55% non-jacketed and 29% jacketed) and the DOT-111 was used to transport 94% of the ethanol (AAR, 2015). Effective October 2015 all new tank cars transporting Class 3 Flammable Liquids must now be constructed to the newer DOT-117 tank car specifications. Specifically, DOT-111 and CPC-1232 tank cars transporting ethanol and crude oil must be replaced by DOT-117 tanks in accordance with the schedule in the Fixing America's Surface Transportation (FAST) Act (Public Law Number 114-94), which is as follows:

- Non-jacketed DOT-111's: crude oil by January 1, 2018 (by November 1, 2016 in California) and ethanol by May 1, 2023;
- Jacketed DOT-111's by March 1, 2018 (by November 1, 2016 in California) and ethanol by May 1, 2023;
- Non-jacketed CPC-1232's by April 1, 2020 and ethanol by July 1, 2023; and
- Jacketed CPC-1232's by May 1, 2025 and ethanol by May 1, 2025.

Furthermore, AAR (2016) stated that in 2016 there were 811 unique tank car loads of crude oil transported in DOT-111's out of a total of 23,833 unique tank car loads transported through the third quarter of the year. However, there were 29,597 unique tank car loads of ethanol transported in DOT-111's out of a total of 35,601 unique tank car loads during the same period.

Number of Cars Derailed vs. Number Breached

In the 27 train derailments examined, a total of 490 tank cars derailed and, of those, 327 cars breached. This represents a 66.7% failure rate. Based upon derailment stressors and impacts, tank car breaches have included head punctures, side tears and gouges, and damaged valves and fittings. Head punctures and side tears have often resulted in an immediate loss of the tank car contents and a subsequent fire of great intensity. Thermal-induced breaches, splits, and tears (i.e., heat-induced tears or HIT's) may also occur due to direct flame impingement from pool or pressure-fed fires and to a lesser extent from radiant heat exposures.

Direct flame impingement on a tank car and/or radiant heat exposures from nearby fire(s) may also overwhelm the capacity of pressure relief devices (PRD), with insufficient pressure relief leading to energetic (i.e., high pressure) ruptures that result in dynamic failures. These dynamic failures (i.e., failures where high pressures exacerbate thermal-induced failures) may result in the rapid release of energy producing a large fireball and high radiant heat levels. In at least two instances involving ethanol tank cars, there has also been fragmentation of the tank car, although at a level significantly below that seen with pressurized tank cars (e.g., DOT-112, DOT-114) and Boiling Liquid Expanding Vapor Explosions (BLEVE's).

Thus, the planning assumptions for emergency responders should include the following:

- Expect that HHFT derailment fires will result in car failures with the associated safety concerns for the first responder as well as the public in the surrounding areas.
- Tank shell punctures can release large volumes of liquid product within a short time frame, which increases the risk of fires and/or spills that can result in significant environmental impacts.
- Expect a rapid escalation early in the incident that will require rapid response rescue, exposure protection, spill control, and the need to rapidly implement the Incident Command System.

Derailments Resulting in Fires

Of the 27 incidents studied, 21 incidents (77.8%) resulted in fires that involved the contents of one or more tank cars. Tank car fires are hot and intense because the volumes of flammable liquid involved. Furthermore, the incident heat flux (i.e., heat given off by a fire) from an ethanol fire can be two to five times greater than the incident heat flux from a gasoline fire. An added firefighting safety concern with ethanol HHFT derailment fires is that after the denaturant burns off, ethanol burns with a colorless flame and has less visible smoke than fires from many other flammable liquids. As a result, the use of a thermal imaging camera or comparable equipment to detect flames is essential. Diluting the released ethanol is not an effective means of firefighting since even diluted ethanol has a fairly low flash point and it will likely exacerbate the potential environmental impacts. For example, 20% ethanol in water has a flash point of 97º F, while 10% ethanol in water has a flash point of 120º F.

Cooling operations for HHFT fires may require water supplies capable of sustaining large volume flows (e.g., 1,000 GPM and higher) for an extended period of time. Likewise, offensive strategies may require larger quantities of water, Class B foam concentrate (on the order of hundreds of gallons), and high volume foam application devices. Experience has shown that rapidly escalating fire scenarios have a high probability of overwhelming the flammable liquid firefighting capabilities of most responding fire departments. For example, consider a 24,000-gallon ethanol tank car derailment where the load is on the ground in a pool that is about 6,400 square feet and six inches deep. Following the NFPA guidance for using 3% Alcohol resistant aqueous film forming foam (AR-AFFF) concentrate on a polar solvent, the finished foam needs to be applied at a rate of 1,285 gallons per minute for 15 minutes, which requires nearly 580 gallons of foam concentrate and 18,700 gallons of water. As will be discussed below, the typical HHFT derailment involves more than one tank car, which further increases water and foam concentrate demands.

It is important to note that suppressing ethanol fires requires AR-AFFF concentrate, because the finished foam from concentrates that are not alcohol resistant will break down on contact with ethanol reducing their efficacy precipitously.

Experience with actual tank car derailment fires indicates that there may be a very narrow window of opportunity to attack and extinguish the fire using offensive strategies (i.e., firefighting efforts aimed at fire suppression) in the very early stages of the fire, as illustrated in

Figure 1. The application and use of risk-based response processes are a critical element in evaluating possible strategic options. Once tank cars are over-pressurized and begin to have PRD activations, the probability of container failure rises and the potential for a successful offensive attack significantly drops. At this point in the incident timeline, there is a very low probability of controlling the fire scenario until "equilibrium" is achieved. Emergency responders have defined "equilibrium" as a point where:

1) Fire is no longer growing in size and intensity;
2) There are no PRD activations;
3) There is a decreasing probability of a container failure; and
4) Fire is primarily a two-dimensional scenario.

Experience has shown that these fire scenarios may burn from 8 to 12 hours, and in some cases have gone as long as 24 hours before reaching equilibrium. Including the spill control and collection from an HHFT derailment, planners should expect that the emergency response operations will last 24 to 48 hours before transitioning to remediation and clean-up operations.

Thus, the planning assumptions for emergency responders should include the following:

- Prepare for large flammable liquid fires involving multiple tank cars; these fires may cause other rail tank cars to eventually breach and fail due to direct flame impingement and/or radiant heat exposure combined with potential PRD failures.
- There may be a very narrow window of opportunity for using offensive strategies. The application and use of risk-based response processes are a critical element in evaluating possible strategic options. Once this window of opportunity closes, do not expect to control and extinguish the fire until equilibrium is achieved.

- Fire suppression should only be attempted for life safety (i.e., rescue), and only if an offensive strategy can be implemented safely. If incident location and exposures permit, it is generally better to control and contain an HHFT derailment fire until it reaches equilibrium and is allowed to self-extinguish.
- For an ethanol fire, fire suppression requires AR-AFFF foam; regular AFFF foam concentrates will be effective for HHFT incidents involving petroleum crude oils and products.
- Although the available amounts of an appropriate foam concentrate and other resources may not be sufficient to extinguish an HHFT derailment fire, foam may be used in other ways to control an incident. For example, if a spilled flammable liquid enters a storm drain or sewer, applying finished foam into the drain or sewer lines will suppress vapors and minimize the ignition potential of the vapors, as well as the ignition potential of the flammable liquid at an outfall, and, therefore, reduce the potential for additional damage.

One last note regarding HHFT derailments is that first responder procedures should include notifying the railroad to confirm that the railroad is aware of the incident, as the train crew may be incapacitated as a result of the accident. Based on our experience working with first responder agencies, it is important that the first responder agencies understand this point, as well as the railroad's role in the Unified Command, and the type and level of resources that they will provide at the incident. During the initial operational period of the incident, Hazardous Materials / Dangerous Goods Officers from the railroad will be on-scene and can function as Technical Specialists to the Incident Commander. These individuals possess considerable technical knowledge on tank car design and construction, the products involved, and the application of risk-based response processes at derailment scenarios. As previously noted, due to the size and complexity of these incidents, an Incident Management Team can be a key resource in managing the operational, planning, logistical, and financial challenges of the incident.

Quantities Released

In the first quarter of 2015, the crude oil block sizes ranged from 1 to 120 cars with by far the greatest number of movements (about 64% of the total) in the 91 to 110 tank car block sizes (AAR, 2015). The AAR also stated that for ethanol movements during the same time period the block sizes ranged from 1 to 110 cars with the greatest number of movements in the 1 to 10 tank car block size (about 35% of the total) and the next greatest number of movements in the 71 to 80 and 91 to 100 tank car block sizes, about 25% and 10% of the total, respectively.

In the 27 incidents included in our study, the average size spill was approximately 245,100 gallons, which is equivalent to about 8 to 10 tank cars. Not only does this affect the size of a potential fire that may result, but this also means that the response strategies should also address control and containment of spills to minimize potential environmental impacts

When public safety and the risk of the fire spreading to structures is not a factor, allowing continued controlled burning may be the best strategy for minimizing potential environmental impacts. The decision to allow for controlled burning should be based upon the application of risk-based assessment processes, and be coordinated through unified command. Note that it is highly unlikely that permission from the regulatory agencies to relight a HHFT fire after it has been extinguished will be granted easily or quickly, so the decision regarding controlled burning should be whether or not to allow a fire to continue to burn in a controlled manner.

Every effort should be made to control any released liquids and keep them from entering waterways. This is especially true for ethanol because it readily mixes with water. Although ethanol is biodegradable (however the denaturant is usually not as readily biodegradable), high ethanol concentrations in surface waters may kill fish and other aquatic organisms in the short-term by direct contact or in a longer timeframe by decreased dissolved oxygen levels in water due to biodegradation. In addition, flammable liquids that enter underground structures, such as storm drains or sewer lines, can pose additional risks as the liquid and vapors move away from the source of the release. Flammable liquids (especially ethanol) may also kill the microbes used for wastewater treatment.

Thus, the planning assumptions for emergency responders should include the following:

- Anticipate large volumes of flammable liquids to be released and/or involved in fire.
- Controlled burn following an HHTF incident may result in less environmental damage compared to active fire suppression and management of runoff.
- Given the average size of the release and frequency of fires on HHFT derailments, emergency planners must consider both spill control and public protective options and in their incident response planning.

Track Speed at Time of Derailment

Derailment speeds ranged from 9 to 65 miles per hour (mph) with one case where the train speed at the time of derailment was not provided. The average derailment speed was 33.5 mph and the median derailment speed was 35.5 mph.

Sixteen of the cases in our study where the speeds were provided were considered to be “high” speed derailments. Not including the Lac Magantic derailment, the train speed for “high” speed derailments ranged from 25 mph to 48 mph. Critical aspects of these cases are as follow:

- Three to 39 tank cars derailed with an average of about 18 tank cars derailing.

- Two to 36 of the derailed tank cars were breached with an average of about 14 tank cars breaching in each incident.
- There were large releases of flammable liquids, on the order of 4,300 to 835,000 gallons with an average of about 268,000 gallons released, which is equivalent to 9 to 13 loaded tank cars.
- 81.3% of these incidents resulted in fires.

In those geographic areas where the FRA has identified as High Threat Urban Areas (HTUA), HHFT speeds are limited to less than 40 mph if any of the tank cars containing a Class 3 flammable liquid do not meet the DOT-117 car design specifications. Moreover, the train speeds in HTUA are typically less than 25 mph. Of the 26 cases in our study where the speed was provided, nine of the incidents occurred at less than 25 mph and were considered to be "low" speed derailments. For HHFT derailments at "low" speeds, it is important to note the following:

- Derailments involved fewer tank cars than in the higher speed incidents – 5 to 21 with an average of about 11 tank cars derailing.
- Fewer of the derailed cars breached than in the higher speed incidents – 1 to 12 with an average of about five tank cars breaching in each incident.
- Releases of flammable liquids were typically smaller than in the higher speed incidents, on the order of 7,900 to 245,000 gallons with an average of about 80,000 gallons released, which is equivalent to 3 to 4 loaded tank cars.
- 77.8% of these "low" speed derailments resulted in fires.

Therefore, it is important that the planning assumptions for emergency responders include the following:

- Do not overlook the risks from “low” speed derailments, such as those that may occur in built-up or urban areas where track speeds may be regulated to speeds under 25 mph or even under 10 mph. Although the number of tank cars involved in their planning scenarios may be reduced, the risk of fire is still significant.
- In areas with “high” train speeds, response planners should consider scenarios involving a large number of tank cars derailing, breaching, and subsequently catching on fire.

CONCLUSIONS

As this paper demonstrates, HHFT derailments that result in tank car breaches are large, complex incidents that often involve fires. Due to the potential size of these incidents (number of cars involved, amount of flammable material released, etc.) and incident resource requirements, they will generate numerous response issues beyond those normally experienced by most local and state response agencies. As a result of our analysis, a number of planning assumptions were developed that need to be considered when developing suitable firefighting strategies for HHFT derailment fires. Key planning assumptions include the following:

- There is a high probability that HHFT derailment scenarios involving DOT-111 or CPC-1232 tank cars will result in multiple container failures; to date, the newer DOT-117 tank cars have not been involved in any HHFT derailment scenarios.
- These incidents present large, complex response scenarios, and will quickly challenge the incident management capabilities of most local response agencies. Consideration

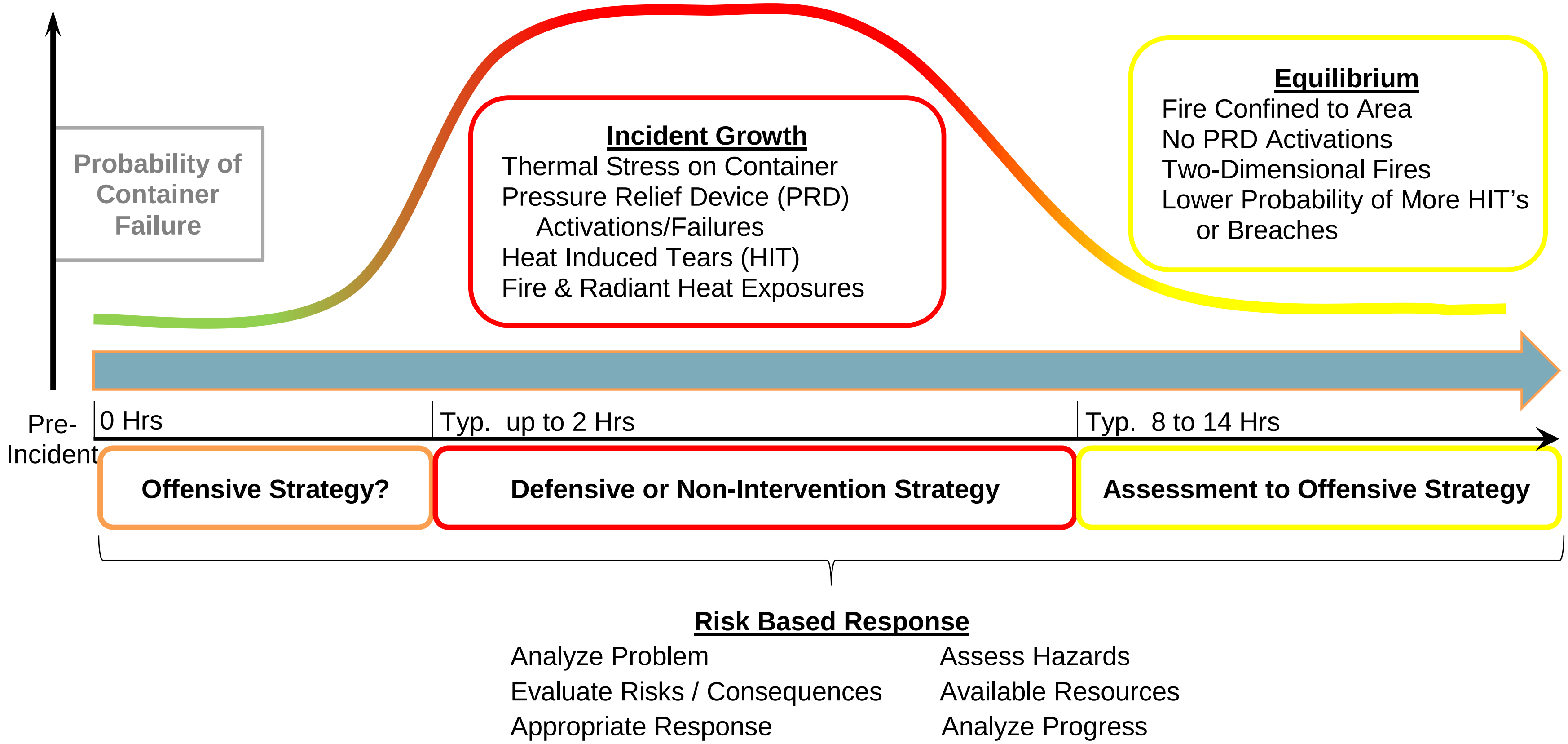
should be given to the response of All-Hazard Incident Management Teams (IMT) to provide incident management assistance.

- Prepare for large fires involving multiple tank cars; there is a low probability of offensive fire tactics successfully suppressing these fires for scenarios in which the incident rapidly escalates and grows.
- Expect large volumes of flammable liquids to be released and/or involved in fire. The potential environmental impacts from allowing the material to burn off versus the potential impacts to water or soil should be considered.

TABLE 1: SUMMARY OF HIGH HAZARD FLAMMABLE TRAIN DERAILMENT INCIDENTS (2006 TO 2015)

LOCATION	DATE	CARS DERAILED	CARS BREACHED	MATERIAL RELEASED	FIRE (Y/N)	GALLONS RELEASED	SPEED (MPH)
Bon Homme, SD	9/19/2015	7	3	Ethanol	Yes	49,748	10
Alma, WI	7/11/2015	32	5	Ethanol	No	20,000	Unknown
Heimdal, ND	5/6/2015	6	5	Crude Oil	Yes	98,090	24
Gogama, ON (MP 88.7)	3./7/2015	39	36	Crude Oil	Yes	500,000	43
Galena, IL	3/5/2016	21	10	Crude Oil	Yes	110,543	23
Mt. Carbon, WV	2/16/2016	27	20	Crude Oil	Yes	378,034	30
Gogama, ON (MP 111.6)	2./14/2015	29	19	Crude Oil	Yes	264,200	43
Dubuque, IA	2/4/2015	14	8	Ethanol	Yes	53,000	24
Lasalle, CO	5/9/2014	6	1	Crude Oil	No	7,932	9
Lychburg, VA	4/30/2014	17	1	Crude Oil	Yes	29,416	23
Vandergrift, PA	2/13/2014	21	4	Crude Oil	No	4,310	31
New Augusta, MS	1/31/2014	15	7	Crude Oil	No	50,450	47
Plaster Rock, NB	1/7/2014	6	2	Crude/Ethanol	Yes	60,759	47
Casselton, ND	12/30/2013	20	18	Crude Oil	Yes	436,437	42
Aliceville, AL	11/8/2013	26	25	Crude Oil	Yes	630,000	39
Lac Magantic, PQ	7/6/2013	63	59	Crude Oil	Yes	1,580,000	65
Charles City, IA	5/2/2013	5	2	Ethanol	No	49,000	24
White River, ON	4/3/2013	7	2	Crude Oil	Yes	26,600	35
Parkers Prairie, MN	3/27/2013	14	3	Crude Oil	No	30,000	40
Plevna, MT	8/5/2012	18	12	Ethanol	Yes	245,335	23
Columbus, OH	7/11/2012	3	3	Ethanol	Yes	54,748	25
Tiskilwa, IL	10/7/2011	10	9	Ethanol	Yes	162,000	37
Arcadia, OH	2/6/2011	31	31	Ethanol	Yes	834,840	46
Cherry Valley, IL	6/19/2009	15	13	Ethanol	Yes	323,963	36
Luther, OK	8/22/2008	8	5	Crude Oil	Yes	80,746	19
Painesville, OH	10/10/2007	7	4	Ethanol	Yes	52,200	48
New Brighton, PA	10/20/2006	23	20	Ethanol	Yes	485,278	37
Total	**27 Derailments**	**490**	**327**			**6,618,000**	**33.5 mph (Average)**

FIGURE 1 – SCHEMATIC REPRESENTATION OF THE INCIDENT PROGRESSION FOR A "TYPICAL" HHFT DERAILMENT.



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