Review of a Special Permit Application and Supporting (Risk Analysis) Document

submitted to

Pipeline & Hazardous Materials Administration

by

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Review by

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I-1 Background

In August 2017, the Energy Transportation Solutions, LLC ("ETS") of Doral, FL., submitted a Special Permit application to the Pipeline & Hazardous Materials Administration ("PHMSA") requesting authorization to transport methane refrigerated liquid [UN 1972, Division 2.1 material, also commonly referred to as Liquefied Natural Gas - LNG] by rail in DOT 113 specification cryogenic tank cars. Furthermore, the application requested authorization[1] to ship Methane, refrigerated liquid (UN 1972) in unit trains containing up to 100 tank cars at the rate of two unit trains per day, 365 days/year in three different regions of the US, as indicated in the following Table.

From:	To:
The Marcellus Region (Northeastern United States)	Atlantic Coastal Areas
The Bakken Region (Northern Midwest)	The Gulf Coast
The Northwest Region (Colorado/Wyoming)	The Gulf Coast

The ETS application does not provide any additional details of the routes of shipment, distances of shipments, densities of populations along the routes, or the locations of sensitive assets [such as schools, hospitals, public gathering places, churches, sports stadiums, emergency response operational facilities, etc.] in proximity to possible rail routes.

The Hazmat Regulations [49 CFR, parts 171 – 180] do not define an equivalent level of safety for the shipments of Division 2.1 materials in unit trains, or for that matter for the shipment in unit trains of any other hazardous material. As a part of the this Special Permit request and to "*demonstrate via analyses, data, and/or test results that issuance of the special permit achieves a level of safety at least equal to that required by regulation,*" the applicant has submitted a detailed risk assessment of hypothetical campaign of shipping 100 tank cars of LNG in unit trains over a hypothetical rail corridor over a distance of 227 miles with very specific distribution of populations along this hypothetical shipment corridor.

FRA was requested by PHMSA to perform a technical review the application and the supporting risk analysis document and provide its findings and recommendations. This paper provides the details of this technical review, indicates the findings and provides the recommendations.

1 *The shipment of methane refrigerated liquid [UN 1972] in rail tank cars is not authorized in the current Hazardous Material Regulations [49 CFR §172.101 Table of Hazardous Materials].*

I-2 Review Process

In reviewing the technical information in the application and the supporting risk assessment the following questions were considered.

a) Whether the statements and justifications indicated in the application are scientifically supportable?
b) Did the Risk Analysis (RA) procedure indicated follow normally accepted (in the literature) processes and procedures?
c) Was the system to be analyzed properly defined and considered? That is, were the details of the origin-destination and population densities along the route provided?
d) Were the assumptions made clearly indicated and justified?
e) Did the RA consider all possible rail accident scenarios?
f) Were proper rail accident data considered?
g) Were different phenomena of physical behavior of LNG (before and after) accident caused release modeled properly?
h) Were the risk results properly presented (with proper units)?
i) Was any discussion provided on the overall risks and their acceptability and how they may satisfy the "Equivalent Level of Safety" criterion of HMR?
j) Were the risk results compared with National and International standards for the acceptance of risks, both individual risks and societal risks?

In addition, to considering the above questions, the review has included comments on and challenges to several technical statements and data considerations in the Risk Analysis Report. These are indicated separately in Appendix 1.

I-3 Findings

Special Permit Application

1 ETs' Special Permit request has many misstated facts, errors in scientific justifications and incorrect comparisons of hazardous materials to justify the application (see section II-1).

2 The ETS application does not provide any details of the origin-destination pairs for proposed LNG shipments, geographic routes of shipment, distances of shipments, densities of populations along the routes, or the locations of sensitive assets [such as schools, hospitals, public gathering places, churches, sports stadiums, emergency response operational facilities, etc.] in proximity to possible rail routes.

Risk Analysis

3 The methodology used, in the Risk Analysis report submitted by ETS, for calculating risk to the public from the proposed LNG transportation by rail follows generally accepted procedures discussed in risk analysis literature.

However, the correctness of the risk results does not depend upon just the methodology but on the assumptions made, the data used for accident rates, values used for conditional probabilities of release of LNG from tank cars after the accident, the consideration of different hazardous behavior of released LNG and enumeration of the number of people potentially exposed to harm from such releases.

This reviewer has found several shortcomings (discussed below) in the above consideration of route characteristics and parameters in the risk analysis presented.

4 The entire risk calculation is based on the assumption that the first LNG tank car in the unit train consist will be located at the 11th position behind the locomotive.

This is contrary to the practice in unit trains where there may be only one buffer car behind the locomotive and all other cars, starting from position # 2 behind the locomotive are the commodity cars[2]. The effect of the assumption made in ETS' contractor report is to reduce the probability of derailment (and puncture) of a LNG tank car by a factor of 10 for both high speed derailments and lower speed derailments [See Table E4 of Risk report]. The upshot of this assumption is to make the annual probability values in both Individual Risk and Societal Risk values about 10 times lower than what they would be if the real definition of unit train is included in the calculations.

5 The risk analysis includes only derailment types of accidents and not collisions or side swipes.

While the annual probability of collisions and sideswipes may be lower than that of derailments, in a unit train configuration with the first tank car at the 2nd position from the locomotive it could suffer more serious damage in a collision (resulting in large LNG releases). i.e., higher probability of release than a tank car in 11th position in the train. The AAR TAG has spent considerable resources to evaluate the crashworthiness of tank car type LNG tender cars behind the locomotive. These tender cars are required to be designed to a much higher standard of crashworthiness than ordinary DOT 113 specification tank cars. Therefore, a DOT 113 car very close to a locomotive could suffer very serious damage in a train-to-train collision, however remote this may be. The result of

[2] Letter dated March 29, 2007 from PHMSA to NTSB clarifying *"the train placement requirements prescribed in § 174.85 of the Hazardous Materials Regulations (HMR; 49 CFR Parts 171-180) for unit trains consisting of placarded amounts of hazardous materials."*

such collisions could be the exposure of a larger number of population to harm than has been considered in the risk analysis presented.

6 The total volume (30,000 gallons) of the DOT 113 tank car is correctly considered in this risk analysis. However, the net volume of LNG in the tank car is indicated to be 10,830 gallons (see Table below).

Table 1. DOT-113 tank container parameters used in this study.

Parameter	Value
MAWP (psig)	90
LNG Capacity (gallon)	30,000 (nominal)
Net Volume (gal)	10,830

The latter figure if used in the study is incorrect and will reduce the hazard areas calculated significantly, leading to a low estimate of the number of people exposed to LNG hazards. The applicant needs to clarify this issue and indicate whether the correct maximum LNG volume (25,500 gallons at 85% fill) was used and the number indicated in Table 2, page 7 of the report is a typographical error.

7 All risk calculations are based on a maximum allowable working pressure (MAWP) of 90 psig within the tank car, consistent with DOT 113C140W specification.

This is a very high-pressure value for a commodity that is normally stored in large tanks at or near ambient pressure. In addition, 24% of the mass of LNG released from this pressure (minor or major release) flashes instantaneously to produce a large vapor cloud. It is unclear from the description of the hazard assessment and LNG behavior models discussed, whether this phenomenon has been considered explicitly in every size release.

8 The presentation of the majority of the results for the Societal Risk is on the basis of one mile of track. This is not consistent with how transportation risk results are presented in many papers and reports (from several researchers in NA, US DOT, and other US and Canadian agencies).

The one mile based societal risk presentation is incorrect in that it does not provide the decisionmaker a complete picture of the magnitude of the societal risk. The contention of the ETS contractor is that such presentations are made in Europe, which begs the question of why the total value of the societal risk is not presented [3]. Because of insistence by FRA in a prior project risk assessment review, the contractor has included a graph of the total Societal Risk for a single example route studied. (More on this is discussed in Appendix 2).

9 The report presents risk acceptable criteria from US ANSI Standard (NFPA 59A) but never uses them to compare the calculated risk results nor does the report discuss whether the risks are high or not.

NFPA 59A ("Standard for the Siting of LNG Storage Facilities") provides criteria for the acceptability of risk results. These criteria are for both Individual Risks [IR] and Societal Risks [SR] and are based on "fatality" harm to the population exposed. Different zones are identified, for acceptable and non-acceptable locations of individuals and assets, based on the magnitude of the IR value. Similarly, the Societal Risk (which is a plot of the annual frequency of exposing to harm greater than "N" people vs. the number of people "N"] is also divided into zones where the risk is acceptable, not acceptable and a region of As Low As Reasonably Possible ["ALARP"]. The risk in ALARP region is acceptable with regulatory review and institution of mitigation measures. See Figure E2 below.

10 The cross-track distances to specified Individual Risk (IR) values are calculated and presented in the report. However, there is no enumeration of the number of people affected by these risk values within each zone of individual risk and whether any sensitive assets along the route fall within the unacceptable IR zones.

Mere presentation of theoretical values of Individual Risk is insufficient to evaluate the potential harm to the people along the route. The report does not provide, on a mile by mile basis, the locations of and cross-track distances to sensitive assets. It is very important to ensure that sensitive assets along the route are not within non-acceptable IR zones.

11 The aggregate Societal Risk presented in the report for both low speed and higher speed operations are significantly above the acceptable range, per the NFPA 59A criteria.

The following figure from the risk analysis report illustrates the results (shown with dot-connected lines). In the same figure two lines from the NFPA 59A standard on societal risk acceptability are shown. The red line illustrates the upper bound of risk acceptability. The green line indicates the lower bound, below which the risk is acceptable without review. The region in between is

[3] In another risk assessment of LNG transportation by rail developed by the same contractor, which this reviewer evaluated, it was made clear to the contractor that the total Societal Risk values should be presented to include all risks from the origin to the destination. Because of this request, the total risk value is presented in this report.

termed "ALARP" where if the risk results lie, they need to be reduced using mitigation techniques.

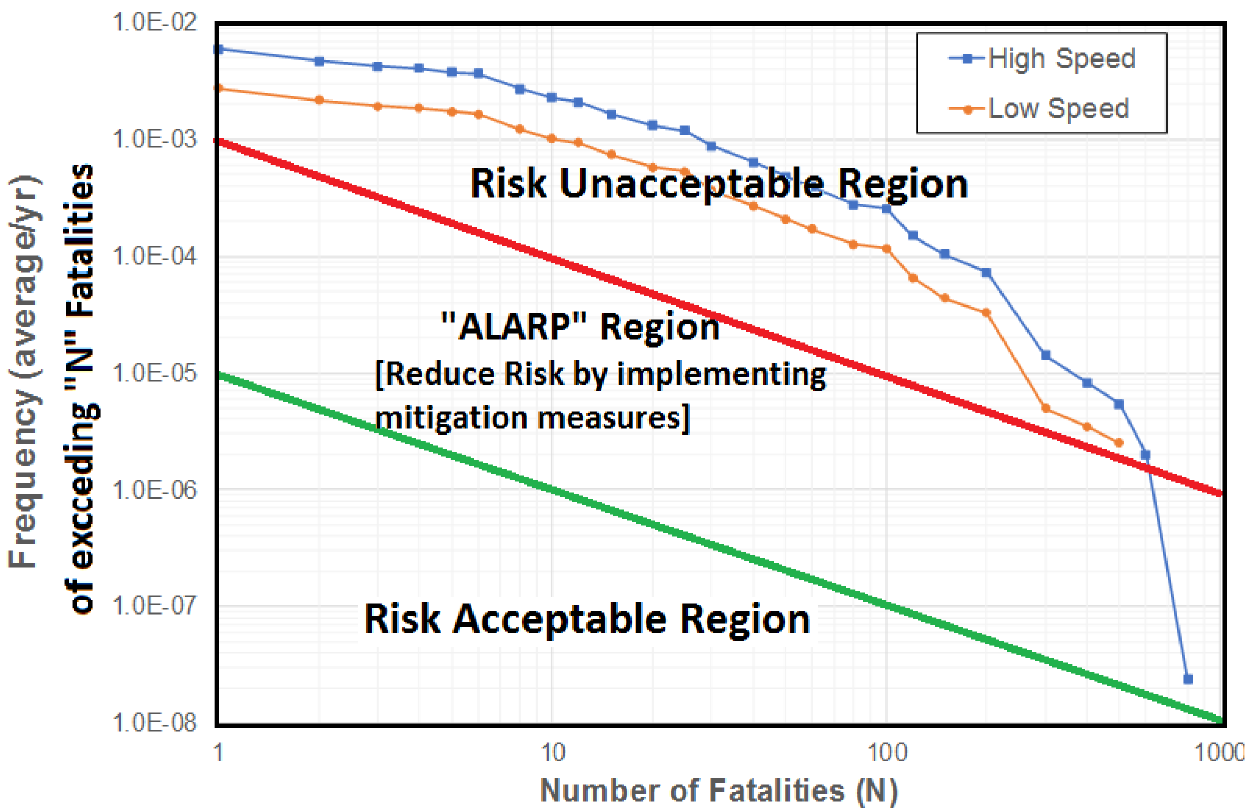


Figure E2. FN curve of the aggregate SR for the mainline train movement of LNG DOT-113s for the low speed case (up to 25 mph) and high speed case (greater than 25 mph and up to 50 mph) along the 227 mile long example mainline route.

As can be seen the aggregate societal risk values for the example route (of 227 miles) chosen for evaluation indicate that in both high speed (> 25 mph and less than 50 mph) and low speed (< 25 mph) the risks are well above the red line – the limit of risk acceptability, over most of the population exposure (fatality) values. From just this criterion alone, the risks are too high and are not acceptable. It is not known what the societal risks are for real routes proposed by ETS.

12 ETS' contractor has contended that the NFPA 59A risk acceptability criteria are applicable only to fixed facility risks and not applicable to risks arising from shipment of hazardous materials in transportation modes.

This is not a scientifically defensible argument. The risk criteria are based on tolerability of people from exposure to harm/risk and are not based on how those harms are generated. A society that is at risk includes the consideration of all individuals and populations that are potentially exposed to the detrimental effects of hazardous material releases, no matter where such releases occur.

In Appendix 2 is shown an analysis that clearly illustrates that the Societal Risk acceptability criteria for risks from fixed facilities are equally applicable to transportation modes.

I-4 Conclusions and Recommendations

Conclusions

1 The ETS application does not provide details of the routes (in the three regions of the US requested in the special permit application) and their characteristics. Without this the risk assessment provided can only be considered as an example and not specific to the application.

2 Locations of sensitive assets along the proposed routes have not been presented nor have the distances to calculated Individual Risk values been compared with the locations of sensitive assets. This is an important omission.

3 The total Societal Risk presented for the route evaluated in the risk analysis is significantly higher than the acceptable risk criteria. No discussion has been provided in the report as to what mitigation methods can be used to reduce the SR to acceptable levels and by how much the SR reduces by the mitigation measures.

4 No sensitivity analysis has been provided in the risk assessments as to how the risks will change if different values of are considered for some of the parameters whose values have been assumed in the model. An example is the variation of the derailment probability if the first LNG car is in position 2 from the locomotive rather than in the assumed 11th position.

5 Notwithstanding the (unsupported) statement in the risk assessment report that the risk acceptability criteria in a US Standard are applicable to only fixed LNG facility accidents, it is demonstrated that these are applicable to determine the acceptability of risks from transportation accidents also.

Recommendations

1 A blanket Special Permit covering all that are requested in the ETS application should not be issued by PHMSA.

The total Societal Risk results presented are not in the acceptable risk range. Also, the analysis has not considered the impact of Individual Risk on sensitive assets along the route.

2 PHMSA could consider granting the permit for the shipment of a limited number of LNG tanks in a train consist. It is recommended that the permit allow less than or equal to 30 tank cars/train, one train per day for 365 day/year, over a very specific and designated route, with restrictions on train speed.

Such a permit could initiate a pilot project so that all parties involved in this project (shipper, railroad and regulator) can learn the various issues that may come up during the shipments of 30 or less tank cars of LNG in a train. There have never been shipments of LNG in tank cars on rail. The recommended volume of shipment (of about 11,000 tank cars per year) will be a great leap, which will provide significant data on safe handling and transporting LNG in tank cars.

3 PHMSA should consider limiting the shipments in only DOT 113C120W tank car, and also require that LNG be shipped at pressures as close to atmospheric pressure as possible.

There is no economic or technical advantage in transporting LNG at higher pressures than at or slightly higher than atmospheric pressure. The higher the pressure the greater is the mass of release (from instantaneous flash vaporization) in the form of vapor and the greater will be the liquid release rate, from any puncture of the inner vessel. These higher rates and mass of release will result in larger hazard areas, in case of leak.

II-1 Detailed Comments on the Information in the Application

a) On page 6 of the application the applicant proposes unit trains (2 per day, 365 days a year) with up to a maximum of 100 loaded tank cars of LNG. If this level of shipments is permitted over the three different regions of the US (identified in the application), it will amount to a total of 219,000 tank cars of LNG shipments per year in the US by a single shipper. This is a good fraction (81%) of the total loaded tank car shipments of crude oil by rail [271,154] in the US in 2016!

b) On page 4, the applicant "*proposes that the railroads transporting the LNG in unit trains conduct a routing analysis of the rail routes consistent with the 27 safety and security factors prescribed in 49 C.F.R. § 172.820 and that State and Regional Fusion Centers have access to schedules and routing for these trains*."

   First, the application does not indicate any agreement with a railroad that indicates that it is willing to transport the volume levels of LNG contemplated by the applicant. Second, the levels of shipments, as indicated in item (a) is bound to elicit responses (not favorable to the shipments) from the general public.

c) On page 4, the application states, *"This risk assessment will be submitted as an addendum to this permit application. The assessment will focus on the risks of operating unit trains of LNG, comparing these risks to other forms of rail and road transportation that have already been approved and evaluating the extent to which similar mitigation measures can be relied on to address the similar but less likely risks associated with transporting LNG."*

   The Risk Assessment does not provide any comparison of the risks from other forms of transportation nor does it allude to any mitigation measures used in those other forms of transportation.

d) On page 6, the application states, "*When comparing the properties of LNG to the properties of other commodities currently authorized for transport by rail, there is no scientific or practical reason for LNG to be precluded from rail transport*."

   This statement is not factually correct. LNG shipments on rail using portable tanks is authorized in 49 CFR, §172.101 Table, subject to the approval of the Associate Administrator for Safety, FRA, per the requirements in 49 CFR §174.63 (a). In addition, the scientific basis for authorizing very large volumes of shipments, carried in unit trains, should be based on risks not comparing just the properties of one chemical against another.

e) On page 6 it is stated that "*The reason the hazardous materials regulations do not currently authorize the transportation of LNG by rail is simply due to the lack of demand for rail transport of LNG...*"

This is just a guess on the part of the applicant. Nowhere in the preamble to the regulations do these statements appear in relation to LNG. In addition, as shown in the response in (d) above, this statement is not entirely correct, either.

f) On page 8 it is stated *"Natural gas has a high ignition temperature (over 1,000°F) relative to other hydrocarbon fuels, such as diesel (which has an ignition temperature of 500°F). This makes natural gas relatively difficult to ignite."*

This is not relevant in the context of LNG release from a rail accident and its vaporization. Historical records indicate that even in truck accidents LNG vapors generated by LNG release have ignited. The energy in rail accidents will be an order of magnitude more than in truck accidents and there are always ignition sources of sufficient strength and temperature to ignite LNG vapors in rail accidents.

g) Page 8: "*If LNG spills, it will rise and disperse rapidly as it warms, returning to its vapor form, leaving behind no residues. Natural gas vapor is lighter than air and when released, will rapidly rise into the atmosphere, and disperse*."

This is a very misleading statement that, if publicize to emergency response personnel, could potentially cause harm. Natural gas is buoyant when the gas it ambient pressure and ambient temperature. LNG vapor released from the vaporization of LNG is cold (- 260 F) and is heavier than air. The mixing of this cold vapor with air produces a mixture that is always heavier than air. This has been demonstrated in many field tests. Therefore, any notion that after a few minutes the vapors will rise and disperse harmlessly is a dangerous misrepresentation of science.

h) Page 9*: "The activities to be authorized by this permit and the associated risks are well within the experience and expertise of PHMSA to address under its existing programs."*

This statement has no foundation. To the best of knowledge of this reviewer PHMSA has not, in previous Special Permits related to shipment of hazardous materials in tank cars, considered risk analysis results as a basis of issuing or denying Special Permits.

II-2 <u>Detailed Comments on the Risk Analysis submitted with the application</u>

Important comments on the risk analysis report are presented in Appendix 1. More detailed comments and questions are shown in the margins of the appended WORD version of the risk analysis report by Exponent, Inc.

QRA Methodology, Input Data and Risk Evaluation Approach For Rail Transportation of LNG (and other Hazardous Materials)

1 Background

The evaluation of the potential risks to the general population arising from the transportation of hazardous materials ("hazmat" and, in particular, LNG) by rail can be performed objectively by using the Quantitative Risk Assessment (QRA) methodology indicated and generally accepted in the literature. The basic philosophy of a QRA involves the considerations of the frequency of accidents that lead to the release of hazardous materials and the consequence of such releases on the involuntarily exposed population. Different metrics are used in QRAs to determine the consequences of accidents, including, fatalities, injuries, economic losses, opportunity loss, etc. In general, the consequence metric used to assess the risks from hazmat transportation is fatality.

Risk values calculated from a QRA are generally compared with risks from other activities that the same population is exposed to and tolerates. Therefore, a QRA result must be viewed in comparison with other risks and not on an absolute scale.

This risk evaluation approach is not intended to be an industry standard. It is a part of a multifaceted process to evaluate and understand the types and magnitude of risks posed by LNG when moved by rail in order to identify and assess measures that can reduce these risks, and prepare for and respond to any accidents that may arise.

2 Approach to performing a QRA for rail transportation of LNG

The first and foremost in initiating a QRA for rail transportation of LNG is to specify the origin point and destination point (O-D pair) and the rail route by which the shipment will be moving. The route length is then divided into segments of appropriate length and the risk in each segment is calculated. The segments should be longer than the train length. In most cases the length of each segment is chosen such that the principal characteristics (such as the track class, speed of train, reasonable constancy of the general population density in vicinity of the track, reasonably similar geographic features- flat land, agricultural land, suburban or urban built up areas, etc.) remain constant within the segment. Many times, the segment length is arbitrarily set to one mile; this may increase the computational effort significantly, without much benefit in the accuracy of the calculated risk value, if the distance between origin and destination is large (say, hundreds of miles). In the segmentation of the O-D route length, yards, if any, in the route must be included as separate segments. Also, for completeness, the loading facility and unloading facility are also included in the calculation of the total risk.

Figure 1 is a calculation flow diagram for performing a QRA. QRA procedure includes the gathering of the following data (from historical accident records and correlations), performing calculations (of the probability of accident occurrence, hazmat release and its harmful effect areas), and consideration of the populations that may be exposed to the harmful effects of hazmat released.

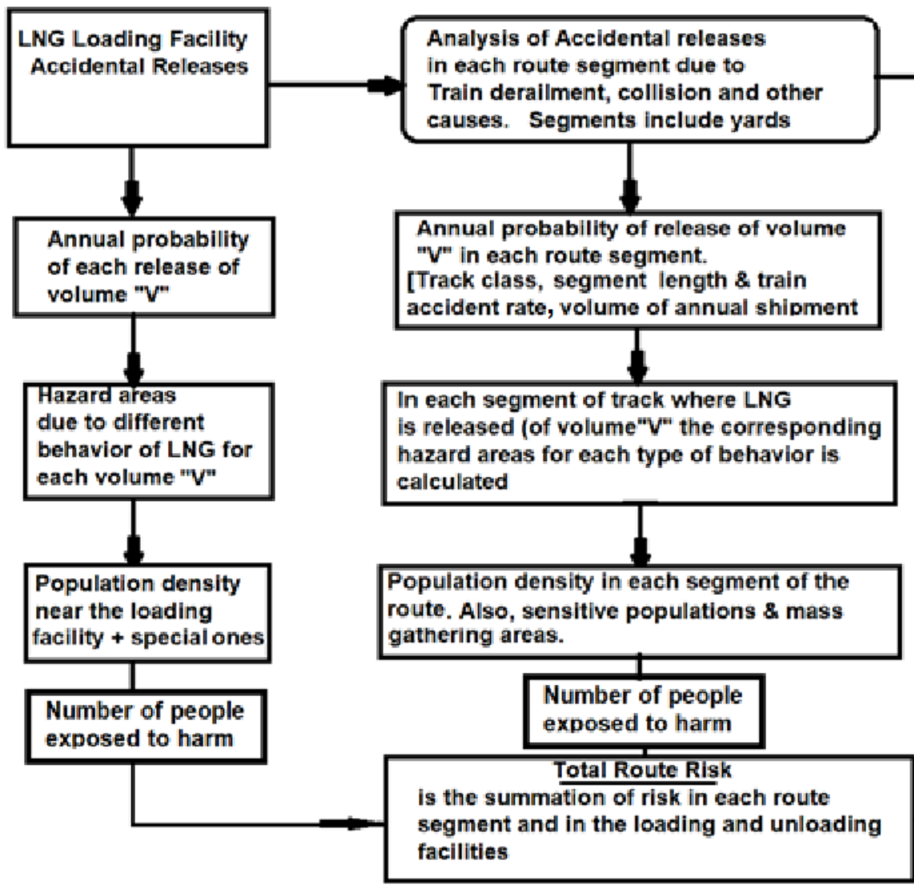


Figure 1: A flow diagram of the calculation sequence in performing a QRA.

The following data will need to be collected first, before performing a hazmat transportation QRA.

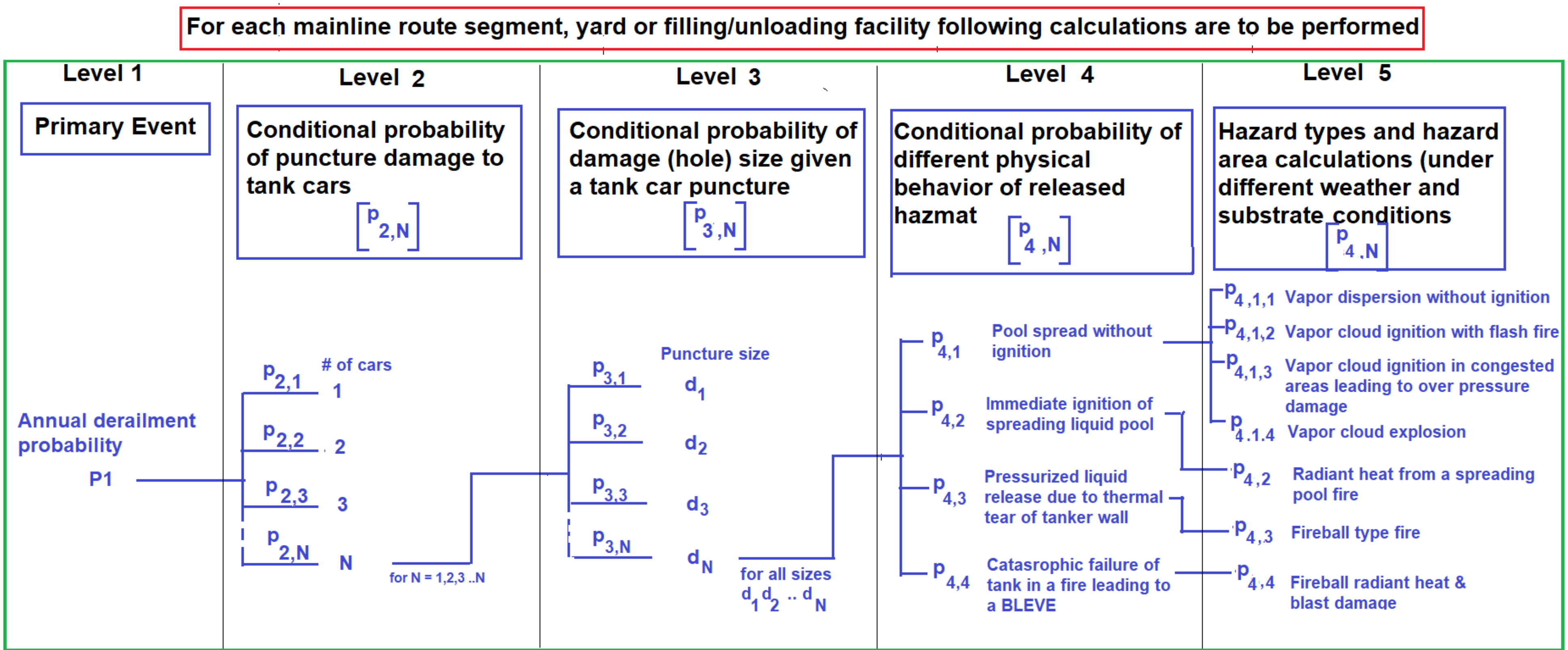
1. Annual probabilities of LNG (or hazmat) releases at the loading facility, by magnitude/volume of spilled quantities due to mechanical or human errors during the loading operations.
2. Annual probabilities of derailment/collision/or other train accidents occurring in each chosen segment of the route, corresponding to the class of track, speed of train, and number of trains per year.
3. Annual probabilities of mainline train accidents in each route segment and in yard operations (switching, train making and other associated activities).
4. The conditional probabilities of number of cars derailing and damaged as to release LNG, in each route segment.

5. Mean size of damage (or release hole equivalent diameter) as a function of the severity of the accident (with speed of train before derailment as the metric and track and geographic conditions of each route segment).
6. Population density within 2 km on either side of the track in each route segment.
7. Enumeration of the type and location of (and distance from the track, normal to the track direction) sensitive assets and population gathering venues next to each route segment. These sensitive assets include (but not limited to) schools, churches, hospitals, jails, emergency/police response centers, sports stadiums, drinking water lakes, ponds and other ecologically sensitive water bodies.
8. The annual average weather conditions for the location of each route segment should be gathered (from the national weather service or other meteorological data reporting entities). This data should include % of occurrences of different types of weather stability classes (A through F), associated wind speeds, and directions (i.e., "wind rose," expressed as % of time in a year during which wind blows from a particular compass direction) and average atmospheric temperature by seasons.

Once the above preliminary statistical data for train accidents occurring in mainline, in yards, and releases in filling and unloading stations and other data for the physical characteristics at different locations are gathered, the quantitative risk assessment can be performed. The principle of such an assessment is indicated, schematically, in Figure 2.

First, the annual probability [P_1] of train accident occurrence (derailment, collision, side swipe, etc.) is obtained for each route segment from FRA accident rate database, knowing the volume of traffic, track class and speed. The same type of information is also obtained for yard operations for the specified train (carrying the hazmat) and for the loading/unloading facilities. The conditional probabilities [$p_{2,1}$ $p_{2,2}$ ..$p_{2,N}$] of damage occurring to, respectively, one tank car, two tank cars … and "N" tank cars have to be obtained from train dynamic models such as TEDS or from any correlations that may be available developed from statistical analysis of past accident data [Conditional Probability of Releases – CPR – published by AAR/RPI project].

The release from each damaged tank car due to a train accident could occur from damaged valves and piping or due to tank wall punctures of different sizes. The rate of liquid release and the total volume of liquid released depend on both the internal tank pressure and location of the puncture relative to the liquid level line after the tank car comes to rest following a derailment. There is generally a spectrum of sizes of punctures that occur depending upon the severity of the accident. The Sharma model has attempted to provide broad classification of the sizes of punctures that occur and their conditional probabilities [$p_{3,1}$, $p_{3,2}$, …$p_{3,N}$) of occurrence, respectively, for nominal puncture sizes d_1, d_2,…d_N, given that a puncture has occurred.



$$\sum_{i=1}^{i=N} p_{2,i} = 1 \qquad \sum_{i=1}^{i=N} p_{3,i} = 1 \qquad \sum_{i=1}^{i=4} p_{4,i} = 1 \qquad \sum_{i=1}^{i=4} p_{4,1,i} = 1$$

Figure 2: Calculation Procedure for Developing Quantitative Risk Values for the Transport of Hazmat on Rail

The rate of release of the hazmat (assuming it is a liquid and may be in a pressurized state within the tank car) is dependent on the liquid condition inside the tank car, the size of the puncture hole and the location (depth) of the hole relative to the liquid level once the tank car comes to rest after the accident. Generally, the location of the hole after the accident position, and its probability of occurrence relative to the geometry of the tank car, are very difficult, if not impossible, to obtain from accident databases – there is not such fidelity in these databases. Hence, it may be conservatively assumed that the hole is the lowest position of the at-rest tank car. Not only is the rate of (initial) release calculated but also the duration of release and the total quantity of liquid released from each tank car. In addition, if the liquid is under pressure and a fraction of the released mass flashed directly to vapor due to initial thermodynamic condition, the flash fraction should be calculated and considered in subsequent effect calculations.

The subsequent behavior of the released liquid in the environment will determine the magnitude of the risk. In the case of LNG releases, a number of different hazardous behavior outcomes are possible, each with a conditional probability of occurrence [$p_{4,1}$, $p_{4,2}$, $p_{4,3}$, $p_{4,4}$] upon release. These include pool spread without ignition [$p_{4,1}$] leading to vapor generation and its dispersal in the form of a flammable vapor cloud. The hazard from this dispersing vapor cloud itself takes many forms, each with its own conditional probability of occurrence. For example, the cloud may disperse to below lower flammability limit without ever encountering an ignition source [$p_{4,1,1}$]. Alternatively, the cloud may be ignited at different locations, each location of ignition being identified by a conditional probability of ignition. The hazard that such ignition poses is the formation of a flash fire, whose size and therefore the number of people potentially exposed to the flash fire harm will depend upon where (and hence, the conditional probability of) ignition occurs.

In calculating the conditional probability of the vapor cloud behavior during dispersal additional considerations should be given to the occurrence (probabilities) of different types of weather, wind speed and wind direction. These make the dispersion risk calculations numerous and time consuming. These types of finer details need to be enumerated and calculated to get an overall risk to population, both the individual risk and the societal risk.

The pool spread of the released liquid with immediate ignition forming a spreading burning pool fire is considered to have a conditional probability [$p_{4,2}$]. The extent of hazard from such a fire is the distance to which the human tolerance radiant heat flux extends from the fire edge. If the release is due to a thermal tear on the tank wall (generally on the wall section wetted by vapor and exposed to an external fire), the sudden depressurization of the tank will result in a substantial amount of vapor and liquid aerosols being thrown into the environment in a very short time leading to the formation of a fireball – this phenomenon is characterized by a conditional probability [$p_{4,3}$] given a release. However, the data for enumerating this conditional probability not only do not exist, but will depend upon the conditions that must occur (such as the neighboring cars should be leaking forming a pool fire which exposes the subject tank car to a fire engulfment).

Last but not the least consideration should be given in a risk analysis to the possibility (however low the probability is) of occurrence of a BLEVE in a double hulled LNG tank car. [No such accidents have been observed in US made portable tanks or tank trucks carrying LNG with service data of over 50 years]. BLEVE results when a tank car fails catastrophically releasing all of tank car contents into a fireball and at the same time producing a blast wave due to sudden depressurization (and in very rare flammable liquids due to the formation of a detonation wave).

<u>Risk results</u>: Risk results are presented for both an individual ("Involuntary Individual Risk-IIR" and for the society as a whole ("Societal Risk"- SR). In the case of societal risk it is emphasized that all of the population next to the track from the origin to destination should be taken into consideration.

The risk is presented as a combination of (all principal and conditional probabilities) and the consequence in the form of number of people exposed to harm. In most QRA's, the metric of harm is the fatality to an individual exposed. The specific way in which the risk results are presented depend upon whether the IIR or the SR is being considered.

In the case of the Individual Risk, different contours are shown somewhat parallel to the track, each representing a total annual probability of fatality to an individual located at the contour location (i.e., distance normal to the track from the center of the track along the entire route). An example of typical IIR contour representation for LNG shipments on rail is shown in Figure 3.

Figure 3: Example representation of constant Individual Risk contours along the tracks in a rail yard handling hazardous material shipments through it.

In the case of the Societal Risk, the representation is in the form of annual probability [for the entire O-D route] of exceeding a given level of harm in terms of numbers of persons exposed. The graph is called the F-N graph which plots (on the Y-axis) the annual probability (from all accidents and hazmat behavior characteristics) of exceeding a specified level of harm (fatality) vs. the level of harm (fatality) on the X-axis. In general, in a QRA it is necessary to provide error bars on these graphs (both in X and Y coordinate directions) to understand the accuracy of risk calculations. A single line on a log-log plot has very little meaning without some representation of the errors and unknown (data limited) magnitudes of some of the parameters used. A representation of F-N plot for Societal Risk is shown in Figure 4.

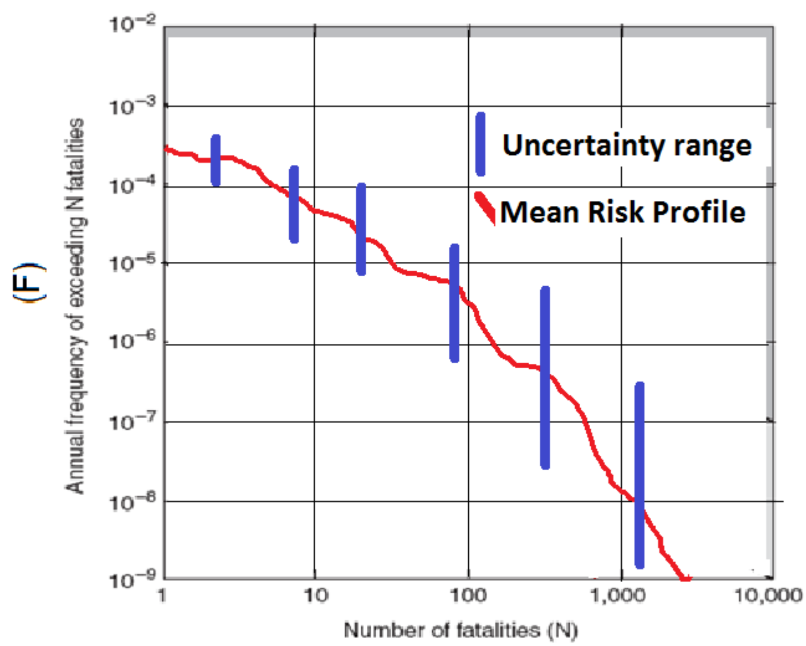


Figure 4: Example of the F-N curve for Societal Risk values presentation for hazardous materials transportation from an origin to destination.

3 <u>State of knowledge of availability of the values for the parameters</u>

In this section is discussed the state of knowledge and availability of the values of the parameters that are essential to performing a QRA. Each of the probabilities and other physical parameters discussed in section 2 is evaluated, individually. The result of this evaluation is presented in the form of a table.

Parameter	Definition of the parameter	State of knowledge to obtain its value
P_1	Annual probability of train accident in each mainline segment of the route	Mainline train accident rates (in either # of accidents/train-mile or # /gross ton-mile) can be gathered from FRA published Train Accident Data. Data needs to be chosen properly to reflect the conditions relevant to the time frame for which the QRA is being performed.
P_1	Annual probability of accidents occurring in yard operations	Past accident data obtained from FRA published yard accident statistics, in terms of yard accident rates in #/train mile.
P_1	Annual probability of accidents in loading and unloading facilities.	This is a much harder number to obtain. There is no LNG tank car loading and unloading experience base. The closest similar operation is the loading and unloading of LNG highway trucks at terminals. It is not clear if there exists a database that captures this information. An equivalent experience base database for loading/unloading cryogenic / flammable materials may be available in the chemical industry. PHMSA's incident database captures loading/unloading related incidents, however, it is not clear to what extent these types of incidents get reported to PHMSA[1]. This is, therefore, a research topic.
$p_{2,N}$	Conditional probability of damage **and** puncture of "N" tank cars, N = 1, 2 ,3 …, in **mainline accidents**	The train dynamics model (by Sharma & Associates) provides a physical model based evaluation of the number of cars that derail in a given train, track and speed conditions. Very general values for the occurrence of punctures within the set of derailed cars are also from the output of this model. These numbers have been benchmarked against several train accidents involving crude oil tank cars and ethanol tank cars in which the numbers of cars leaking were known.
$p_{2,N}$	Conditional probability of damage **and** puncture of "N" tank cars, N = 1, 2 ,3 …, in **yard accidents**	It is less certain whether this conditional probability value for accidents in yards is easily available.
$p_{2,N}$	Conditional probability that an accident in a loading/unloading facility leads to N = 1, 2 ,3 …, releases from these #s of tank cars	This value is extremely difficult to obtain because of the lack of any LNG loading and unloading experience in railhead facilities. If any such data exists (very unlikely) they may have to be obtained from the experience of the general chemical industry. Topic for research
$p_{3,N}$	Conditional probability of the puncture being of various sizes "d_N" given that a puncture has occurred **in mainline or yard accidents**.	The train dynamics model also predicts, in very approximate terms, the sizes of punctures for the circumstances of the accident. It is not certain whether the CPR model developed by the University of Illinois, Urbana Campus, has the capability to predict, using statistical analysis of tank car accident data the size distribution of the punctures in tank cars. In any case, it is also doubtful whether such statistics obtained from single shell tank cars will be applicable at all to double tank cars, such as the ones proposed to be used for LNG shipments on rail. This is an important topic for further research.

[1] On March 23, 2020, PHMSA and FRA will visit a loading/unloading facility in Hialeah, FL. The purpose is to gather information about the process of loading/unloading of portable tanks of LNG by rail and about the LNG portable tanks loading/unloading incidents reporting to PHMSA,

		PHMSA database of hazmat releases from rail cars [based on the reporting on 5800.1] provides possible way of segregating the probability of releases into different volumes of spill. However, whether such a classification can be applied to a cryogenic liquid, under some pressure in the tank car, is uncertain. There are no direct data on the size distribution of the "holes" created in tank cars in a rail accident.
$p_{3,N}$	Conditional probability that given an accident in the loading and unloading facility the release is equivalent to a release from puncture size "d_N."	No such database exists. Again, this is a good topic for research.
$p_{4,N}$	Conditional probabilities for different physical behaviors of the released hazmat.	See discussions below specifically for LNG releases.
Hazard assessment specific to LNG releases		
$p_{4,1}$	LNG pool spread without immediate ignition	Models are available for calculating the passive release rate of LNG from a hole in the tank wall in a tank under pressure, the liquid flow rate, flash vaporization rate and the spread of pool on the ground (while simultaneously evaporating due to heat transfer from the ground). The rate of release can vary with time and the pool spread rate on the ground (depends on the thermal properties and roughness of ground) can also vary with time. Maximum spread diameter, mean pool size and the mean evaporation rate can also be calculated. These values are used as inputs to the vapor dispersion models. The conditional probability [$p_{4,1}$] of a LNG spill spreading as a non-ignited pool is dependent upon a number of factors including the severity of the accident, the local electrical conditions and how strong the ignition source(s) near the liquid release are. There is no single value that can be assigned to this conditional probability. In rail accidents involving multiple tank car releases, it can be safely assumed that $p_{4,1}$ is less than 10%.
$p_{4,1,1}$	Dispersion of vapors from the pool without encountering any ignition source	The dispersion of LNG vapor emanating from the boiling and spreading pool is modeled as dispersion of a heavy gas. Complex 3-D models are available in the literature to determine the downwind distance to lower flammability level (LFL) concentration at ground level, the ground area swept by the flammable contour and the vertical extent of the cloud. In the non-ignition dispersion case, the hazard area is the total ground area covered by the LFL contour. The conditional probability [$p_{4,1,1}$] of the vapors emanating from the pool do not encounter any ignition source given that liquid spreading without ignition has occurred is very much dependent on the location of the spill. If the spill occurs in relatively sparsely populated areas (say, as in farmland or a rural community), the chances are the [$p_{4,1,1}$] is close to 1.

		The calculation of the concentration and physical size characteristics of the dispersing cloud depends also upon the local topography, atmospheric conditions, the wind speed and wind direction, each of which can be assigned a conditional probability. If good meteorological data exists for the location of the spill, then these additional conditional probabilities of environmental condition occurrences can be determined and used in the QRA.
$p_{4,1,2}$	Vapor cloud ignition resulting in the formation of a flash fire	A dispersing LNG vapor cloud can be ignited if (i) the ignition source is of sufficient strength and is (ii) within the volume of the cloud where the vapor concentration is within the flammable range and (iii) the ignition source is on. The development of an actual number for the conditional probability [$p_{4,1,2}$] that a flash fire forming dispersion will occur is difficult. It may vary between 10% and 90%. In the case of release in a suburban or densely populated urban locations there are likely to be a number of ignition sources that can light the cloud. Depending upon the density (#/unit area) of the ignition sources (population density could be used as a proxy), the distance of penetration of the cloud without being ignited will be relatively short. Therefore, in order to perform the QRA properly it is necessary to know the ignition source densities in the areas that the vapor cloud will be dispersing and from it obtain a conditional probability of ignition as a function of the cloud penetration distance. Models to perform these calculations do exist. And are based on certain assumptions of relationship between types and number of ignition sources with the population density.
$p_{4,1,3}$	Vapor cloud ignition in congested urban areas potentially leading to an overpressure flash fire event	In the case of release in a very densely populated urban locations and ignition of the vapor cloud the density structures in the path of the flash fire can lead to turbulence enhancement. This can lead to flame speed increase and result in over pressure waves being formed. The conditional probability [$p_{4,1,3}$] of occurrence of flame acceleration due to congestion and obstruction is dependent upon the vapor concentration at the time of ignition, the density and porosity of obstructions and other thermal factors, none of which are easy to determine for use in a QRA. There are no simple models that can predict the value of this conditional probability with any accuracy. Hence, in most cases an assumption has to be made as to its value (0 -1 % for suburban area, 2-5 % in built up area, etc.).
$p_{4,1,4}$	Vapor cloud ignition leading to a vapor cloud explosion [VCE].	There has not been any documented VCE with either accidental releases of methane from pipelines or from field tests involving LNG releases, when the dispersed vapor cloud is ignited by a passive ignition source. However, confinement or near total confinement conditions in which the flammable vapor is “contained” and ignited may cause a VCE. However, lack of data or models to specifically address this issue means that the value of the conditional probability [$p_{4,1,4}$] will remain very uncertain. It can be argued that this value is less than 1%.

$p_{4,2}$	Immediate ignition of the spreading pool resulting in a pool fire	This is probably most likely scenario in a train accident leading to the release of LNG. However, it is difficult to estimate the value of the conditional probability [$p_{4,2}$] of a pool fire occurring upon release from a damaged tank car. This will depend upon where the ignition source is relative to the liquid release point. If it too close, it would be drenched and hence quenched by the liquid flow. Also, the very high concentration of vapor generated will make it non-flammable in the immediate vicinity of the ignition source. In most QRA studies for transportation accidents, the value of [$p_{4,2}$] is generally assumed to be between 50% and 80%.
$p_{4,3}$	Pressurized liquid release due to a thermal tear on the vapor wetted tank wall resulting in a fireball.	This conditional probability [$p_{4,3}$] value will depend not only upon the characteristics of the tank car (to suffer a thermal tear), the thermodynamic properties of the liquid (LNG) inside the tank car but also on the extent to which damage has occurred to the outer tank and the insulation and more importantly whether the subject car is engulfed in a pool fire of hydrocarbon liquid released from a neighboring car and its duration. That is, the value of this conditional probability depends on too many external factors. At present, there are no accident data analyses that have estimated the value of this parameter. It is highly likely that this number will be less than 0.5%. A research project could consider reviewing all recent accidents involving single tank tank-cars which release through a thermal tear and the total number of cars releasing the hazmat. Needless to say, a number from singe shell tank cars may not even apply to double tank LNG tanks.
$p_{4,4}$	Catastrophic failure of the LNG inner tank (from thermal exposure) resulting in a BLEVE, fireball and radiant heat exposure	The conditional probability [$p_{4,4}$] for the occurrence of a BLEVE given that a release has occurred from a LNG tank car is even more difficult to estimate simply because of lack of data (definitely from LNG tank cars) even from other flammable hydrocarbon liquid transporting tank cars. There are not too many instances of BLEVEs occurring in tank cars ever since the thermal protection rule came into being. A significant amount of research, both theoretical and experimental, needs to be accomplished before the precise conditions under which a double tank LNG tank car can undergo a BLEVE and from which an assessment of the magnitude of this conditional probability can be established. It is guessed, however, that the value of this conditional probability is in order of 0.1 % or less.

4 Recommendations

In order to perform a reasonably accurate QRA for assessing the risks of transporting LNG by rail the following research needs to be undertaken.

1) A more thorough structural analysis of the puncture resistance of DOT113C120W tank car (for LNG shipments) should be undertaken to provide guidance on the severity of derailment in which the inner tank of the tank car could be punctured.

2) The train dynamics model must be improved to be able to estimate the values of the conditional probabilities of different puncture sizes of the inner LNG tank, given that the inner tank is punctured (and the dependence of this conditional probability on the accident parameters).

3) The loading and unloading process in a facility filling/unloading a LNG rail tank car needs to be studied and estimate of the potential frequency of spills (as a fraction of the number of operations) must be developed. Lessons can be learned from LNG trucking operations and data on loading/unloading of tank cars in chemical facilities can be evaluated to get initial magnitude of the frequency of spills.

4) A physical modeling effort must be initiated to understand the fractions of the time a LNG release will manifest in different types of hazards (pool spread, vapor dispersion with flash fire, pool fire, fire ball, BLEVE). The conditions under which each of the above behavior is possible and the congruence of such conditions in a O-D pair transportation route may be used to evaluate the magnitudes of the conditional probabilities of different types of behavior.

5) BLEVE has been mentioned as a potential large impact hazard that could be an outcome of a train accident involving LNG shipments on rail. However, the circumstances, the physical and thermal conditions necessary before such an event can take place in a double tank, DOT113C120W style tank car are completely unknown. This is an important area of research that should be addressed immediately.

U.S. Department
of Transportation

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Volpe Center Review of Exponent Inc. Quantitative Risk Analysis

ETS Movement of LNG in DOT-113 Tank Cars by Rail

Introduction

Pipeline and Hazardous Materials Safety Administration's (PHMSA) Office of Hazardous Materials Safety (OHMS) is responsible for processing, analyzing, and coordinating with appropriate operating administrations for issuing or denying applications for special permits (SP). A special permit enables the transport of hazardous materials under conditions not addressed in the Hazardous Materials Regulations (HMR). Federal hazardous materials transportation law authorizes PHMSA to issue such variances when special permits provide at least an equivalent level of safety to the safety level required under the HMR or is consistent with the public interest if a required safety level does not exist. PHMSA received a SP application from Energy Transport Solutions, LLC (ETS) for the rail movement of LNG in DOT- 113 tank cars in unit trains. Currently, unit trains in the U.S. are not authorized to transport LNG. In support of ETS's SP application ETS provided a quantitative risk analysis (QRA) prepared by Exponent, Inc. (Exponent Project No. 1705991.000) entitled "Energy Transport Solutions, LLC., ETS Movement of LNG in DOT- 113 Tank Cars by Rail, Quantitative Risk Analysis (QRA) Considering DOT-113 Tank Car Position in Train and Train Speed".

The Volpe National Transportation Systems Center (Volpe) is providing technical support to PHMSA by reviewing the QRA submitted by Energy Transport Solutions. This document describes Volpe's review, providing an assessment of whether the QRA was prepared following accepted practices and whether the QRA's analysis, conclusion and recommendations appear reasonable. Volpe's review of the QRA was limited to the information provided within the QRA report itself and ETS's SP application and did not include verification of the report's findings through an independent analysis.

The QRA addresses the risk of unit train movements of LNG by DOT-113 tank cars along one example route along the eastern portion of Pennsylvania. The example uses the per-route mile risk findings to determine aggregate risk along the route. The unit train movements were limited to mainline movements at high and low speeds. The QRA assumed that each unit train includes LNG DOT-113 tank cars, starting at train position eleven (11), and one train movement was accomplished per day along the 227 mile example route. The hazard scenarios corresponded to accidents involving the DOT-113 type tank car, which is a double-walled vessel containing nominally 30,000 gallons of LNG. The QRA results are tabulated as a function of population density and train speed, providing per-route mile risk results.

This review provides a summary of the operation described in the special permit application, as well as what the special permit application states will be demonstrated in the QRA. The QRA methodology, including applied assumptions and the probability analysis is then discussed. The applicability of the QRA provided to the special permit application is reviewed. Volpe's conclusions are provided.

Background

On August 21, 2017, Energy Transport Solutions LLC submitted a request to PHMSA for a special permit to transport methane, refrigerated liquid in DOT-113 tank cars. This special permit application includes the regions in which transport is proposed, as well as a description of the proposed consist. The frequency of shipments is not described.

The special permit application indicates three regions of the United States for which transportation is being proposed. The Marcellus Region in the Northeastern United States to the Atlantic Coastal Areas, The Bakken Region from the Northern Midwest to the Gulf Coast, and the Northwest Region of Colorado and Wyoming to the Gulf Coast.

The special permit application proposes transport of LNG by rail in DOT-113 rail tank cars. The Applicant indicates that manifest trains comprising 20 or more tank cars containing LNG in a continuous block, or unit trains comprising 35 or more tank cars containing LNG are being considered. The application also states the applicant will daily transport unit train quantities of 50-100 cars. Although it is unclear if daily volume is for one or two unit trains. The frequency of shipments, or the total number of shipments over the two-year period for which relief is being requested is not specified.

Energy Transport Solutions provided a QRA prepared by Exponent, Inc. in support of this special permit application. ETS has provided a description of the operational characteristics that they expect to be included in the QRA as well as their expectation of what conclusions they will be able to draw as a result. The QRA will be evaluated to determine if the operation evaluated is representative of the operation described in the special permit application. In addition, the results of the QRA that ETS expects to obtain will be discussed.

The special permit application also mentions the rail risk analysis factors listed in Appendix D to part 172 of the code of federal regulations shall be taken into consideration. It is not clear that the QRA prepared by Exponent, Inc. is intended to consider each of these 27 factors, but a discussion will be provided as to which factors are addressed and which have been neglected.

Risk Assessment Overview

The risk is assessed for the consequences of a fire event resulting from the loss of containment (LOC) of LNG. The QRA addresses unit train movements of LNG on an example 227 mile route along the eastern portion of Pennsylvania. The individual and societal risk is evaluated for discreet segments of the route, for two different speeds.

The analysis uses the commercially available software tool PHAST Risk v6.7 to model the consequences of potential releases. Release is assumed to happen as a result of the derailment of one or more cars containing LNG. Probability of release is evaluated by considering the frequency and severity of accidents as well as the likelihood of an accident to damage the car to the extent that LNG is released. The frequency and severity of accidents is considered for low-speed operation (< 25 mph) and high speed operation (25-50 mph).

The description of the unit train is limited to the number and location of cars containing LNG under consideration. The LNG is assumed to be transported in DOT-113 rail tank cars. No information description of the locomotive configuration is provided. The maximum length of the unit train is not explicitly specified. The QRA assumes average daily movement rate of eleven or more DOT-113 tank cars with a capacity of 30,000 gallons (assuming the route is travelled once per day, every day of the year).

The route under consideration is broken down into one-mile increments. Each increment is assigned a representative population density. The individual and societal risk is evaluated for each increment, and then reported for the entire length of the example route. Daily shipments along this route are considered.

Risk Assessment Methodology

In order to determine the risks associated with the transport of LNG in DOT-113 rail tank cars, a chain of events leading to fatalities is prescribed. There is a chain of events leading to the release of LNG, as well as a chain of events where the LNG released will lead to a fatality. The probability of each event occurring, and the outcome of each event is determined. The individual and societal risk is evaluated and compared to an appropriate risk criteria.

Release scenarios are developed based on the proposed operation and historical data. The consequences of the release are evaluated using a commercially available software package. The aggregate risk is then calculated for the length of the route. The key parameters are discussed below with emphasis on the assumptions and information provided to determine the release scenarios.

Accident

This QRA assumes that loss of containment of LNG is the result of a derailment. Accident data from the 20-year period between 1997 and 2016 was obtained from the Federal Railroad Administration's rail accident database [4]. Using this data, the probability of an accident occurring was determined, as well as the probability that an accident would result in a derailment of one or more cars.

The analysis limits LOC to being initiated by derailment events. No consideration of LOC due to puncture of the tank car wall, damaged or defective valves, or pool fires occurring while the car is still on the track is considered. No discussion of the probability of these types of events relative to a derailment is provided.

The probability of derailment was determined by considering all freight traffic over a 20-year period. However, the probability of a derailment is influenced by multiple factors. The track class, the length of the train, and the miles travelled will contribute to the probability that a train will be involved in a derailment [5]. While the QRA example does identify and consider the miles travelled, the analysis does not provide the track class of the proposed route, the maximum length of the unit train, or the length effects on risk. It is not clear if the probability based off of all rail traffic is representative of the proposed operation over this route.

Once the probability of a derailment was established, the likelihood that an individual car within the consist would derail was then determined. The data obtained from the FRA database was reviewed to determine the point of derailment and the number of cars derailed in each accident to obtain the probability of one or more LNG cars derailing. In addition the average number of cars derailed for both low speed and high speed operation was determined. It was determined that at low speeds (<25 mph) the average number of five cars derailed, and for higher speeds (25-50 mph) an average number of eleven cars derailed.

The probability of an individual car derailing was determined by considering all freight traffic over a 20-year period. There are multiple contributing factors to the probability of an individual car derailing, including the point of derailment, train speed, train length and the accident cause [5]. The total length of the example unit train is not provided in this analysis. It is not clear if the probability of the derailment determined would be significantly affected if the length of the train proposed for operation was taken into account.

The trainset being evaluated is described as a unit train with the DOT-113 rail tank cars containing LNG starting at the eleventh position. There is no description of the number of locomotives or the types of rail cars that would be present between the locomotive and the first DOT-113 rail tank car containing LNG. This does not appear to be representative of the proposed operation described in the special permit application, which indicates unit trains and does not describe any plan for buffer cars. The QRA report indicates that starting the DOT 113 rail tank cars in the eleventh position is conservative, but this is not clear. The QRA provides data on the probability of which car will derail first, and the number of cars to derail, but does not discuss the probability of an individual car within the consist derailing. Previous data suggests that the car in the eleventh position derails most frequently [5]. But the QRA does not provide this type of data.

The QRA's probability of derailment determined on average at low speeds 5 DOT-113 tank cars containing LNG will derail, and for higher speeds, on average eleven cars will derail. The trainset being evaluated considers no more than eleven DOT-113 tank cars containing LNG derailing. The probability of derailment is based solely on historical accident data in regards to the location of the first derailed car and average number of cars that derailed. The QRA does not appear to consider the effects of the train length on the number of derailed cars. It is not clear what effect considering the total number of cars planned for operation would have on the probability of a tank car containing LNG being derailed and whether the determined averages are representative of the train lengths to be operated under special permit application.

A reasonable approach was taken to determine the probability that an accident would occur resulting in the derailment of one or more cars containing LNG. However, the probabilities were determined by considering all rail operation over a 20-year period. It is not clear if a more tailored approach would appreciably increase or decrease the probability of derailment for operation described over this specific route.

The length of the trainset can be a contributing factor to the probability of derailment, as well as the number of cars derailed. The length of the trainset are not considered in the QRA and therefore it is unclear whether the QRA average estimates are representative of the trainset proposed for operation. There is no discussion provided in the QRA as to why no more than the average number of cars derailing was considered. If the contribution of any additional cars derailing is negligible, this should be discussed.

Loss of Containment

The conditional probability of release, the probability that there will be a release of LNG from DOT-113 rail tank car that has derailed, was then determined. The QRA reviewed the historical data on LOC from PHMSA's database [6] to determine the probability of a release of LNG from a DOT-113 rail tank car. In addition, the values determined were compared to a probabilistic puncture model [7].

The PHMSA database includes information from any accident involving hazardous materials. Data from the last 46 years is available. Accidents which resulted in a loss of containment were reviewed. Due to the relatively few number of DOT-113 rail tank cars, the release from any pressure tank car was considered.

The probability of any LOC due to a derailment determined from the PHMSA data was compared to the probabilistic puncture model developed to simulate head puncture. This model uses the physics of the impact, including the wall thickness and indenter size and speed, and was calibrated using historical data from the Railway Supply Institute and the Association of American Railroads. The total probability of loss of containment determined from the PHMSA data (4.5%) was consistent with the range determined for head puncture of jacketed vessels due to derailment or collision (1-3%).

The PHMSA data was grouped by the volume of material released to determine the probability for different volumes of material released. The volume ranges were used to approximate the leak size. The probability for each leak size was determined.

In order to utilize the PHAST software, a single value for the release in an accident must be determined. The volume of material released by each derailed tank car is determined. The probability of each of these combinations of release is determined. This combined probability was filtered and any value less than 1×10^{-7} was neglected. This resulted in derailments of a single tank car being neglected.

A reasonable approach was taken to determine the conditional probability of release. Historical data was utilized and compared to an existing model. The results were combined in order to provide global release values that can be utilized by PHAST.

Formation of Flammable Atmosphere and Ignition of Flammable Atmosphere

The QRA utilizes the software tool PHAST Risk v6.7 to model the consequences of potential releases of LNG. This tool is capable of modeling the dispersion of LNG given a specified release. The dispersion model does not take any obstructions into account, and is conservative. This dispersion model determines the flammable atmosphere that can develop.

The PHAST software uses ignition models to determine the probability of different times of flammable events occurring. The model includes immediate ignition and delayed ignition of the flammable atmosphere. The immediate ignition model is not discussed, however the delayed ignition model only considers potential for ignition due to surrounding population. It is not clear that the probability of ignition from a source on the train itself, such as a diesel fuel fire would be considered.

A reasonable approach was taken to determine the probability of the formation of a flammable atmosphere and the ignition of a flammable atmosphere. This appears to be a comprehensive analysis tool that has been developed for the specific purpose of determining the risks associated with flammable or toxic effects. The model is specifically developed for LNG.

Exposure to Population

The individual and societal risks are determined. The Individual Risk is the frequency (yr-1) where an individual with continuous potential exposure may be expected to sustain a specified level of harm. The societal risk can be used to represent the probability of multiple people suffering from a specified level of harm in a given population. The QRA states that the individual risk considers both serious injury and fatality. It is not clear if the societal risk considered the possibility of severe injury, or only considers fatalities. In order to determine the individual and societal risk along a transportation route, the route is broken into one-mile segments. A representative population density for each segment is used.

The individual risk is calculated for each one-mile segment. The PHAST tool assumes that the entire population is outside. The individual risk is evaluated against the criteria in NFPA 59A [8]. NFPA defines three different zones of acceptable risk levels. Each zone defines acceptable population densities and the types of building and structures permitted. Zone 1 is the most restrictive with the highest associated risk level. Zone 3 has the lowest associated risk and the fewest restrictions on the surrounding district.

The societal risk is calculated for each one-mile segment. The PHAST tool assumes that 90% of the population is outside. The societal risk along the route is an aggregate result of the risk calculated for each one-mile segment. The risk increases with the length of the route. The total societal risk for the route cannot be evaluated against a criteria. The results must be scaled and the highest risk sections are compared to the acceptable risk for a stationary LNG facility.

The criteria used for evaluating the individual and societal risk are reasonable and follow current practice for stationary facilities as well as recommendations made by FRA. There is no existing transportation requirement for quantitative risk. The risk for transportation of LNG in modes where it is permitted by the regulation, or the risk for transportation of other cryogenic flammable material in DOT-113 rail tank cars was not considered.

Applicability to Special Permit Application

The special permit application states that "The risk assessment will be based on anticipated train speeds, the number of cars anticipated on each train, the frequency of shipments, length of route and population along the route." [1] The QRA provided in support of this special permit application did consider some of the aspects of the operation described in the special permit application, while other were not well-defined.

The special permit application indicates that speeds below 50 mph are considered. The QRA determines the risk for two different speed ranges. Low-speed operations (<25 mph) and high speed operations (25-50 mph). By evaluating the risk at two different speeds, it can be demonstrated that lowering the speed of operation could be used to reduce the risk.

The special permit application is for unit train movements containing no fewer than 35 DOT-113 cars containing LNG and no fewer than 20 DOT-113 cars in a continuous block for non-unit train cars. While the QRA overall train length assumed in the QRA was never defined. It states that it assumes unit trains of eleven or more DOT-113 tank cars and does not consider derailment of more than 5 tank cars at lower speeds, or more than eleven tank cars at higher speeds. There is no discussion of why more than the average number of cars derailing was not considered. In addition, the QRA does not consider the train length as a potential a contributing factor to the probability and severity of a derailment.

The frequency of shipments, or the total number of shipments over the two-year period for which relief is being requested is somewhat ambiguous in the special permit application. The applicant does indicate anticipating operating two unit trains a day, but it is unclear if the applicant is referring to operating two unit trains per day per route or across all anticipated routes. The application also states it is for shipments throughout three regions and the applicant will transport unit train quantities (50-100 cars per day). It is unclear if the stated unit train volumes is for one or two unit trains. The QRA assumes an average daily rate of eleven or more DOT-113 rail tank cars. It is not clear if this value is representative of the planned operations.

The special permit application indicates planned operation along three different routes. The QRA provides an analysis for a single route only. The only geographical detail provided in the QRA is "Pennsylvania," if the route described in the QRA is intended to be representative of the planned routes included in the special permit application, the only region that corresponds is the Marcellus Region in the Northeastern United States to the Atlantic Coastal Areas. Since Pennsylvania does not have a coastline, it is not clear if the route description is too vague, or if only a portion of the route was considered. Additionally, the example route is only 227 miles in length, which seems much shorter than any of the regional routes indicated in the special permit application. The only distinguishing feature of the route is the population density. Details about the route, such as major metropolitan areas or environmentally vulnerable areas, are not provided. There is no information provided as to why this route was selected, whether alternative routes were considered, or how this route corresponds to those indicated in the special permit application.

A population density for each one-mile segment of track is provided. While the location of this route it not specified, it must be assumed that the population densities assumed are representative. The population density is a significant factor in determining the overall risk. The additional routes included in the special permit application may not be well-represented by the population densities in this region of Pennsylvania.

The special permit application indicates that the QRA performed by Exponent is intended to:

> *(i) demonstrate via analyses, data, and/or test results that issuance of the special permit achieves a level of safety at least equal to that required by regulation and (ii) identify each hazard, potential failure mode and the probability of its occurrence and describe how the risks associated with each are controlled for the duration of the proposed activity as well as the life-cycle of the DOT 113C120 and 140W rail tank cars* [1].

It is not clear that this assessment demonstrates that a level of safety at least equal to that required by regulation is achieved. There is no quantitative risk criteria required by regulation. Regulations exist for the rail transportation of other cryogenic flammable liquids in DOT-113 rail tank cars, and regulations exist for the transportation of LNG via highway and rail (ISO containers). The relative risk of these scenarios was not provided for comparison.

It is not clear that each hazard and potential failure mode contributing to the release of LNG was considered. The release scenario only considers LOC due to derailments. No discussion of why alternative scenarios were neglected is provided. The only operational factors that were considered as contributing to the probability of a derailment were the speed and the miles travelled. There is no discussion of why other contributing factors were neglected.

The special permit application mentions the rail risk analysis factors listed in Appendix D to part 172 of the code of federal regulations shall be taken into consideration. Of these 27 factors, it appears that only Volume of hazardous material transported, the trip length for the route, the population density along the route, and the speed of train operations are considered. While past incidents were evaluated in order to determine accident probability, these accidents were not specific to the route being considered, and were limited to accidents that met the reporting threshold for the FRA.

Limitations of Analysis

The probability that an accident would occur resulting in the derailment of one or more cars containing LNG was determined by considering the accident history across all mainline rail operation over a 20-year period. It is not clear if a more tailored approach considering track class, grade crossings, traffic density and maintenance would appreciably increase or decrease the probability of derailment for operation described over this specific route. By neglecting the characteristics specific to the route, the probability of derailment cannot be considered to be route specific. The QRA probability of derailment would apply to any one-mile segment of track in the United States and could not be used to compare the probability of derailment of different specific routes.

The exposure to the population was specifically developed to be representative of the example route selected. There is a strong correlation between the population densities and the individual and societal risks provided. The risk determinations of this QRA or specific to the example route and should not be applied to the movement of LNG in DOT-113 rail tank cars along other routes.

The transportation risk is the aggregate of the per mile risk along the route. The aggregate will be directly related to the number of miles traveled. The 227 mile route described in the QRA may be only a segment of one of the routes indicated in the special permit application. In addition, the QRA assumes one movement per day, while the special permit application anticipates 2 unit trains per day.

Of the 27 safety and security factors prescribed in 49 C.F.R. § 172.820 only 4 are considered in the examination of the example route in this QRA, including: trip length for route, population density along the route, and speed of train operations. Many of the other prescribed safety and security factors should be considered outside of the QRA itself, however others are directly related to risk. The 23 factors not considered include:

- Rail traffic density;
- Presence and characteristics of railroad facilities;
- Track type, class, and maintenance schedule;
- Track grade and curvature;
- Presence or absence of signals and train control systems along the route ("dark" versus signaled territory);
- Presence or absence of wayside hazard detectors;
- Number and types of grade crossings;
- Single versus double track territory;
- Frequency and location of track turnouts;
- Proximity to iconic targets;
- Environmentally sensitive or significant areas;
- Venues along the route (stations, events, places of congregation);
- Emergency response capability along the route;
- Areas of high consequence along the route, including high consequence targets as defined in § 172.820(c);

- Presence of passenger traffic along route (shared track);
- Proximity to en-route storage or repair facilities;
- Known threats, including any non-public threat scenarios provided by the Department of Homeland Security or the Department of Transportation for carrier use in the development of the route assessment;
- Measures in place to address apparent safety and security risks;
- Availability of practicable alternative routes;
- Past incidents;
- Overall times in transit;
- Training and skill level of crews; and
- Impact on rail network traffic and congestion

Conclusions

The special permit application indicates that the QRA would:

- Identify and quantify the risks associated with train shipments of LNG and will evaluate these risks in light of the protections and measures to address the risks from the transportation by rail and other transportation modalities of other hazardous materials.
- Focus on the risks of operating unit trains of LNG, comparing these risks to other forms of rail and road transportation that have already been approved and evaluating the extent to which similar mitigation measures can be relied on to address the similar but less likely risks associated with transporting LNG.
- Be based on anticipated train speeds, the number of cars anticipated on each train, the frequency of shipments, length of route and population along the route.
- Examine the probability of derailment and other events across Class I, II and III rail, loss of containment probability in the event of any such event and risk related to population densities along various rail routes.
- Both (i) demonstrate via analyses, data, and/or test results that issuance of the special permit achieves a level of safety at least equal to that required by regulation and (ii) identify each hazard, potential failure mode and the probability of its occurrence and describe how the risks associated with each are controlled for the duration of the proposed activity as well as the life-cycle of the DOT 113C120 and 140W rail tank cars.

In summary it is Volpe's conclusion that the methodology utilized within the QRA to evaluate risk was reasonable, however:

1. It is not clear that this assessment demonstrates an equivalent level of safety to that required by regulation. There is no quantitative risk criteria for transportation of hazardous material required by regulation. No values for the risk of transporting LNG by currently regulated modes or transporting cryogenic flammable materials already regulated are provided for comparison.
2. It is not clear that each hazard and potential failure mode was considered. Only LOC due to derailments were considered, and the only operational factors that were considered as contributing to the probability of a derailment were the speed and the miles travelled. It was

not specified that the QRA would consider the 27 safety and security factors prescribed in 49 C.F.R. § 172.820, but many of these considerations were neglected in the QRA.

3. The length of the trainset can be a contributing factor to the probability of derailment, as well as the number of cars derailed. The overall length of the example trainset is not specified or considered in the QRA.
4. There is no discussion provided in the QRA as to why no more than the average number of cars derailing was considered. If the contribution of any additional cars derailing is negligible, this should be discussed.
5. The route analyzed is only one example route. It is not clear if it corresponds to an entire route or a single portion only. The example route is only 227 miles in length, which seems much shorter than any of the regional routes indicated the special permit. The risk determinations of the QRA or specific to the example route and should not be applied to the movement of LNG in DOT-113 rail tank cars along other routes. The QRA assumes one movement per day, but the special permit application states that the applicant anticipates operating two unit trains per day.
6. A reasonable approach was taken to determine the probability that an accident would occur resulting in the derailment of one or more cars containing LNG. However, the probabilities were determined by considering all mainline rail operations over a 20-year period. It is not clear if a more tailored approach would appreciably increase or decrease the probability of derailment for operation described over this specific route.
7. A reasonable approach was taken to determine the conditional probability of release, as well as the approach taken to determine the probability of the formation of a flammable atmosphere and the ignition of a flammable atmosphere.

References

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