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Regarding the
Jordan Cove Export Terminal
Draft Environmental Impact Statement
Docket No. CP13-483

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UNITED STATES LNG TERMINAL SAFE-SITING POLICY IS FAULTY

We have commented repeatedly to the Federal Energy Regulatory Commission (FERC) and the Department of Transportation (DOT) that we believe FERC is approving variances to the requirements of 49 CFR 193, Liquefied Natural Gas Facilities: Federal Safety Standards, that have not been subjected to adequate science based review and appear to provide inadequate fire and explosion exclusion zones to protect the public.

This submission focuses on the Draft Environmental Impact Statement (DEIS) for the Jordan Cove Export (JCE) Terminal Project. We believe the JCE DEIS fails to provide for protection of the public from credible fire and explosion hazards. The conversion of the Jordan Cove facility for export, including provision of gas treatment technology utilizing mixed hydrocarbon refrigerants for liquefaction and removal of heavy hydrocarbons from the natural gas feed to the plant, presents hazards to the project more serious (on a unit weight basis) than with LNG. We believe these additional hazards have been discounted without sufficient scientific justification in spite of multiple international reports during the last decade of catastrophic accidents involving unconfined (hydrocarbon) vapor cloud explosions. It is clear that the increased hazards due to the presence of significant amounts of heavier-than-methane hydrocarbons, for which there is considerably more extensive research and accident experience than for LNG-ONLY projects, and which are "game-changing" in importance, have been seriously under-estimated in this DEIS. We believe the hazards attending the proposed operations at the Jordan Cove export facility could have the potential to rise, as a result of cascading events, to catastrophic levels that could cause the near-total and possibly total loss of the facility, including any LNG ship berthed there. Such an event could present serious hazards to the public well beyond the facility boundaries.

We also believe there remains significant potential for cascading fire and explosion events attending "LNG only" storage and handling that have not been sufficiently addressed, particularly regarding the worst-possible case events that should be considered on the shore side storage tanks and marine side (ship related), either by accident or terrorist activity. Instead of considering the findings of extensive LNG Safety research conducted at the direction of Congress during the last decade that might influence the judgment of the acceptability (to the public) of the worst case

events that should be considered for this proposed terminal, the present JCE DEIS appears to largely ignore those findings.

The JCE DEIS focuses principally on arguments directed to meeting the "letter" of the federal regulations governing a <u>single</u> index of public safety - mathematical modeled exclusion zones (safe separation distances) intended to keep the public out of harm's way. But this DEIS relies, for prediction of exclusion zone distances, on the use of mathematical models which have not been subjected to adequate (open for public inspection) validation requirements either by comparison with experimental data or independent scientific peer review. Furthermore, the calculations of the exclusion distances for vapor dispersion and vapor-cloud-explosion hazards do not provide any evidence of applicability in near calm conditions coupled with reliance on impermeable (concrete) vapor fences designed to retard vapor cloud travel. Until there is produced by the applicant meaningful evidence of the accuracy and applicability-for-purpose of these modeling techniques, and that information is made available for public evaluation and oversight, it must be considered that the potential hazards of storage, handling, and shipping of such massive quantities of energy as are involved in this project could have been seriously underestimated.

The Jordan Cove Export Terminal DEIS Section 4 (<u>Environmental Analysis</u>), which contains the section on <u>Reliability and Safety</u>, comes to nearly twelve hundred pages, much of which is technically complex and therefore unlikely to be very helpful to the public. In view of shortcomings in the DEIS that we will identify, we believe it is particularly timely to summarize the hazards that require careful address for the proposed export terminal, as well as provide DOT and FERC with our independent assessment of the current state of scientific knowledge, <u>including limitations thereof</u>, upon which proper quantification of the risks and consequences of credible accidental or intentional events should be based.

We believe the present methodology of regulating LNG Terminal (import and export) hazards-to-the-public are overdue for careful review and assessment. During the brief (six-decade) history of LNG trans-ocean transport, LNG Storage and Handling Facilities have increased in size by an order of magnitude (factor 10). At the same time, it appears that the regulatory guidelines have not been continually reviewed and updated in consideration of extensive research programs required by Congress to better provide for public safety from LNG import terminals or the ships that service them. Most importantly, the regulations that are being applied to the proposed JCE Terminal appear to give only cursory attention to the additional hazards that will be involved by the proposed expansion of the terminal for export service. For this reason alone, we believe it is important for the public to consider "how we got here". We have prepared a short history of the development of the current LNG Facility Siting-for-Safety regulations which we believe would be helpful for all involved (public and regulators alike) to consider. However, in order to focus on the concerns that we believe require immediate address in the JCE Terminal DEIS, we have placed that historical appendix at the end of our comments. We recommend it to the reader.

There is a rich history of experience with the hazards of hydrocarbon fuels and chemicals heavier than methane (the principal component of LNG). That history describes numerous catastrophic accidents involving complete destruction of plant facilities due to fire and explosion. In the present JCE DEIS, FERC appears to have accepted extensions of arguments previously prepared for the application to build the facility as an import terminal. However, as our history (appendix) shows, the regulations regarding approval of import terminals have in the past been guided by the premise that LNG, as methane, poses significantly lesser hazards than heavier hydrocarbons routinely handled in the petroleum industry. We do not disagree with this characterization. What we find disconcerting is the extent to which the "safety" characteristics of

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methane have been misunderstood (and misrepresented) as the industry has expanded; today involving extremely large volumes of LNG (energy) concentrated in storage and handling facilities. After all, methane is the prize fuel that it is in that it ignites easily and burns hotly and cleanly, and those attributes entail hazards that multiply with the amounts of fuel involved. Therefore, we believe that insufficient attention has been given to the potential magnitude of the hazards that accompany the large scale storage-and-handling LNG-ONLY operations now operating and planned. But, we want to make it clear that our more serious concerns relating to the JCE Terminal result from the combined storage and handling, in gaseous and liquid forms, of methane and heavier hydrocarbons including ethylene, propane, pentane, and amines in such large amounts.

We believe the proposed JCE Terminal DEIS is a signal example of the (unwarranted) extent to which regulations designed for LNG-only handling facilities are being used as the basis for regulating large-scale projects involving heavier-than-methane hydrocarbon chemicals and fuels in volumes, particularly in combination, that involve significantly greater hazard potential than do import-only LNG terminals. With the current concerns for terrorist activity, and in view of the recent international experience of catastrophic accidental unconfined vapor cloud explosions of hydrocarbon fuels, it is time for a careful review.

Volume of Hazardous Hydrocarbons Stored at the Proposed JCE Terminal
- Hazardous Materials Tank (s) Storage Volumes, gallons
  - LNG (2) – 89,662,000
  - Ethylene (1) – 14,000
  - Propane (1) – 15,670
  - Isopentane (1) – 31,030
  - Amine (1) – 17,205
- Hazardous Materials Design Spill Volumes and Spill Impoundment Volumes, gallons
  - LNG (2) – 89,662,000 – 112,338,200 (outer tank concrete wall)
  - 36-inch Ship Load Header (at dock) – 784,600 – 785,170 (concrete sump)
  - 36-inch Ship Load Header (at tanks) – 827,740 – 833,400 (concrete sump, shared)
  - 24-inch LNG Rundown Line – 71,980 – 833,400 (concrete sump, shared)
  - 6-inch Mixed Refrigerant Line – 61,060 – 833,400 (concrete sump, shared)
  - Ethylene Storage Tank – 14,000 – 43,935 (concrete sump, shared)
  - Propane Storage Tank – 15,670 – 43,935 (concrete sump, shared)
  - Isopentane Storage Tank – 31,030 – 43,395 (concrete sump, shared)
  - Amine Makeup Tank – 17,205 – 17,245 (concrete sump)

We focus on these large hazardous materials inventories, the "design" spills that are considered, and the estimation of potential consequences which determine the safety exclusion distances for fire and explosion hazards - to provide our summary assessment of the JCE DEIS.

FAILURE TO ADEQUATELY PROVIDE FOR PUBLIC SAFETY

The JCE Terminal DEIS issued by FERC concludes that the principal regulatory requirements of 49 CFR 193: *Liquefied Natural Gas Facilities: Federal Safety Standards* providing exclusion zones to protect the public from liquid pool fire, vapor cloud dispersion, and vapor cloud explosion hazards have been met satisfactorily (with FERC-stated actions required) by the applicant's submitted mathematical-model calculated exclusion distances.

In our opinion, the DEIS-proposed approval of the JCE Terminal, in the absence of careful address of the concerns we describe below, will not provide for sufficient separation distances (exclusion zones) to protect the public from credible events, whether by accident or intentional act. However, our principal intent is not to engage in argument regarding the <u>details</u> of the methodology or the accuracy of the predictions submitted by Jordan Cove to calculate the exclusion distances (we do believe there are deficiencies in that regard because sufficient evidence of the accuracy and applicability of the mathematical models and model-inputs thereto has not been presented). Most importantly, we believe that the JCE DEIS has developed too rapidly, we suspect partly due to its evolvement from the DEIS previously submitted for approval as an import (only) terminal at the Coos Bay site, and as a result has become mired in the details of exclusion zone determination using theoretical models without proper recognition of the overall potential for catastrophic hazards that must be considered for operation as an export terminal.

Our primary purpose in these comments is to state the following serious concerns which we believe require science-based adjudication prior to approval of this application-for-siting:

1. The current consequence-driven regulatory process (see appendix on history), which decides the acceptability of an LNG siting process by ensuring that the consequences of accidents will not extend offsite to affect the public), has developed similarly to that which forms the basis for nuclear plant siting approval – reliance on determination of so-called credible "design accidents" (here called "design spills") to determine the required exclusion distances (from the accident (spill) location) to the applicant's property line. The determination of these design accidents is a complex process which has developed *ad hoc*. Initially the design accident (release) was taken as the catastrophic release of the entire contents of the largest storage vessel on the site. It later was changed to the "guillotine" severance of the largest transfer line in the facility, with the release duration assumed to be ten minutes, or a shorter time if the applicant could demonstrate the ability to limit the spill duration (such as by incorporation of emergency shutdown procedures). There followed the adoption of a provision by which an alternative release rate and total amount (termed an "accidental leakage rate (ACR) spill") can be submitted by the applicant for approval. Such ACR spills are typically spills from smaller lines (such as branch or instrument lines) rather than the largest lines carrying the hazardous material. The regulation provisions now allow consideration of even smaller releases from "holes" in the selected lines. In our opinion these developments can only be understood as resulting from pressures on the applicants to seek approval of smaller and smaller required exclusion distance determinations. But the requirements placed on the applicant to demonstrate the probability or lack thereof of the different kinds of releases assumed for designation as an ACR are not sufficiently quantified – the process appears to be largely a "good-faith" decision reached jointly by the applicant and the DOT/FERC staffs. In our judgment this is not good science or engineering; <u>it is indicative of regulation that facilitates facility approval</u> – potentially at the expense of public safety.

2. Further compromising the effectiveness of the current regulations for public safety, the system has become dependent upon modeling methods using

complex mathematical calculations (computer programs) that are not available to the public for independent evaluation of their applicability-for-purpose; we believe this prevents a basic public right-to-know.

3. The calculations supporting the exclusion zone distance for the LNG "tanktop" fire chosen by the applicant as the controlling "design spill" fire do not consider potential cascading failure hazards to the public that could follow such a fire. We believe such failures have the potential to lead to structural failures of the LNG tank(s) which could lead to catastrophe.

4. There are numerous potential hazards from fires and explosions that could result in cascading events involving the liquefaction trains at the facility as well as LNG ships berthed at the facility. We realize the ship is not FERC's responsibility; however, the worst-case hazard potential for the marine side of the proposed terminal should be considered before approval in view of the public concerns recently addressed in research required by Congress.

5. The methods used to determine vapor-cloud exclusion zones, particularly the use of "mitigation" methods such as gas-impervious concrete fences to prevent advance of vapor clouds beyond the applicant's property lines, could increase the potential for serious, even catastrophic, vapor cloud explosions. The JCE Terminal DEIS appears to ignore international experiences of catastrophic unconfined vapor cloud explosions (UVCE), at least four of which occurred in the last decade, destroying the facilities involved as a result of cascading events.

- **Design Spill Accident Selection**

The design spill specified for the ship's cargo unloading line for the Jordan Cove Export facility has been designated as a guillotine break of a 36 inch line with a ten minute duration spill of 827,740 gallons. Havens' 2009 review[1] of eleven LNG import terminal environmental impact statements indicates approvals for ship unloading line design spills ranging from 28,900 gallons (Keyspan, not approved) to 812,000 gallons (Trunkline, approved). FERC provided no quantitative justification for approving such large variations for these eleven spills, which resulted in large variations in the extent of vapor cloud exclusion zones. Since the vapor cloud zone determinations are directly related to the amount of LNG spilled, this lack of consistency in the design spills selected for analysis by the various applicants has the appearance of simply determining the size of the spill that the applicant's property line distance will allow. None of these widely varying approvals appear to have been supported by quantitative science-based analysis.

The Jordan Cove Export (JCE) DEIS illustrates the potential for misunderstanding in the current design-spill-selection process. The JCE DEIS specifies a ship unloading line (SUL) spill of more than 827,000 gallons into a concrete impoundment basin. To our knowledge this JCE SUL spill is the largest specified by any terminal applicant to date. To the reader uninitiated in the complexities of this process, this choice of design spill might be viewed as conservative (assuming a worst case spill of nearly a million gallons of LNG). However, current scientific knowledge concerning such events ensures that the applicant would have no hope of guaranteeing that the vapor cloud from such a large spill could be maintained within their property boundary *without incorporating extreme*

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[1] Havens, J., Consequence Analyses for Credible LNG Hazards, Second Annual AICHE/CSCHE Topical Conference, Montreal, Quebec, August 2009

measures. The extreme measures proposed to contain the cloud on the JCE's property are vapor-impervious concrete fences, some forty feet tall, which prevent the advance of a vapor cloud in selected directions. We believe this provision could result in defeating the purpose of the exclusion zones for ensuring public safety - by introducing additional severe hazards of vapor cloud explosion.

There are other serious problems with the design spill quantities and vapor dispersion (vapor cloud formation) predictions. The vapor dispersion model predictions presented assume maximum wind speeds (presumably at 10 meters elevation) of 1-2 m/s. Near the ground (one to five meters elevation) the wind direction fluctuation (as well as the speed) is very uncertain in near-calm wind conditions. There are proven scientific reasons to expect that low-wind speed (near-calm) conditions combined with the high density stratification of the cold LNG vapor cloud near the spill can increase the potential for damaging vapor cloud explosions. In such conditions the advance of the LNG vapor cloud is determined primarily by gravity forces on the cloud; typical cloud advance speeds would be around one (or even a fraction of one) meter per second. As a consequence, mixing of LNG vapor with air would be exceptionally "slow", and some degree of partial "containment of the cloud" would result due to the vapor fences' holdup effect. Finally, we expect that since the fences do not surround the property (there are gaps where the gas could get through) it is likely that simulations of the vapor dispersion, even with the presently specified fences, might not predict containment of the flammable gas cloud boundaries at higher wind speeds.

- **Vapor Dispersion Models are Proprietary and are not Available for Public Vetting**

The vapor dispersion models (also used for the damaging explosion-overpressure predictions) are not available for independent inspection or evaluation. While the models are presumably available to anyone requesting such services, the cost would probably be prohibitive to the public. This is a very significant development in government regulation policy; previously such models (DEGADIS and FEM3A) were available to the public at no cost. We believe this situation should be reviewed; it has the potential to undermine confidence in the entire process.

At least two new vapor dispersion models have been approved, for a total of four; DEGADIS, FEM3A, and two new ones, PHAST and FLACS. In contrast to DEGADIS and FEM3A, the development of which were paid for with public funds and which were (and still are) freely available for use and independent evaluation, the new models are privately held (proprietary), prohibitively expensive to the public, and they are not freely available for evaluation of applicability and accuracy. To our knowledge PHAST and FLACS are the only models which have been used since they were approved, and they are the only (vapor dispersion) models used for the preparation of the JCE Terminal DEIS.

- **The Fire Radiation Design Spill Ignores the Potential for Severe Cascading Effects**

The controlling fire radiation exclusion zone distance calculated using LNGFIRE3 and presented in the JCE DEIS barely falls within the applicant's property boundaries. We believe that the application of the LNGFIRE3 model to such a tank-top scenario requires assumptions which are erroneous to describe the wind speed and flow patterns at the top of the tank and that these deficiencies could result in non-conservative predictions of exclusion zones. However, as we want to prioritize our concerns regarding hazards with severe (catastrophe) potential, we focus here on our concern that such a fire (tank-top), if it were to occur in a nearly full LNG tank, could burn for a protracted time period, perhaps twenty to thirty hours, and there would be no practicable way to extinguish it.

Professor Venart's study of this fire scenario raises serious questions regarding the possibility of massive failure of a full-containment LNG tank due to severe, long-term, fire heat exposure to the tank with such a fire atop it. We believe that if this Design Spill Fire is to be used to determine the fire-radiation exclusion zone, there must also be considered the potential for such a fire to cause catastrophic failure of the tank (or tanks), resulting in the rapid release (spill) of perhaps half a million gallons of burning LNG. Should that occur, the fire radiation distances from the earthen-berm tertiary containment provided would surely extend the estimated fire radiation exclusion zone requirements to provide for public safety well beyond the facility property lines, to say nothing of the potential for catastrophic damage to the entire facility. We present below excerpts from Venart's presentation to DOT's Pipeline and Hazardous Materials Safety Administration (PHMSA)[2] that illustrate our concerns for cascading failures following such a tank-top-fire-scenario.

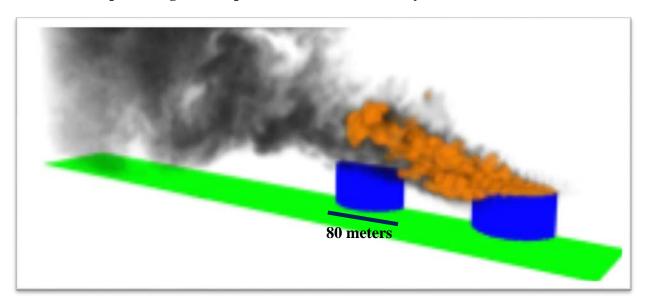**Description of full-containment LNG tanks**

- Very large – 80 > 90 meters diameter, 40 > 50 meters tall

- Post tensioned reinforced concrete, walls 0.7 m thick, roof 0.5 m thick

- Post tension; steel, vertical and circumferential through buttresses and tendons

- Concrete shell outer layer, inner layers, vapor barrier (steel), insulation (perlite) Nickel-
  steel LNG containment

- Plumbing, in and out, through the tank top

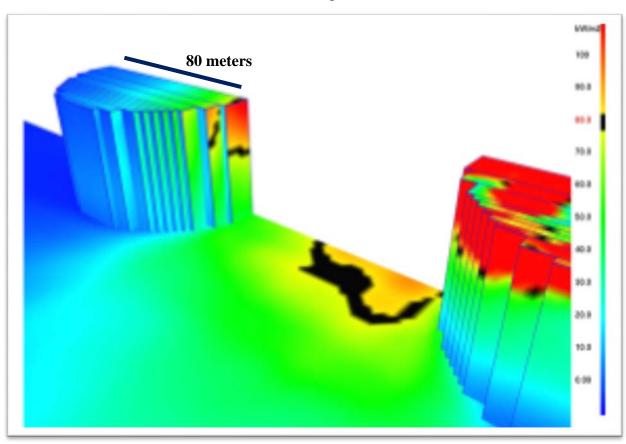**Typical Tank(s)**

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[2] Venart, J., LNG Tank-top Fires: Radiation Exclusion Zones, Presented to DOT PHMSA, Washington, DC, May 30, 2013.

LNG tank-top fire (high wind speed) FDS model results by Venart

Smoke and Fire Development for Two Tanks

Down-wind tank being exposed to an up-wind tank-top fire
Boundary heat flux for two tanks at 1 minute after fire initiation.
Incident heat flux exposures to both tanks in excess of 80 kW/m^2, wind 7.5 m/s.

Conclusions regarding tank-top fire and cascading failure scenario

- LNGFIRE3 has NOT been validated for the size of LNG fires anticipated for tank-top fires. Its use to establish conservative thermal exclusion zones is suspect.
- If not extinguished such a tank-top fire could possibly burn for 20-30 hours.
- NIST FDS CFD and experimental studies establish that the wind flowing around the sides of the tank tends to drag the flame down over the edge of the tank towards the ground. This exposes the concrete containment to high temperatures, radiant fluxes greater-than-design and thus thermal stresses with a potential for spalling, cracking, and other failure modes, thus loss of support to the interior mild steel moisture barrier and the insulating perlite.
- Thermal stresses to this complex system over the many hours of fire exposure could possibly cause collapse of the downwind edges of the Nickel steel primary containment and loss of LNG into the Perlite, a situation perhaps sufficient to result in total collapse of the containment system due to thermal stress. Under such conditions escalation of the event would be inevitable.
- The extent of the pool fire could now increase to the edges of any berm-impoundment surrounding the tank area, if provided, and a very much larger pool fire could result (of shorter duration).
- With two tanks, if one tank did not collapse, its adjacent neighbor would be exposed to heat fluxes greater than 80 kW/m^2 should the prevailing wind result in its flame exposure. Due to the increased fire size, plant processing areas could be adversely affected and the public radiation exclusion zone substantially increased.

- **Potential for Cascading Events Increases with Heavier-than-Methane Hydrocarbons**

The JCE DEIS pays little attention to the potential for boiling liquid expanding vapor explosions (BLEVEs) and UVCEs involving the liquefaction facilities. There appears to be a lack of coordination between the federal agencies (FERC and EPA[3] in this instance) in consideration of hydrocarbon explosion potential. We suspect that this is due to past emphasis of the regulations on LNG-only facilities. We quote from the Executive Summary of EPA 744-R-94-002:

This report assesses the potential consequences of accidents involving flammable chemicals to support the evaluation of whether such chemicals may warrant addition to the list of extremely hazardous substances (EHSs) under section 302 of Title III of the Superfund Amendments and Reauthorization Act (SARA). EPA's analysis included identification and evaluation of existing listing and classification systems, along with any applicable criteria; review of existing regulations and codes dealing with flammable materials; analysis of histories of accidents involving flammable substances; and modeling potential consequences of fires and explosions of flammable substances. …

A review of accident history indicates that flammable substances have been involved in many accidents, and, in many cases, fires and explosions of flammable

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[3] Flammable Gases And Liquids And Their Hazards, United States Environmental Protection Agency, EPA 744-R-94-002, February 1994

substances have caused deaths and injuries. Accidents involving flammable substances may lead to vapor cloud explosions, vapor cloud fires, boiling liquid expanding vapor explosions (BLEVEs), pool fires, and jet fires, depending on the type of substance involved and the circumstances of the accident.

Vapor cloud explosions produce blast waves that can potentially cause offsite damage and kill or injure people. EPA reviewed the effects of blast wave overpressures to determine the level that has the potential to cause death or injury. High overpressure levels can cause death or injury as a direct result of an explosion; such effects generally occur close to the site of an explosion. EPA's analysis of the literature indicates that people also could be killed or injured because of indirect effects of the blast (e.g., collapse of buildings, flying glass or debris); these effects could occur farther from the site of the blast. A vapor cloud may burn without exploding; the effects of such a vapor cloud fire are limited primarily to the area covered by the burning cloud. The primary hazard of BLEVEs, pool fires and jet fires is thermal radiation; the potential effects of thermal radiation generally do not extend for as great a distance as those of blast waves. In addition, the effects of thermal radiation are related to duration of exposure; people exposed at some distance from a fire would likely be able to escape. BLEVEs, which generally involve rupture of a container, can cause container fragments to be thrown substantial distances; such fragments have the potential to cause damage and injury. Fragments and debris may also be thrown out as a result of the blast from a vapor cloud explosion.

The probability of occurrence of vapor cloud explosions appears to be rather low, based on analysis of the literature. EPA reviewed factors that may affect the probability of occurrence of a vapor cloud explosion, including the quantity of flammable vapor in a cloud, the presence of obstacles or partial confinement, and the type of ignition source. _Analysis of accidents indicates that vapor cloud explosions are less likely when the quantity in the cloud is less than 10,000 pounds._ *(emphasis added)* It is generally thought that some type of obstruction or confinement enhances the probability that a vapor cloud explosion, rather than a vapor cloud fire, will occur. A high energy ignition source also contributes to the probability of occurrence of a vapor cloud explosion. …

Based on modeling and analysis of the literature, flammable gases and volatile flammable liquids appear to be the flammable substances of most concern, because they may readily form vapor clouds, with the potential for damaging vapor cloud explosions. EPA identified a number of such substances of concern. The analysis carried out by EPA for this report was intended to provide a general background on the hazards of flammable gases and liquids. The modeling results and accident data illustrate and compare the consequences of vapor cloud explosions, vapor cloud fires, BLEVEs, and pool fires. …

There have been a large number of devastating hydrocarbon explosions, particularly BLEVEs, since 1994. Finally, we note that the design spills considered in the JCE DEIS exceed the 10,000

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pound figure suggested by EPA as demarcating the size below which UVCEs are "improbable" (see emphasis added text in the EPA report quoted above) by at least a factor of 10, and in the case of LNG spills, by a factor of perhaps 300.

- **The Vapor Clouds Formed from the Design Spills Pose Severe Explosion Hazards**

The vapor dispersion distances calculated using PHAST and FLACS, while extending in some cases slightly past the applicant's property boundaries, obviously could not have been determined by the (dispersion) models used without the applicant's provision of gas-impermeable vapor fences to retain the flammable cloud boundaries within the property boundary. The Figure below indicates the position of the proposed vapor fences; gas-impermeable concrete fences as tall as forty feet.
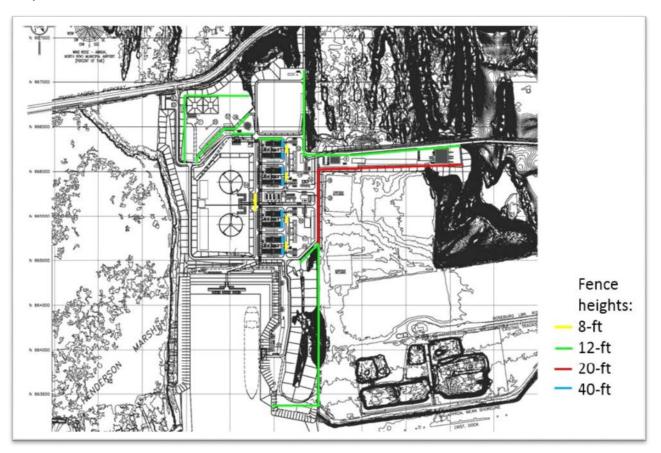

Figure 4.13-1 from DEIS
Vapor Fences at Jordan Cove Facility

Vapor Cloud Explosion hazards of LNG

The Jordan Cove Export DEIS FERC summarily dismisses the potential for methane vapor cloud explosions with the following statement:

> *The potential for unconfined LNG vapor cloud detonations was investigated by the Coast Guard in the late 1970s at the Naval Weapons Center at China Lake, California. Using methane, the primary component of natural gas, several experiments were conducted to determine if unconfined vapor clouds would*

detonate. Unconfined methane vapor clouds ignited with low-energy ignition sources (13.5 joules), produced flame speeds ranging from 12 to 20 mph. These flame speeds are much lower than the flame speeds associated with a deflagration with damaging overpressures or a detonation.

In consideration of the potential for mixtures of methane with heavier hydrocarbons that could be present at the terminal, the DEIS continues the statement immediately above with the following:

To examine the potential for detonation of an unconfined natural gas cloud containing heavier hydrocarbons that are more reactive, such as ethane and propane, the Coast Guard conducted further tests on ambient-temperature fuel mixtures of methane-ethane and methane-propane. The tests indicated that the addition of heavier hydrocarbons influenced the tendency of an unconfined natural gas vapor cloud to detonate. Less processed natural gas with greater amounts of heavier hydrocarbons would be more sensitive to detonation. ... Although it has been possible to produce damaging overpressures and detonations of unconfined LNG vapor clouds, the Jordan Cove Project would be designed to receive feed gas with methane concentrations as low as 94 percent, which are not in the range shown to exhibit overpressures and flame speeds associated with high-order explosions and detonations.

However there is an important scientific paper describing the Coast Guard sponsored tests at China Lake[4] which contains the following (page 13):

The second group of tests was designed to test a postulated accident scenario in which the vapor formed during a LNG spill is mixed with air to form a flammable mixture and then diffuses into a culvert system. The mixture in the culvert ignites and the combustion wave accelerates and transitions to a detonation. This detonation wave then exits the culvert and detonates the remaining unconfined vapor cloud. ... a 6 m long culvert, 2.4 m in diameter, was buried vertically in the ground in the center of the polyethylene hemisphere. A stoichiometric mixture of methane/propane and air was introduced into the hemisphere and a detonation was initiated at the bottom of the culvert using a 3.2 mm thick layer of datasheet explosive (13 kg). In tests 1 and 3 (reported to be 85% methane and 94% methane), a strong shock wave was felt at the bunker and also in the town of Ridgecrest, 22 km from the test site. ... Based on the test data, it appears that in tests 1 and 3 a detonation was produced within the unconfined cloud (emphasis added).

The Coast Guard Test No. 3 described immediately above was 94% methane, the lower limit methane concentration that Jordan Coves plans to accept as input feed to the terminal. While we acknowledge the use of a high-energy ignition source in CG Test No. 3, that is not sufficient reason to dismiss this test result as being meaningful for the Jordan Cove Export Terminal hazard assessment. The possibility of intentional use of high-explosives to ignite a vapor cloud must be considered - such methods are used routinely in the military to ignite the vapor/aerosol

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[4] Parnarouskis, M., et.al., "Vapor Cloud Explosion Study", Sixth International Congress on Liquefied Natural Gas, 1980.

hydrocarbon/air clouds formed in the use of fuel-air (FAE) weapons. There are additional factors which can add to the potential for accidental occurrence of a "boosted" ignition source in the vapor clouds that could be formed following the spills being considered at the JCE facility.

Perhaps most importantly, as vapor fences at the Jordan Cove Facility could (in addition to the spill-guidance trenches and impoundments themselves) provide a degree of partial confinement to the cloud, there is additional potential for run up to detonation, especially if the cloud contains more than a few percent ethane/propane or equivalent heavy components.

All of the figures presented in the DEIS of flammable vapor cloud travel distance for the LNG design spills illustrate simply that the vapor fences prevent travel (except in minor cases which FERC has provided exceptions for) beyond the applicant's property boundary. We believe these results entirely miss the point of the intention of the regulations – to provide for public safety. These figures appear to indicate that the authors of the application (Jordan Cove and their Consultants) believe that the hazard extent of these spills ends at the calculated lower flammable limit concentration reached by the cloud (the cloud boundaries depicted represent concentration LFL/2, as required by the regulation). However, this assumption was historically based on the fact that a reasonable limit on the fire damage from a vapor cloud fire, which would be of short duration, would not extend significantly beyond the flammable vapor concentration boundary. The parties that prepared the JCE DEIS must surely be aware of the serious potential for an unconfined vapor cloud explosion to extend well beyond the limits of the flammable cloud boundary. In the text above describing the Coast Guard's explosion tests at China Lake, we provided evidence of the potential for LNG clouds that contain small amounts of heavier-than-methane hydrocarbons to develop damaging overpressures. We focus on two of the figures presented in the JCE DEIS, both for the design spills from the LNG ship unloading line. The points we wish to emphasize are specified immediately following the figures.

Figure 4.13.5 from DEIS
LNG Spill from a Guillotine Rupture of the Ship Loading Header

The area covered by the cloud in Figure 4.13.5 is estimated to be approximately 320 meters wide and 480 meters long (top to bottom in the figure). We estimate this gas cloud would be between 2 and 4 meters deep. The cloud envelops a large portion of the liquefaction trains; these trains are dense packed equipment structures which are known to accelerate flames in such a gas cloud sufficiently to cause damaging overpressures. The cloud essentially surrounds the LNG storage tanks.
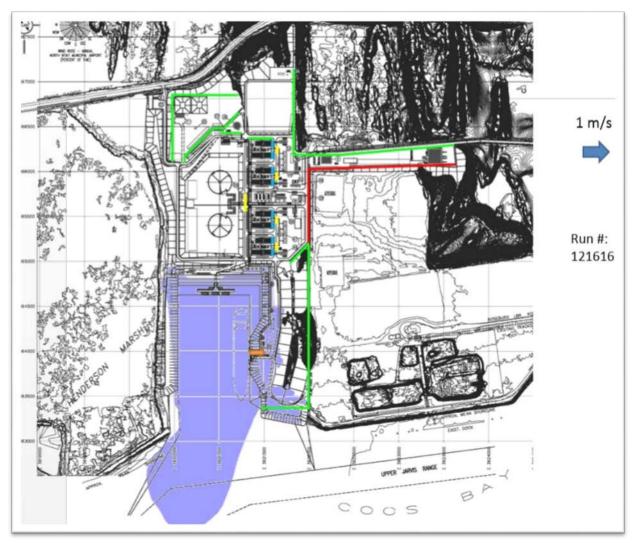

Figure 4.13-7 from DEIS
LNG Jetting and Flashing Scenario from a Rupture of the Ship Loading Header

The area covered by the cloud in Figure 4.13.7 is estimated to be approximately 400 meters wide and 720 meters long (top to bottom in the figure). We estimate this gas cloud would be between 2 and 5 meters deep. The cloud envelops the LNG shipping berth, indicating that a ship at the berth would be completely surrounded by the flammable cloud. While the dense packing of equipment seen in the previous figure associated with the liquefaction trains is not inside the cloud, there are containment factors associated with the space between the sea wall and the carrier that could cause damaging flame accelerations leading to explosions. We wonder what an LNG ship's Master would say if she were informed that a flammable cloud of hydrocarbons was about to surround her ship.

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Vapor Cloud Explosion hazards of mixed refrigerant liquids (hydrocarbons C2-C5)

For brevity, we focus on only one of the figures presented in the JCE DEIS for mixed refrigerant liquids; the design spill from the rupture of the inter-stage refrigerant pump discharge piping. The points we want to emphasize are specified immediately below the figure.

Figure 4.13-10 from DEIS
Mixed Refrigerant Release from Rupture of the Inter-stage Refrigerant Pump Discharge Piping

The area covered by the cloud in Figure 4.13.10 is estimated to be approximately 400 meters wide and 720 meters long (top to bottom in the figure). We estimate this gas cloud would be between 2 and 4 meters deep. The cloud envelops large portions of the liquefaction trains as well as at least half of the LNG shipping berth, including the space between the ship and the sea wall. We believe that an unignited MRL vapor cloud as indicated here could have the potential to cause a catastrophic UVCE that would result in severe cascading effects endangering the entire terminal.

Vapor Cloud Explosion hazards of ethylene

The DEIS presents a single vapor cloud prediction for the 14,000 gallon ethylene design spill. The wind speed is specified as 1 m/s (essentially calm). The area covered by the cloud in Figure 4.13-13 is estimated to be approximately 320 meters wide and 400 meters long (top to bottom in the figure). We estimate this gas cloud to be between 2 and 4 meters deep as well. The cloud envelops large portions of the liquefaction trains as well as all of one of the LNG tanks and about ¼ of the other one. The DEIS states that the ethylene release scenario at the refrigerant trucking area would remain within Jordan Cove's property or extend over a navigable body of water, so it would not have a significant impact on public safety with respect to flammable vapor dispersion.

Figure 4.13-13. Ethylene Release from Rupture of the Ethylene Trucking Hose

Overpressure Analyses

The DEIS at page 4-963 states the following. "… the propensity of a vapor cloud to detonate or produce damaging overpressures is influenced by the reactivity of the material, the level of confinement and congestion surrounding and within the vapor cloud, and the flame travel distance." We add that the potential flame travel distance is the distance that can be traversed by the flame in gas/air concentrations lying within the flammable region, i.e., between the LFL and UFL. This travel distance is in turn determined by the amount of flammable gas that is mixed with air in the cloud, and thus by the amount released into the atmosphere. The implications are clear; if a very large vapor cloud can form with large distances that can be traversed by a flame burning in the flammable region, the potential for flame acceleration increases.
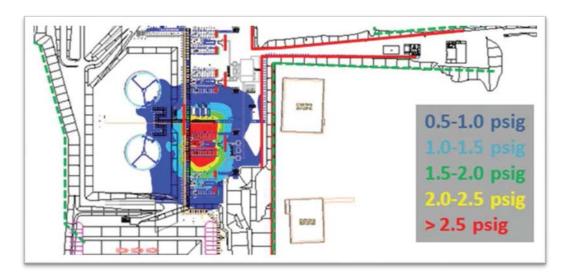
While the DEIS presents explosion overpressure predictions for the mixed refrigerant gases, it dismisses the (UVCE) explosion hazards for LNG. We believe this cannot be justified for the following reasons:

- The Coast Guard Tests show that with a strong igniter (high explosive), methane with about 6% propane added detonated. The DEIS states that Jordan Cove "will limit the heavier than methane hydrocarbon content in the LNG streams to 6%". This leaves no margin for safety, even if they could be certain of maintaining those levels.

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- The LNG spills are huge, and the vapor clouds formed have linear dimensions of hundreds of meters, with a corresponding potential for excessive flame acceleration.

- Secondary explosions that could boost the explosion processes cannot be discounted.

Nor do the overpressure calculations for the mixed refrigerant spills offer any consolation:

- The calculations of overpressure presented indicate very large areas of flammable gas envelopment of process equipment as well as the LNG tanks

- There are regions with linear dimensions of approximately 100 meters where the calculated pressures exceed 2.5 psig, but there is no specification of the maximum pressures reached. (See Figure 4.15-13 from the DEIS below.)

- If there exists evidence of agreement of the calculation methods used in the DEIS with large scale experiments and/or accidents that provide some confirmation of these predictions, including statements of the uncertainty which must be assumed in the overpressure predictions, such evidence should be made available for assessment, otherwise the calculations have little value, particularly in the face of recent accident experience we present below.

The DEIS acknowledges the potential for ethylene vapor clouds to detonate, but there are no overpressure calculations presented to accompany the ethylene dispersion calculations presented earlier. The mixed refrigerant spill overpressure calculations indicated approximately 2.3 psig overpressure at the LNG storage tanks. This statement is followed by "Jordan Cove stated that the LNG storage tanks would be designed to withstand an overpressure of 2.3 psig"… and that "We (presumably FERC) conclude that the siting of the proposed Project would not have a significant impact on public safety". In our opinion that statement does not indicate good engineering judgment, as it assumes a precision and accuracy of the model predictions that no scientist or engineer we know would endorse.

Potential for Catastrophic Unconfined Vapor Cloud Explosions (UVCEs)

Recent accident experience demonstrates that conditions are best for large vapor clouds to form if there is a mechanism for rapid evaporation of the spilled liquid and if there are near calm conditions which prevent rapid dispersion. The design spills considered for the Jordan Cove Export Terminal fit both criteria; the conditions considered are low-wind, near calm, and the materials are highly volatile; most volatile in the order of decreasing carbon content: methane, ethylene, propane, and pentane. The simple fact is that while the vapor clouds considered in this DEIS are prevented by physical barriers (vapor fences) from posing a vapor cloud hazard extending much beyond the property line, the holdup of very large quantities of flammable hydrocarbons by the vapor fences causes the gases to accumulate, with spreading largely driven by gravity spreading, so as to completely fill the affected areas to depths of a few meters, with large portions of those gas clouds having concentrations between the flammable limits. With these hazard-worsening conditions and the presence of densely packed processing equipment and the vapor fences which become enveloped in the cloud, one could hardly design the releases to better maximize the potential for catastrophic explosion hazard.

Catastrophic UVCEs are Becoming More Frequent

Confirmed scientific knowledge of the causes of UVCEs indicates that their frequency would increase with the potential for release of large quantities of hydrocarbons, especially highly volatile ones. As we have stated earlier, the sizes of flammable hydrocarbon vapor clouds described in the JCE DEIS have lateral dimensions of up to 720 meters (~2,400 feet). To our knowledge, there have been no UVCEs in the continental United States involving flammable clouds that large. The largest vapor cloud considered at JCE, which would follow a spill of ~3/4 million gallons of LNG, involves the most volatile of the hydrocarbons, methane (CH_4), which is lowest on the explosion sensitivity scale; but the mixed refrigerant liquid (MRL) spills are very large, and they approach the range of maximum sensitivity to explosion.

It appears that the relative rarity of large UVCEs (until recently) is very likely due to the fact that most of the very large spills that have occurred did not evaporate rapidly enough, and/or were dispersed readily by the action of wind, to allow formation of a large flammable cloud . But, now there have been at least four instances within the last ten years of devastating UVCEs following very large releases of gasoline class hydrocarbons where the evaporation of the fuels was rapid enough, and the wind speed essentially non-existent, to allow the formation of flammable vapor clouds with lateral dimensions of several hundred meters. In all four cases these clouds were ignited (presumably accidentally) and the explosions resulted in cascading events leading to catastrophic damages to the facilities (refineries/tank-farms) and injury/and/or deaths in the public sector. The first occurred in December, 2005, at Buncefield in the United Kingdom. There followed three more: Jaipur, India, 2009; San Juan, Puerto Rico, 2009; and Amuay, Venezuela, 2012. The following facts are a matter of record for all four:

- The events occurred in very low wind (near calm or calm) weather conditions.
- The maximum linear extents of the flammable clouds were at least 250 meters, ranging to at least 650 meters at Amuay.
- UCVEs occurred in every case that registered above 2.0 on the Richter Scale.
- The initiating explosions resulted in cascading events leading to total loss of the facilities.

We provide below photographs of these accidents (depicting the cascading fire and explosion effects) indicating the catastrophic damages that resulted. In our view, these four events, which have similar descriptions of the weather conditions and physical factors that could cause extremely

large flammable vapor clouds to form, and with which the vapor cloud scenarios considered in the JCE DEIS are clearly similar, should be a clear warning to parties planning facilities with similar potential for catastrophe.

Buncefield, United Kingdom

Jaipur, India

Amuay, Venezuela

San Juan, Puerto Rico

Scientific Conclusions re the Buncefield Event are Directly Relevant to the JCE DEIS

To our knowledge, detailed reports of the explosions in India, Venezuela, and Puerto Rico have not been completed. However, during the decade 2005-2015 since the Buncefield explosion occurred there have been published extensive reports of analyses thereof. The Buncefield explosion, which has been definitely established to be a UVCE, is thought to be the largest explosion that has occurred in peacetime Europe; damages now exceed two billion dollars.

In 2012, there appeared a paper in the Philosophical Transactions of The Royal Society (Great Britain) by D. Bradley, G.A. Chamberlain and D.D. Drysdale[5] entitled "Large vapour cloud explosions, with particular reference to that at Buncefield". As this paper appears to be the most

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[5] Phil. Trans. R. Soc, A 2012 370, doi: 10 1098/rsta.2011.0419, published 2 January 2012

recent to summarize the present understanding of the increasing potential hazards of unconfined vapor cloud explosions (UVCE) of hydrocarbon-air mixtures, we quote directly from the Conclusions section thereof:

A number of mechanisms for the propagation of combustion have been discussed, without reaching any definite conclusions as to what precisely happened at Buncefield. Of particular importance was the acceleration of turbulent flames along the line of trees and hedgerows. There was no unequivocal evidence that a principal mode of reaction was a fully developed detonation sweeping across the site. There was, however, evidence that the observed damage and various camera records could be explained in terms of high-speed deflagrations and quasi-detonations. The former could generate localized flamefront over-pressures of 400 kPa and, with sufficient confinement, shock pressures of 1 MPa. Quasi-detonations, the details of which are complex, can create constant volume combustion over-pressures of about 0.7-0.8 MPa, while a detonation would give a pressure spike of 1.75 MPa.

…

Other areas for further study emerge, some of which are included in the Buncefield Explosion Mechanism Phase 2 programme. The most significant should include the following.

i. **Analysis of the complexities of multi-component gasoline spillage, involving droplet break-up, air entrainment and vapour production, followed by dispersion in still air over uneven terrain. Dispersion under almost still conditions provides significant modelling challenges.**

ii. **The mathematical modelling of explosions through densely packed, small-scale, flexible obstacles and the question of whether reactant temperatures and pressures can become high enough for a DDT. The modelling of transitions to detonation and the conditions for their continuing propagation are particularly challenging, in terms of both the underlying science and the required computing power.**

iii. **A related experimental investigation of flame acceleration, with and without "bang-box" initiation, along hedgerows and lines of trees to ascertain the probability of a DDT and its continuing propagation into an uncongested cloud. Further investigations are also needed of direct jet flame "bang-box" ignition of external vapour clouds, to define the conditions that can lead to detonation of the cloud.**

iv. **The generation of necessary fundamental experimental and theoretical data on autoignition delay times, laminar burning velocities, and the effects of flame stretch on high turbulent burning velocities, including extinctions, all over the relevant ranges of temperature and pressure. The combinations of (ii), (iii), and (iv) could provide retrospective guidance on the relative contributions of high-speed deflagrations, quasi-detonations and detonations to the damage at Buncefield.**

In closing with these selected conclusions of this scientific paper summarizing the research that experts consider necessary in order to develop a methodology applicable to the determination of the potential for unconfined vapor cloud explosions of hydrocarbon-air

mixtures, we hope to send a clear message to the Federal Energy Regulatory Commission as well at the regulatory authority (DOT) that the methodologies depended on to ensure Public Safety in the Jordan Cove Export DEIS require careful, scientific, adjudication of the concerns we have raised – all of which we believe are supported by the extensive research regarding UVCE potential hazards post-Buncefield.

Appendix - A Brief History of LNG Regulation for Public Safety

LNG trans-ocean shipping, enabling import and export projects, has a relatively short history. The first cargo of LNG (27,400 m^3) shipped trans-ocean was delivered in 1964 from Lake Charles, Louisiana to Canvey Island (near London) in the United Kingdom[6]. The number of LNG carriers has now increased to more than 370, while ship capacities have increased by a factor of ten, with the largest ships today each carrying 266,000 cubic meters (70,264,000$^+$ gallons) of LNG. As the development of this industry has been decidedly fast-track, yet involves truly huge concentrations of energy-posing hazards in storage on land and in the ships, it is important to review the history of the development of methodology currently used by the United States Government to identify and regulate the hazards to the public that attend the operation of such facilities, onshore and off.

The Federal regulation 49 CFR 193: *Liquefied Natural Gas Facilities: Federal Safety Standards* was promulgated in 1980. 49 CFR 193, addressing the safety requirements regulated by DOT, is applicable on the land portion of the terminal(s) only. For our purposes in these comments, DOT's regulatory authority can be assumed to end at the point where the connections are made from the storage tanks on land to the loading lines on the ship. Beyond the shore-to-ship connection point, the principal authority granting approval for and regulating the operations is the Coast Guard. Both DOT and the Coast Guard have conducted extensive research, including field scale experiments, to define and quantify the hazards of fire radiation (heat damage) that could occur from vapor cloud and liquid pool fires, as well as the potential for explosion (generation of damaging overpressures) should a vapor cloud explode, to determine the appropriate measures which must be taken to provide for public safety.

Historically, the hazards of LNG are regulated based on the assumption that LNG is (primarily) liquefied methane (CH_4). In contrast, heavier-than-methane hydrocarbons, including the so-called Liquefied Petroleum Gases (LPG) which are necessarily present in large quantity in an LNG export terminal, are mixtures of hydrocarbon gases with molecular weights heavier than methane, such as ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), and pentane (C_5H_{12}). According to the JCE DEIS the heaviest hydrocarbons handled in significant quantities at this terminal will be C_5H_{12}. This is a vitally important point for the present discussion, because while it may be reasonable to identify, even limit, LNG hazards at import terminals assuming the LNG properties are similar to those of pure methane, LNG export terminals are another matter. Export terminals thus must receive gas (normally by pipeline) for liquefaction and shipping that contain significant amounts of heavier (than methane) hydrocarbons. Because shipped LNG must be sufficiently pure methane in order to be burned efficiently in typical natural gas burning equipment, the heavier hydrocarbons present in the gas feed stream must be removed in a natural-gas-liquefaction facility before shipping. Significant amounts of heavier-than-methane hydrocarbons must be temporarily stored at the export terminal site and ultimately become part of the products that are shipped out of the

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[6] http://www.eia.gov/todayinenergy/detail.cfm?id=16771

export terminal by various means. The result is that export terminals involve storage, handling, and usage of significant amounts of these heavy hydrocarbons which constitute hazards different from, and often more-severe-than, methane (the principal component of LNG).

The first author began research on LNG safety in 1976 (before the advent of 49 CFR 193) while on leave from the University of Arkansas serving as a technical advisor to the Office of Merchant Marine Safety of Coast Guard Headquarters in Washington, D.C. Havens' initial assignment was to review a collection of six mathematical (computer) model predictions of the maximum distance that could be reached by a flammable cloud of methane and air formed by spillage on water of the contents of a single tank of LNG from a typical LNG carrier of that day. The contents of a single tank on such a ship (typically containing five such tanks) was 25,000 cubic meters, or about 6 million gallons.

The problem the Coast Guard faced in 1976 was that the predictions of maximum flammable-gas-cloud extent from such a spill by six independent expert-preparers ranged from ¾ mile to 75 miles! In 1977 near the end of his off-campus-leave period Havens completed an analysis of the collection of predictions and prepared a report[7] for the Coast Guard which concluded that the lowest and highest estimates of distance were not credible and suggested that the range of distances would be much more likely to be between 3 and 10 miles. This was some progress, but the Coast Guard wanted a higher-confidence answer. Havens returned to the University of Arkansas with a contract to develop a personal-computer (PC) model capable of predicting hazardous vapor cloud dispersion distances for specified amounts of LNG spilled on water. The result was the DEGADIS model adopted by DOT and incorporated in 49 CFR 193 as the dispersion model used for LNG facility regulation to determine vapor dispersion exclusion zone (safe separation) distances.

Havens' 1977 report, in addition to enabling continuation of research on LNG vapor dispersion upon return to the University of Arkansas, had another very important effect on Havens, one which was brought back vividly while studying the Jordan Cove Export Project DEIS in preparation of these comments. Havens, at the suggestion of the Coast Guard, had sent his draft report to the authors of the predictions, requesting they provide reply-comments to the (Coast Guard) report. The authors of the predictions were informed that their replies would be published as part of the report. While all of the model-prediction-preparers provided written comments which were published in the report, and all were helpful, one preparer's reply still profoundly affects Havens' conclusions about the effectiveness of the United States regulatory program to provide for the public safety. Dr. James Fay, Professor of Mechanical Engineering at MIT, replied to Havens' request beginning with the paragraph quoted below.

> *"The discussion in the introduction (pp. 15-17) of the probability of various accident scenarios, which is clearly not an aspect of the scientific review of the various dispersion theories but more nearly a policy statement regarding risk, unfortunately tends to denigrate the value of this analysis. The reader may wonder whether the assessment is to be taken seriously, or has been carefully made, given the asserted unlikelyhood of the process being discussed. But if one ignores the casuistry of this portion of the introduction, the subsequent analysis is scientifically useful and more than worth the effort to have performed it."*

Fay's statement had focused on a very important failing of the report - the fact that Havens

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[7] Havens, Jerry, "Predictability of LNG Vapor Dispersion From Catastrophic Spills Onto Water: AN ASSESSMENT", USCG-M-09-77, April 1977.
http://www.dtic.mil/dtic/tr/fulltext/u2/a040525.pdf

appeared to have felt a responsibility to give the report's readers an excuse to discount the hazards being discussed on the basis that they were very unlikely (low probability). But the report had provided absolutely no information supporting any estimate of such events' probability of occurrence; the inclusion of the statements about "likelihood" therefore had no valid purpose. Havens continues today to acknowledge that failure; Professor Fay was entirely correct. We leave it to the readers of the Jordan Cove Export Terminal DEIS to determine the validity/justification of the suggestions therein regarding the probability of the events under discussion. Of course, our concern is that any such analysis which includes discussion of the probability of occurrence of specific realizations of the hazards must be scientifically quantified to be useful. Without careful quantitative justification such assertions are likely to encourage wishful thinking that is dangerous given the potential severity of the consequences being considered.

There were five major SAFETY HAZARDS identified that determine the regulation of safe-siting (separation) distances from the terminal to protect the public. Those five hazards are still applicable to the Jordan Cove Export (JCE) Export Terminal (we are not addressing potential environmental hazards):

- Toxicity
- Cryogenic Exposure
- Liquid Pool Fires
- Vapor Cloud Fires
- Vapor Cloud Explosions

As this submission focuses on safety hazards to the public offsite, we agree that toxicity and cryogenic exposure hazards are not nearly as likely (compared to the remaining three) to pose serious threats to the public.

The United States Government has conducted major research programs to define and quantify the hazards that attend the siting on land of LNG import terminals and the marine operations associated with LNG ship carriage. We will not attempt to describe the research efforts conducted by industry; our discussion focuses on government sponsored research designed to quantify, for regulatory purposes to provide for public safety, the three hazards identified above; liquid pool fires, vapor cloud fires, and vapor cloud explosions.

The interest in LNG importation in the United States has been highly cyclic. During the period ~1970-1985, the first four import terminals were constructed in the continental U.S., all on the East and Gulf Coasts: Everett, MA; Cove Point, MD; Elba Island, GA; and Lake Charles, LA. There were several import terminals proposed onshore and offshore California, but none were ever constructed. Extensive LNG research was performed during this period to develop the Government's knowledge base supporting public safety-regulation. Then, after a decade or more lull in interest in LNG terminals, another rush to construct import terminals developed at the turn of the century with more than fifty import terminals proposed in short order. The attack on the World Trade Towers on 9-11-2001 heightened concerns about LNG safety, partly because of the presence of the import terminal in Boston Harbor (Everett, MA). The Government's responses to the multiple terrorist attacks on 911 included preventing a scheduled LNG ship from entering the Everett, MA, terminal, holding it offshore for several days before directing it to proceed to Elba Island, GA to unload. This was due to concerns that LNG facilities in highly populated areas might be considered attractive targets for terrorist attack; this concern is still with us. Research directed to LNG safety following 911 was primarily directed to hazards to the public of the shipping side of import projects then operating. There developed as a result another period of

LNG safety research, primarily directed at marine (shipping) operations, which has continued to the present.

The First Research Period: ~1970-1985

At about the same time that Havens was digesting Professor Fay's review of the Coast Guard Report, Congress appropriated substantial sums (~$40,000,000) for the Lawrence Livermore Laboratory (LLNL) and several other Contractors, including the China Lake Naval Weapons Center, to research outstanding questions about LNG liquid pool fires, vapor cloud dispersion, and vapor cloud explosion hazards. LLNL built a purpose-designed spill test facility at the Nevada Test Site on the old (Frenchman Flat) nuclear weapons test site to conduct LNG spill research. A principal product of this work was the complex mathematical model for LNG vapor dispersion called FEM3 (acronym for Finite Element Model – 3 dimensional). The model was designed to address the need for prediction of vapor dispersion in the presence of terrain effects and obstacles such as buildings and plant structures. Extensive reports of this work are available. The University of Arkansas was subsequently contracted by the then Gas Research Institute to develop a PC version of FEM3, and the University carried out some validation experiments using a purpose-built ultra-low-speed wind tunnel (the largest ultra-low-speed wind tunnel in the world at that time). That PC version became known as FEM3A, and it was adopted by DOT as an alternative (to DEGADIS) model that could be used by LNG facility applicants to consider the effects on dispersion distances that would result from the presence of obstacles or terrain features.

Meanwhile, the China Lake Naval Weapons Test Station conducted (for the Coast Guard) a series of liquid methane and propane spills to investigate the potential for fire radiation damage extending from fires of different sizes and also conducted an extensive series of tests of unconfined gas clouds of methane and propane mixtures of uniform concentration (contained in balloons) to determine the potential for such clouds to cause damaging overpressures (explosions). Extensive reports of this work are available.

The pool fire test data from China Lake was used to develop the LNGFIRE model series, which is still used to determine the regulation-required separation distances to prevent radiative (fire) fluxes that can cause serious burns to the public. The principal results of the unconfined gas cloud explosion work, here intentionally simplified for brevity, were:

- Pure methane (unconfined) did not burn with damaging overpressures (explode) unless a sufficiently energetic "starting" explosion ignited the cloud.
- The presence of sufficient amounts (say >10-15%) heavier components such as propane mixed with methane resulted in damaging overpressures.

Since that early work there have been numerous severely-damaging accidental explosions of <u>unconfined</u> mixtures of propane (and heavier hydrocarbon gases) with air.

The research conducted by the Government described above occurred in the same decade in which the Atomic Energy Commission was abolished in favor of the Energy Research and Development Agency, later succeeded by the present Department of Energy. At first there was a move to design the regulatory framework for LNG management (LNG had been promoted to the class of Major Hazards by the British Health and Safety Agency by that time) based on probabilistic risk assessment procedures, as was being suggested as the favored method to regulate the safety aspects of nuclear electric power plants. However, DOE and DOT (the latter by that time the agency responsible for natural gas pipeline safety) took on the responsibility of developing regulations governing the siting of LNG terminals. The responsibility for the shipping side went to the Coast Guard.

DOT incorporated a purely consequence-based approach (with no consideration of quantitative measures of risk, meaning the probability with which an event might occur) which is still in use. Initially, regulations required the terminal applicant to determine safe separation distances, separately, for (unignited) vapor cloud travel and pool-fire radiation hazards. The applicant was required to use regulatory approved mathematical (computer) models to determine the maximum hazard distance for "worst case" vapor cloud releases and liquid pool fires. Up to ~2000, such calculations were required to be completed using DEGADIS (and later FEM3A) for vapor dispersion, and LNGFIRE for pool fires). The starting assumption (the event required to be modeled) was typically complete failure, resulting in rapid release, of the largest contained volume of LNG at the site, with no regard to the probability (or in many minds, the impossibility) of such an occurrence.

But, just as had occurred during this time period in the Nuclear Industry, there was soon adopted a practice of selecting so-called "Design" accidents which set lower requirements for the amounts of LNG to be released. The LNG regulations adopted specification of "Design" Spills to place limits upon the amount of material released and the rate at which it could be released. That is where we are today, which leads the authors to believe that an "inevitable" result has occurred - when the calculated distances required to separate the public from the hazard became "unmanageable" the release magnitudes (the so called "SOURCE" terms) were decreased. While we realize that the realities of economy as well as other factors can sometimes indicate, if not require, such changes, and that this pattern is established more or less world-wide today by major hazards industries in siting practice to protect the public, we believe it is a classic example of a process involving a seriously slippery slope. We believe that we have already reached the condition in LNG safety regulation where the determination of the design spill is effectively inseparable from the determination of the amount of land that the facility operator can purchase to insure that the public cannot intrude on. And, most importantly, the methodology for determining the "maximum" design spills that must be planned for appear to have evolved based on far-less-than-scientific reasoning processes. Although this issue is far too big to "take on" here, we want to state clearly our belief that the "agreements" on the sufficiency of the materials submitted to FERC by the applicants for the Jordan Cove Export Project have resulted far too much from "helpful cooperation" with the regulatory authority, with the result that the design spills (read spill quantity and rate of release as well as usage of vapor cloud travel "mitigation" methods) now effectively limit the hazard distances to a level considered "manageable" by the applicant.

The Second Research Period (2000-present)

As of October of 2014 seven more import terminals (beyond the original four) are in operation: Offshore Boston, Massachusetts (Excelerate Energy); Freeport, Texas; Sabine, Louisiana; Hackberry, Louisiana; Offshore Boston, Massachusetts (GDF-SUEZ); Sabine Pass, Texas; and Pascagoula, Mississippi. Three more import terminals have been approved, but are not yet under construction: Gulf of Mexico (Main Pass McMoRan Exp.); Offshore Florida; and Gulf of Mexico (TORP Technology– Benville LNG). Finally, (as of October, 2014), one export terminal has been approved and is under construction: Sabine, Louisiana. Three other export terminals have been approved but are not yet under construction: Hackberry, Louisiana; Freeport, Texas; Cove Point, Maryland. All of these import and export terminals have been approved by FERC based (with respect to safety and reliability requirements) on meeting the requirements of DOT Regulation 49 CFR 193 and Coast Guard Letters of Recommendation.

Following 911 (2001), new concerns arose that LNG ships, already plying the waters in heavily populated areas such as Boston, could pose unacceptably severe hazards to the public, either

resulting from accidents or terrorist attacks. In response, Congress appropriated substantial additional sums for research to better quantify the severity of hazards that could be realized, with emphasis on LNG ship movements to and from, and berthed at, operating LNG facilities. This research was conducted principally by the Sandia National Laboratory and focused principally on two questions about the hazard distances that could extend from LNG ships which suffered accidental (or intentional) releases of LNG onto water; by vapor cloud travel (if the spill was not immediately ignited upon release), or by fire radiation (heat damage) from the liquid pool-on-water fires that would result if the release was ignited at the spill site. By this time, the "maximum credible" release (from a ship onto water) had been pared down by a factor of two, from 25,000 m^3, still considered the typical single-tank volume, to half that size, 12,500 m^3. This reduction was considered reasonable based on the fact that the principles of physics dictated that since about half of the LNG in a tank was below the water level exterior to the ship it was extremely unlikely that the entire tank could be spilled rapidly (which was the condition originally assumed).

For our purposes (in these comments), it is possible to briefly summarize the Sandia Research Results (published in 2004[8]) of the pool fire and vapor cloud hazard distances (to a concentration of ½ the lower flammable limit of methane, or 2.5%) as follows:

- Pool fire radiation distances - assuming rapid release onto water of ½ tank with immediate ignition, the maximum distance to heat flux levels that could cause second degree burns to unprotected human skin was estimated to be about one mile.
- Vapor cloud dispersion - maximum distances, assuming the cloud is not ignited, extending beyond 1600 meters. For the JCE facility, this suggests that an unignited cloud from a large ship spill could reach well beyond the property boundaries.

Then, in 2007, the Government Accountability Office, as requested by Congress, delivered their report entitled "MARITIME SECURITY: Public Safety Consequences of a Terrorist Attack on a Tanker Carrying Liquefied Natural Gas Need Clarification." This report detailed the findings of an expert panel (seventeen members, one of whom was the first author of these comments) who were individually questioned to provide their opinions on major LNG safety issues that remained controversial. The section of the report entitled "Results in Brief" is repeated verbatim below[9]:

> *The six unclassified studies we reviewed all examined the heat impact of an LNG pool fire but produced varying results; some studies also examined other potential hazards of a large LNG spill and reached consistent conclusions on explosions. Specifically, the studies' conclusions about the distance at which 30 seconds of exposure to the heat could burn people ranged from about three quarters of a mile to 2,000 meters (about 1-1/4 miles). The Sandia National laboratories' study concluded that the most likely distance for a burn is about 1,600 meters (1 mile). These variations occurred because researchers had to make numerous modeling assumptions to scale-up the existing experimental data for large LNG spills since there are no large spill data from actual events. These assumptions involved the size of the hole in the tanker, the number of tanks that fail, the volume*

[8] Hightower, Mike, et. al., Guidance on Risk Analysis and Safety Implications of a Large Liquefied Natural Gas (LNG) Spill Over Water, Sandia Report SAND2004-6258, December 2004.

[9] Maritime Security: Public Safety Consequences of a Terrorist Attack on a Tanker Carrying Liquefied Natural Gas Need Clarification, GAO-07-316, February 2007.

of LNG spilled, key LNG fire properties, and environmental conditions, such as wind and waves. Three of the studies also examined other potential hazard of an LNG spill, including LNG vapor explosions, asphyxiation, and cascading failure. All three studies considered LNG vapor explosions unlikely unless the LNG vapors were in a confined space. Only the Sandia National Laboratories' study examined the potential for cascading failure of LNG tanks and concluded that only three of the five tanks would be involved in such an event and this number of tanks would increase the duration of the LNG fire.

Our panel of 19 experts generally agreed on the public safety impact of an LNG spill, disagreed with a few conclusions reached by the Sandia National Laboratories' study, and suggested priorities for research to clarify the impact of heat and cascading tank failures. Experts agreed that (1) the most likely public safety impact of an LNG spill is the heat impact of a fire; (2) explosions are not likely to occur in the wake of an LNG spill, unless the LNG vapors are in confined spaces, and (3) some hazards, such as freeze burns and asphyxiation, do not pose a hazard to the public. Experts disagreed with the heat impact and cascading tank failure conclusions reached by the Sandia National Laboratories; study, which the Coast Guard uses to prepare WSAs. Specifically, all experts did not agree with the heat impact distance of 1,600 meters. Seven of 15 experts thought Sandia's distance was "about right," and the remaining eight experts were evenly split as to whether the distance was "too conservative" or "not conservative enough" (the other 4 experts did not answer this question).

As a result of the GAO report, Congress directed further research to be conducted by the Sandia National Laboratory. That research (thus far) concludes that the radiant heat fluxes from large LNG fires on water, which burn without much smoke, can exceed 300 kW/m^2, and that there are potential failure modes regarding LNG carriers that could lead to a ship being at risk of sinking. The ship-safety-research continues.