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Review

United states regulations for siting LNG terminals: Problems and potential

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Abstract

The regulations being applied to liquefied natural gas (LNG) import terminal siting in the United States are reviewed. There are no requirements for exclusion zones to protect the public from LNG spills onto water. Serious problems with current practices used to determine exclusion zones on the land-based part of the facility are identified. Many of the questions that are considered relate to the use of computational fluid dynamic (CFD) models, which appear to offer the best potential for realistic modeling to determine vapor cloud exclusion zones that result from LNG spills into impounded areas with or without dispersion in the presence of other obstacles to the wind flow. Failure to use CFD models, which are already approved by the regulation, and continued use of practices which have been demonstrated to be in error, raises important questions of credibility as well as denies the applicant full use of scientific tools that are available to optimize the design of such facilities so as to best provide for safety of the public.

Keywords: LNG; Regulation; Public safety; Plant siting; Dispersion exclusion zone; Thermal radiation exclusion zone

Contents

1. Introduction

The United States is considering greatly increased importation of liquefied natural gas (LNG), and there is a rush to identify terminal sites that appear economically viable and that meet local and national governments' requirements to provide public safety.

It is not generally recognized, as three decades have passed, that the current Federal siting regulations, 49 CFR 193, grew out of concerns about the hazards to the public of LNG import terminals proposed in the early Seventies in California at Oxnard, Point Conception, and Los Angeles. At that time four LNG import terminals were already planned or in operation in the United States—at Everett, Massachusetts; Elba Island, Georgia; Lake Charles, Louisiana; and Cove Point, Maryland. As 49 CFR 193 had not been promulgated, the first four import terminals were sited, with Federal approval, under the provisions of National Fire Protection (NFPA) 59A, entitled "Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)". But as a result of heightened public concern, there followed an extensive research program to determine more confidently what consequences could result from credible releases of LNG that could result in fires or explosions [1].

As a result of the research program described by Koopman and Ermak in this issue, the principal hazards from episodic LNG releases were determined to be two, both fire (thermal radiation) hazards—from pool fires and/or vapor cloud fires. A third haz-

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ard, the hazard of unconfined vapor cloud explosion (UVCE), has been relegated to secondary importance based on the determination that LNG vapor, typically containing more than 90% methane, is highly unlikely to burn fast enough to cause damaging overpressure (either by deflagration or detonation) if it is not confined (so as to increase the potential for turbulence induced run-up) and if it does not contain abnormally large amounts, say greater than about 15%, higher molecular weight hydrocarbons such as propane (typically termed a "hot" gas mixture). A fourth hazard, Rapid Phase Transition (RPT), was also relegated to secondary importance, as scaling considerations appeared to limit the amount of danger (overpressure) that could occur. Consequently, the regulations do not presently address either UVCE or RPT hazards. Although these hazards will not be discussed further here, it is noted that neither should be entirely dismissed. The potential for UVCE can be important if the "hot gas" content exceeds normal limits, and it is certainly possible that there will be LNG received at terminal sites in the United States that exceeds those limiting concentrations. For RPTs, the remaining concern is for the potential of RPTs to cause secondary structural damage, which might lead to cascading containment failures.

But there followed a three-decade lull in interest in imported LNG in the United States, while LNG transoceanic shipping grew rapidly in other parts of the world, most spectacularly to Japan. Then, in 2000, following announcements by the United States Government of renewed interest, a rapidly growing list of proposals resulted, finally surpassing 50. Although the rush began with proposals for onshore terminals, there quickly followed numerous applications for offshore sites, and the first import facility built in the United States since the Seventies commenced operation in 2005 in the Gulf of Mexico.

The need is obvious for carefully conceived regulations that address the question of public safety—What separation distances should be required to ensure that the public is out of harm's way from credible LNG releases at an LNG import facility? The public wants, understandably, to be confident of its safety, and since 9/11 the terrorist threat has immensely complicated the issue, forcing consideration of the consequences of LNG releases that could result from malicious intent.

Offshore, the Coast Guard and Maritime Administration (MARAD) are the responsible agencies, and the process seems to be proceeding largely without contentious debate about the public safety issue, if not about all of the environmental issues. It is clear that the offshore option can, under the right circumstances, obviate the (onshore) public safety concern. The authors of this paper believe that updating the consequence assessment procedures to consider post 9/11 hazard separation distances will result in a finding that people on shore will be out of harm's way from offshore LNG terminals of the size presently being considered if sited 10 or more miles offshore.

Regarding the regulations for onshore siting, then, it is admittedly late in the game to be considering changes, with numerous LNG terminal proposals already approved and others in process. But this paper will argue that changes and clarifications are urgently needed. Furthermore, the authors believe that this call for action has much broader implications, as the changes recommended here are necessitated by the failure of the U.S. Government to follow good science and engineering advice to enforce the requirements for public safety that were intended when 49 CFR 193 became law. The authors have observed numerous complaints of disturbingly similar developments regarding the Government's reticence to accept scientific advice in other areas dealing with important issues in which the public is a primary stakeholder – with concerns ranging from environmental to homeland security issues. If these problems are really indicative of a general change in Government policy, we suggest that a much more serious problem – loss of public confidence – looms [2–4].

2. The problems

2.1. Overview

The U.S. Federal Energy Regulatory Commission (FERC), further empowered by the Energy Act of 2005, is the lead agency that determines the acceptability of land-based LNG import terminal sites. But the U.S. Department of Transportation (DOT) regulation, 49 CFR 193, which FERC relies on for guidance and determination of those siting requirements, was developed during a period when few people were interested – and the regulation remained largely unused and untested – until 2000. More importantly, 49 CFR 193 has morphed, accompanied and aided by the incorporation of NFPA 59A, into a regulation at least in its application that does not fulfill the intent of its writers to incorporate the experience and knowledge that resulted from the US$ 40,000,000 research program concluded in the 1980s. Zinn [5] has described the evolution of 49 CFR 193, beginning with its shortening and incorporation of 59A in 2000. We address here, in summary fashion, only the principal changes that impact questions relating to public safety.

49 CFR 193, and NFPA 59A as well, adopt as their means for ensuring public safety a requirement for *exclusion zones*, defined as areas which are controlled by the terminal operator or the government – effectively prohibiting the public's presence. Although some have disagreed with this approach, preferring a method based on quantitative risk analysis (QRA) which would allow consideration of the probability (likelihood) of events as well as their consequences, 49 CFR is the law, and the authors believe that it should either be followed or changed.

The regulation(s) prescribe the events (spills) which must be considered and then require that specified methods be used to determine the hazard zones that could result. The terminal can receive approval (without a waiver) only if the exclusion zones so determined do not extend beyond the plant boundary onto areas not controlled by the applicant or the Government. Two types of exclusion zones are required to be determined: thermal radiation exclusion zones and vapor cloud dispersion exclusion zones. The problems, both of which can and have lead to downplaying the hazards that are to be quantified (by prediction of too-small exclusion zones), are of two types:

- Misleading or erroneous specification of the input parameters (such as spill amount) or of end-point criteria upon which the exclusion zone extent is based.

- Misleading or erroneous determination (modeling) of exclusion zone extents.

It is important to recognize that 49 CFR 193 and NFPA 59A consider only the land-based part of the facility; indeed, FERC's "jurisdiction" effectively ends at the shoreline. Consequently, the requirements for exclusion zones do not apply to spills that could occur from the ship, either when it is in transit to or located at the unloading pier. As spills from the ship might be in larger amounts (because of the vulnerability of the ship containment systems) and as spreading of LNG spills on water could not be controlled, the present requirement leaves a gaping hole in the regulatory provisions. Although the Coast Guard does consider these risks attending spills on water in their evaluation (with FERC) of a terminal application, the fact remains that there are no exclusion zones required presently at an LNG import terminal to protect the public from spills that might occur onto the water. The following discussion relates solely to spills on land.

2.2. Thermal radiation exclusion zones

Thermal radiation exclusion zones are required to be determined using the LNGFIRE III computer model. LNGFIRE III can be obtained from the Gas Technology Institute and is available to any interested party. We believe the LNGFIRE III model represents reasonably the best available technology. We do not object to current requirements for data input to the model—the fire dimensions are (properly) input by describing the dimensions of the impoundments which must be provided for the spills specified. However, we note that the criterion used to delimit the exclusion zone extent (to protect the public) is a thermal flux exposure of 5 kW/m^2. This thermal exposure to unprotected skin would cause second degree burns in about 30 s to persons who could not take shelter. A lower criterion of approximately 1.5 kW/m^2 is used in some regulations [6], being the accepted exposure that would not cause serious injury for meaningfully longer exposure. Consequently, there have been calls to consider lowering the thermal flux criteria to a level that would ensure public safety. We note that the regulation has been reinterpreted over time so as to require that the LNGFIRE III model be used to determine the wind speed at which the thermal exclusion zone is greatest, and that this requirement typically results in a higher wind speed, and greater exclusion zone extent, because of the wind-bending effect (which can place people "under" the fire).

2.3. Vapor cloud exclusion zones

As specified in 49 CFR 193, vapor cloud dispersion exclusion zones are required to be determined using the DEGADIS [7] or FEM3A [8] model(s), both of which can be obtained by interested parties from the Gas Technology Institute. Alternative models can be used provided they have been approved by the appropriate authority (DOT Administrator). FEM3A, a computational fluid dynamics (CFD) model, was approved by the DOT Administrator in 2000 for optional use by applicants desiring to determine exclusion zones so as to include the effects on dispersion of changes in the wind flow (and cloud movement) caused by obstacles (tanks, dikes, vapor fences, etc.) or terrain features. Ongoing research [9] seeks to improve the performance of FEM3A and other CFD models in LNG applications. DEGADIS, approved in the early 1990s, does not allow for consideration of any such complex effects, and is consequently considered to be more conservative (predict longer distance) than FEM3A when both models are applied for the same amounts of LNG released into the wind field. As shown below, the current practice to determine a (too-small overflow) rate of LNG vapor from an impoundment (using the source model SOURCE5 for input to DEGADIS) can result in a nonconservative underprediction of the exclusion zone.

2.3.1. Specification of design spills for determining exclusion zones

The LNG spills for which vapor cloud dispersion zones are required to be determined, called *design spills*, key on the regulation's requirements to provide impoundment basins to ensure that the spills are fully contained, i.e., no *liquid* overflows the impoundment. Following historical precedent in 49 CFR 193, the spills for which impoundments are required are 10 min, full-rate spills from the largest transfer line in the plant area served by the impoundment. The largest such transfer line in an import terminal is normally the ship unloading line, which for presently proposed plants would give a 10 min full bore spill volume of around 600,000 gal.

However, when NFPA 59A was incorporated in 49 CFR 193, and although the requirements for impoundment basins to collect maximum 10 min duration full-line spills remained, the definitions for design spills (for vapor cloud exclusion zones) were changed – to require only what are called "any accidental leakage sources". The spills so determined vary depending on the specific plant area that is being considered, but as they are rarely larger than 3 in. in diameter based on the present guidance from FERC, the spill amounts are typically smaller by a factor of 10 (or more) than the ship unloading line spills. So, while FERC requires design of impoundment basins that will hold (typically) 600,000 gal of LNG based on the ship unloading line rupture, the vapor dispersion exclusion zone is allowed to be determined for a spill perhaps one-tenth the size. As the requirement for the spill basin size clearly establishes the credibility of the larger spill, it follows that the vapor dispersion exclusion distance should be determined for the same spill, not an arbitrarily designated smaller one as is presently accepted by FERC.

2.3.2. Errors in application of models to determine exclusion zones

Spills into impoundments or diked areas (which normally contain storage tank(s) and other service equipment) cannot be directly modeled with DEGADIS (a flat surface, no obstacles model). A program began in the late 1980s, funded by the Gas Research Institute (now the Gas Technology Institute) and DOT, to select a candidate CFD model for consideration as a tool to provide more realistic vapor cloud travel distances for spills in LNG facilities. After more than a decade of continuous work on that issue, the FEM3A model was approved by DOT in 2000 for use in 49 CFR 193. The primary basis for the approval of

FEM3A was the extensive verification effort using wind tunnel data developed in the purpose-built ultra-low-wind-speed boundary layer tunnel at the Chemical Hazards Research Center of the University of Arkansas [10]. The FEM3A model is intended to provide for consideration of vapor dispersion effects that cannot be treated by DEGADIS:

- FEM3A can account for obstacles to the wind and cloud flow, as well as terrain.
- FEM3A can predict the scooping (entrainment) by the wind of vapor clouds forming in an impoundment into which LNG is spilled and subsequently evaporates.

Both DEGADIS and FEM3A must be provided, via input data, the amount and rates at which LNG vapor enters the wind field, and this is where DEGADIS is being used incorrectly to determine the vapor cloud exclusion zones *for spills into impoundments*.

The present practice is to use the SOURCE5 model in conjunction with DEGADIS to model spills into impoundments. SOURCE5 calculates the rate of LNG vapor formation following LNG spills into impoundments, given the dimensions and thermal properties of the impoundment. Although there may remain questions about the general validity of SOURCE5, there is no disagreement with its defining feature: SOURCE5 determines the volumetric rate of formation of pure LNG vapor (at its boiling point) and integrates that volume production rate to determine when (or if) that pure LNG vapor exceeds the volume of the impoundment, and if so, the time at which overflow occurs and the rate of overflow. That overflow rate is then used as input to DEGADIS to predict the exclusion zones. The principal error in this process is the assumption in SOURCE5 that no air mixes with the LNG vapor in the impoundment. The assumption that no air would mix with the vapor forming in the impoundment if there is a wind blowing over the impoundment has no validity – it can be dismissed on physical grounds alone. Indeed, there have been extensive field tests and wind tunnel tests that disprove the premise [11]. Nevertheless, the faulty process continues, with the result that the vapor cloud exclusion zones so determined are decreased in extent (downplayed), resulting in failure to protect the public.

Including the effect of air mixing causes the vapor impoundment to fill much more rapidly than would otherwise be predicted because the NG vapor/air mixture expansion ratio (the ratio of gas/air volume to liquid volume for a given mass of LNG) is much larger than the expansion ratio for LNG vapor (typically taken to be around 235). As with many other models that incorporate similar (and accepted) heat transfer principles, SOURCE5 assumes that the LNG boil-off rate is inversely proportional to the square root of the time after the spill starts. Consequently, the LNG boil-off rate decreases rapidly with time; thus resulting in underestimation of the NG vapor (and air/NG mixture) overflow rate that SOURCE5 predicts to occur at a later time. Consider the following example: If the average concentration of NG vapor (in the air/vapor mixture) is 25% (0.25 mole fraction) inside the vapor impoundment (as indicated typically by wind tunnel measurements and CFD model predictions), then the expansion ratio of the NG vapor/air mixture overflowing the impoundment is more than 2000 (based on adiabatic mixing of LNG vapor with ambient air); for an example scenario taken from a recent Environmental Impact Statement, the boil-off rate of LNG (and overflow rate of NG vapor) would then be over 8 times larger than predicted with SOURCE5. Further, it is known that the concentration at a given downwind distance is roughly proportional (for a steady state release) to the release (boil-off) rate, so concentration predictions are anticipated to be artificially low (not conservative) when using SOURCE5 to model the vapor source. Finally, since the average LNG vapor concentration inside the vapor impoundment will decrease as the wind speed increases, the lowest wind speeds may not give the largest exclusion zones when the effect of air mixing in the vapor impoundment is taken into account. Hence, it is now clear as a result of both wind tunnel research and CFD modeling that the current regulation is likely to be in error as well in allowing low wind speed, stable atmospheric conditions (2 m/s at 10 m, F atmospheric stability) to be used to calculate the worst case exclusion zone distance when vapor impoundments are involved. Since the scooping action of the wind (the mechanism for removal of the vapor–air mixture from the impoundment) increases with wind speed, while downwind dispersion also is expected to increase with wind speed, there is a clear indication that the worst case wind speed for determining vapor cloud exclusion distance will be an intermediate wind speed – very likely greater than 2 m/s. It was stated above that the LNGFIRE III model has already been required by DOT and NFPA to be used for the wind speed that will give the maximum thermal radiation exclusion zone. The vapor cloud dispersion zone determination should also be required to be made at the wind speed that would give the maximum exclusion zone extent.

3. The potential

There has been little or no interest by any of the applicants for import terminals in using FEM3A to determine the exclusion zones for spills into impoundments, although it was designed and verified for that purpose. We have observed that the continued use of SOURCE5 with subsequent input to DEGADIS, is expected to underpredict the vapor cloud exclusion distance for spills into impoundments. In some applications with which one of us (Havens [12]) is involved, there have been claims from the applicant that they were given *provisional* permission by DOT to perform the calculations using SOURCE5 described above. That “provisional” permission appears to have been given (by DOT) in the mid-1980s (with the implied caveat that permission was granted only until the research program designed to solve this problem was complete), but it continues to be used today, even though the completed and widely reported research clearly indicates that the assumption of no air mixing is in error.

Although it appears that the industry is being permitted by FERC to use practices that have been demonstrated to be incorrect, the motivation may be understandable, if disconcerting – as they appear to be using this failed methodology in many cases to simply calculate their problem away, however incorrect the methodology. It appears that the industry is not much interested in increased utilization of computational fluid dynamics (CFD) models for this application, which has been proven by extensive wind tunnel and field test research. It is worth noting that CFD models have been used in the consideration of safety issues for offshore facilities. Whether simulating onshore or offshore LNG release scenarios, a CFD model should undergo verification of its theoretical and numerical foundation as well as validation by comparison with *relevant* wind tunnel and field test research.

But the irony is profound for siting of land-based facilities, because it is widely accepted in the scientific community that CFD models probably hold the key to the determination of optimal designs of tank/dike systems that minimize the resulting hazard extent should a spill occur, and also are the best means available for considering mitigation measures that could be applied to reduce those hazard extents. It appears that the applicants are taking a myopic and short-term view of the situation. This is neither good science nor good business practice.

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