



**U.S. Department of Transportation
Pipeline and Hazardous Materials Safety
Administration**

PHMSA's mission is to protect people and the environment by advancing the safe transportation of energy and other hazardous materials that are essential to our daily lives. To do this, PHMSA establishes national policy, sets and enforces standards, educates, and conducts research to prevent incidents.

Historically, most LNG facilities were peak shavers built to liquefy and store natural gas to be degasified and injected back into the pipeline during periods of peak demand. Today's LNG facilities are being constructed to serve different purposes. Small scale facilities produce LNG for vehicle fuel, industrial use, and to supply satellite natural gas systems. However, due to the recent abundance of domestic shale gas, LNG export terminals are now being constructed that liquefy vast volumes of natural gas. These facilities require significantly greater quantities of refrigerants to liquefy the natural gas than the amount typically used at a peak shavers or small scale facilities. Most refrigerant gases and blends used at the export facilities contain ethane, propane, ethylene, and iso-butane and are referred to as heavy hydrocarbons. These gases are similar to gases that have resulted in VCEs at petrochemical facilities. However, PHMSA is not aware of any reliable reports of explosions of outdoor vapor clouds of natural gas and does not believe that there is a risk of vapor cloud explosions (VCEs) due to a release of methane in an open area.

The understanding of VCEs is evolving. PHMSA recognizes that significant quantities of heavy hydrocarbons present different risks than methane¹ and seeks to better understand that risk. Prior to investigative work on the Buncefield accident, the prevailing understanding was that vapor clouds formed outdoors were unlikely to explode if ignited. Today it is understood that VCEs involving higher hydrocarbons have occurred in outside areas. This paper advances our understanding further.

PHMSA sponsored the *Review of Vapour Cloud Explosion Incidents* report with the primary objective to improve the scientific understanding of vapor cloud development and explosion in order to more reliably assess hazards at large Liquid Natural Gas (LNG) export facilities. It is important to note that today's LNG export facilities have many layers of protection that were not in place at the facilities in the report. Many lessons learned from these events have resulted in safety measures that are required in LNG facilities today. The aim of reviewing the particular incidents in this report is the extensive forensic evidence available that provides the information needed to study how the vapor cloud formed and ignited, the amount of overpressure exerted, and other information about the mechanism of VCE.

This research was performed by the Health and Safety Laboratory (HSL) under a subcontract with the Oak Ridge National Laboratory, a United States Department of Energy (DOE) facility, and was supported by the United States Department of Transportation Pipeline and Hazardous Materials Safety Administration (DOT PHMSA) Office of Pipeline Safety (through an Interagency Agreement between DOT PHMSA and DOE) and the United Kingdom Health and Safety Executive (HSE). The research's objective was to improve understanding of vapor cloud development and explosions in order to more reliably assess hazards and safety measures at facilities that contain significant quantities of heavy hydrocarbons.

The technical review of the report was performed by uncompensated subject matter experts from the National Fire Protection (NFPA) *59A Standard for the Production, Storage, and Handling of Liquefied Natural*

¹ While some peak shaving and small scale facilities may contain heavy hydrocarbons, it is believed that they do not store sufficient quantities of them to consider VCE a viable risk. Additionally, many small scale LNG facilities use nitrogen expansion for the liquefaction process. Nitrogen is non-flammable and non-reactive.

Gas (LNG) committee, engineering and risk consultants, and federal governmental entities including the Federal Energy Regulatory Commission (FERC), the Chemical Safety Board (CSB), Homeland Security Studies and Analysis Institute, the Federal Railroad Administration (FRA), the Department of Energy (DOE), and Oak Ridge National Laboratory (ORNL). The purpose of this independent review was to provide candid and critical comments to make the report as sound as possible. The review, comments, and draft manuscript remain confidential to protect the integrity of the deliberative process. The panel reviewed multiple drafts of the report, held several conference calls, and convened a meeting on May 17th in Washington, D.C. A presentation about the draft report was given at a public meeting, PHMSA's Public Workshop on LNG Regulations, on May 19th, 2016, in Washington, D.C. Members of the public are provided opportunity to comment on the report through the Federal Docket PHMSA-016-0005. PHMSA will continue to present information about this project in open meetings.

PHMSA administers the federal regulation of the safety of gas and hazardous liquid pipelines and liquefied natural gas (LNG) facilities in the pipeline safety laws (49 U.S.C. §§ 60101 et seq.). PHMSA uses its authority to prescribe the pipeline safety regulations, a set of minimum Federal safety standards for the design, construction, testing, operation, and maintenance of such facilities (49 C.F.R. Parts 190-199). Chapter 601 also provides the statutory basis for federal delegation to the States for responsibility for certain LNG facilities through annual intrastate certifications and agreements and interstate agent agreements with PHMSA. PHMSA and States regulate more than 110 LNG facilities operating in the U.S.

The federal safety standard for LNG facilities is CFR 49 Part 193 Liquefied Natural Gas Facilities, which substantially incorporates by reference technical standards including the National Fire Protection Association (NFPA) *59A 2001 Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)* for siting, design, construction, equipment, operations, and fire protection of LNG facilities. Together they represent requirements for many layers of protection from risks inherent in LNG facilities.

NFPA 59A addresses risks of heavy hydrocarbons (i.e. flammable refrigerants and flammable liquids) through many prescriptive requirements and in a performance based requirement in section 2.1.1 (d). In this section, operators must consider 'other factors' that may impact plant personnel and surrounding public. The risk of VCEs of heavy hydrocarbons is a relevant 'other factors' at LNG export terminals. Operators must evaluate potential incidents and safety measures incorporated in the design or operation of the facility. For example, Part 193 and NFPA 59A prescriptively define the tolerable risk to and safety distance from the public due to LNG fires and vapor clouds in Parts §193.2057 and §193.2059. However, the code does not define a tolerable overpressure or safety distance from the public of a VCE of heavy hydrocarbons.

There is still much to learn about VCEs, and PHMSA will use the findings from this research to evaluate the sufficiency of Part 193, NFPA 59A, and the other standards incorporated by reference to prevent and mitigate VCEs. The HSL created an electronic database to store the primary source information used in drawing conclusions. This information is available to the public, regulators, code developers, and industry on PHMSA's website. PHMSA encourages the LNG industry and the scientific community to continue work on this important issue to further its understanding and to develop a body of experimental test data to improve consequence modeling and risk assessment of VCE.