Direct Testimony

of

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Mr. Chairman, Mr. King, Members of the Committee, it is a privilege and high honor for me to be invited to testify and share my knowledge on liquefied natural gas (LNG) safety related to accidental or intentional breach of cargo tanks in a LNG vessel.

1   Introduction

I come before you as a researcher in the field of LNG safety with over 30 years of experience in conducting experiments, analyzing the test results and developing mathematical models for the behavior of LNG upon its release into the environment and the hazards it may pose. My research projects related to LNG have been funded primarily by US Federal agencies (US Coast Guard and US Department of Transportation) and to a lesser extent by the LNG industry. I was one of the members of the research team (and the principal author of the technical report) that conducted the field experiments in mid 1970s to understand the different behavior phenomena associated with the release of LNG on water, including that of the pool fire on water and its radiant heat emission characteristics. This series of tests, which to this day remains as the only comprehensive set of experiments on water, was funded by the United States Coast Guard, and conducted in the US Navy testing facility in China Lake, CA. Many of the mathematical models used today are in one way or other based on the findings from this series of tests, though the test sizes were of a modest scale compared to sizes of postulated spills to which the models are being applied now. My recent research, sponsored jointly by the Pipeline & Hazardous Materials Safety Administration (PHMSA) of the US Department of Transportation and Distrigas of Massachusetts, LLC (DOMAC), has been to evaluate the data from the largest LNG fire experiment to date and model the characteristics of very large LNG pool fires and their radiant heat effects. This research and the model developed are based on the data from larger size LNG fire tests conducted in France in 1987. The model and the findings, which have been published in a peer reviewed technical journal, indicate that large LNG fires behave quite differently than the smaller scale fires (used in China Lake tests) and, in fact, radiate less heat per unit fire area. Other research that I am currently involved in includes the determination of the tolerance (without injury) of human beings to LNG fire radiant heat exposure, and the degree of protection provided by ordinary civilian clothing and other intervening objects to the public from the effects of radiant heat from a large LNG fire.

In my capacity as a scientist and researcher in the field of LNG behavior modeling, I have (i) provided consulting support to the Government agencies, the LNG industry, Standards setting bodies, (ii) testified before administrative and regulatory proceedings, (iii) presented many scientific research findings before peer groups, responded to the safety questions from the public in public hearings, (iv) trained firemen and first responders on the properties and behavior of LNG, and (v) authored a number of technical publications in reputable journals. I also serve on the LNG Standards Committee of the National Fire Protection Association (NFPA), which has developed a consensus standard on LNG facility design, LNG handling and storage, and personnel training requirements. Parts of this standard, especially on LNG fire hazard assessment and protection, have been incorporated in federal regulations.

I review below some of the important questions that have been raised in scientific forums and public debate on LNG behavior and safety and provide my views on the subject. My testimony below will:

(i)   Comment on the exemplary safety record of the LNG industry both in the US and worldwide

(ii)   Highlight some of the LNG properties that have an impact on potential hazards and compared them with properties of other common fuels,

(iii)   Discuss the knowledge related to what is known and unknown in mathematical modeling to predict adverse public impact distances from LNG releases,

(iv)   Identify immediate and near term research needs to fill the gaps in our knowledge, and,

(v)   Argue that results based on risk analyses and not those based on the consideration of a single scenario (however large the hazard) should form the basis of policy decision-making related to LNG activities. This discussion includes, briefly, the current LNG regulatory requirements in the U.S. and potential for improvements in assessment techniques that may lead to a more balanced and efficient use of resources.

2   Safety Record of the LNG Industry

LNG industry has operated safely both in the US and worldwide for over six decades. There is no technical or operational reason why this exemplary record will not continue. New technologies, application of results of careful research, and continued personnel training are expected to contribute to the enhancement of the safety record.

In the U.S., LNG has been used in peak shaving operations (liquefying pipeline natural gas during periods of low demand, storing the liquid, and re-gasifying it to meet peak demand, generally during winter months) for over 60 years. Trans-continental shipments of LNG in ocean-going tankers started in 1959. The worldwide demand for LNG has grown significantly since the 1960s and today over 150 LNG ships safely deliver the liquid to ports in many countries (including the US, Japan, France, et al) in some of the busiest and most congested ports of the world near population centers. The safety record of the LNG industry is enviable and unmatched by any other comparable industry – not a single injury or fatality to a member of the public for over 50 years and extremely low rates of injury even among the workers in the industry. Over 45,000 tanker shipments have occurred world wide to date, without any significant LNG spills (other than very minor leaks through pipe gaskets, overfilling of tanks, and spills during make and break of the unloading arms).

The industry is highly regulated in the US and has to meet very strict mechanical design, personnel training and low public impact standards. The ships are built to international standards, are of double hull design (and have been from the very beginning of the industry). The US Coast Guard inspects every LNG vessel that visits a US port before it enters the port. This inspection includes a check of safety emergency systems, interview with personnel, review of ship's records and a security assessment. In addition, the US Coast Guard (specifically, USCG Sector Boston) has mandated certain exclusion zones in the fore, aft and sides of an LNG ship in transit to minimize collision risks with other vessel traffic in the port. The shore-based operations and facilities of LNG terminals come under the purview of the US DOT regulations and are inspected annually for safety. In addition, the design of storage tanks and other systems in the facility have to conform to the industry consensus standard, namely, the National Fire Protection Association's "Standard for the production, Storage, and Handling of Liquefied Natural Gas,

(NFPA 59A)." The DOT regulations also stipulate the training requirements for industry personnel. Last but not the least, every one of the LNG terminal facilities in the US has to prepare and follow a security plan to thwart any potential sabotage or terrorist acts. This level of scrutiny and regulatory oversight, in addition to the industry's self interest to operate extremely safely, has been the principal cause of the safety success story. As mentioned earlier, no other energy industry has such an outstanding safety record. However, the price for an exemplary safety record is eternal vigilance, personnel training and implementation of advanced technologies.

3   LNG properties that have an impact on potential hazards and comparison with properties of other common fuels

LNG burning properties are not very different compared to similar properties of other commonly used hydrocarbon fuels. Large LNG fires will be very similar in radiant heat emission characteristics to large fires of propane, gasoline, jet fuel, etc.

LNG is natural gas cooled at atmospheric pressure to a low temperature of –260 ^{o}F. It consists, mainly, of methane and few percent by volume of ethane and propane and traces of other hydrocarbons and nitrogen. Methane is a member of the saturated hydrocarbon group of chemicals, which includes ethane, propane, butane, pentane, octane (the principal constituent of gasoline). Each molecule of a hydrocarbon fuel consists of carbon and hydrogen atoms combined in specific proportions. The combustion properties of all hydrocarbon fuels are very similar. For example, the heat produced when a pound of any one of these saturated hydrocarbons is burned in air[1] is the about the same, namely 20,000 Btu (within ± 5%). Also, the pounds of air required to burn completely one pound of any of these fuels are also about the same, namely, 15.5 (± 3%), except for methane, which requires a larger quantity of air. The consequence of the similarity in combustion properties is that the fires all of these fuels should have, within ± 100 ^{o}F, the same temperature, methane fires being the least hot. This observation has been demonstrated by carefully conducted laboratory experiments with different fuels.

The implication of the above observation is that methane (LNG) fires are no different in temperature than other fuels that the industrial society uses. All fires emit heat in the form of radiant heat ("infrared radiation") and the amount of energy emitted is dependent on the fire temperature. The question, therefore, is why methane (or LNG) fires are considered to be more "hazardous" or "hot?" This has to do with one additional phenomenon that occurs in burning, namely, production of soot particles (unburned carbon) in a fire. The higher the number of carbon atoms in the fuel molecule (as in gasoline or diesel fuel) the greater is the production of soot particles during the process of burning. That is, a methane fire will, all other conditions being the same, produce a smaller amount of soot in a given size fire than in a fire burning a heavier oil. The soot particles produced tend to form a mantle or shroud around the fire. The larger the density of the soot particles in the mantle, the higher is the absorption of the radiant heat emitted from inside the fire and the lower is the magnitude of the heat emitted to the surroundings. The soot layer acts as a "heat blocker" much the same way as a smoked glass does to visible light. In the case of smaller fires, this blocking of heat emission is smaller because of

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[1]   In sufficient quantity of air which contains the chemically required amount of oxygen to react with the hydrocarbon for complete combustion (called the "stoichiometric" amount).

the lower soot amount produced. The fire from the burning of methane -which has a single carbon atom in the fuel molecule and which produces the least amount of soot- will therefore appear "brighter" or "hotter" to an observer outside the fire. However, as the methane fire size increases a lot more soot is produced, forming a black shroud around the fire, like fires of "heavier" hydrocarbons.. This reduces the overall radiative heat emission to the outside. Therefore, when the fire sizes become large (such as hundreds of feet in diameter), the distinction between fires of different hydrocarbon fuels tends to diminish and they all look about the same (with small differences in the amount of radiant heat emitted to the outside). That is, LNG is clean burning in relatively small size fires but as its size becomes large it burns "dirty." Exhibit 1 shows a 14 m diameter LNG fire on water observed in the tests conducted at China Lake. The smoky aspects of a large LNG fire is seen in Exhibit 2, which shows the 35 m diameter LNG fire in the tests conducted in 1987 at Montoir, France. The latter fire is the largest LNG fire tested to date.

4   Immediate and near term research needs to fill the gaps in our knowledge

4A   What is known and unknown in mathematical modeling to predict adverse public impact distances from LNG releases

The models that are being currently used in LNG hazard assessment have layer upon layer of conservative calculations, making predicted distance to hazard substantially more than what it may be in reality. New sets of larger LNG pool fire tests and other equally important research will provide the necessary framework for the development of realistic models with which to assess the hazards from potential LNG release scenarios from ships.

To a large extent the fire hazard assessment models used currently are based on the data and findings from tests such as China Lake experiments. These test sizes were of a modest scale compared to sizes of postulated spills to which the models are being applied now. There is considerable uncertainly in the scale-up and applicability to larger LNG releases.

The extent of the potential hazard zone surrounding a LNG release depends upon a number of factors including the quantity and rate of LNG release, the location of release (onto water or land), the environmental conditions and mitigating circumstances and the type of behavior of interest (dispersion and subsequent ignition of a vapor cloud, a pool fire, or other type of behavior of concern). Our knowledge of and confidence in modeling some types of LNG behavior, even in the case of very large spills, are good and in other cases they are very limited or lacking. The gaps in our knowledge of applicability to larger LNG releases make it difficult to model the entire sequence of events as a system and estimate the magnitude of the final consequence.

There are four distinct steps in modeling the consequences of release of any hazardous material, including LNG. These steps include, (i) the quantitative description of the details of the source and the modification that the released material may undergo in the immediate vicinity of release location due to its interaction with air or water. (ii) the description of behavior of the released material in the environment (burning as a pool fire, dispersion of vapor in the atmosphere and later burning as a vapor fire, rapid phase transition-RPT, etc) and quantification of the hazardous

effects caused by the behavior, (iii) the enhancement or reduction of the hazardous effects due to interaction with the atmosphere and, finally, (iv) calculation of the effects on people or structures using the appropriate susceptibility criteria for such hazards (or alternatively, calculating the distance from the release where the hazards are below acceptable levels).

In the case of scenarios of potential LNG release from tankers, there are significant uncertainties and unknowns in the first step itself, namely source modeling. This has a significant impact on the overall hazard prediction. The calculation of the rate of discharge of LNG from a specified size hole on the side of a ship's tank is relatively straight forward, when such a hole is above the water line. Other phenomena may also occur, which substantially reduce the overall flow rate. One such is the creation of a vacuum condition in the tank leading to intermittent discharge ("glug-glug" type of flow as from an inverted bottle). Our knowledge to calculate the LNG outflow and the water inflow rate in the case the hole is either at or below the water line should be supplemented. The physics of mixing of LNG outflow with the water inflow, and mixing of water entering the tank with the LNG inventory in the tank (causing rapid evaporation and exacerbating the tank pressure condition), are some of the potential phenomena that have not been studied carefully. The calculations of how fast LNG comes out and in what form (liquid, vapor, liquid drops) are extremely difficult and full of uncertainties. Currently, there are no experiments to guide us to model the flow when the hole is at or below water line. Performing a chain of calculations using only a single scenario of release cannot be the last word on the extent of the public hazard, however conservative the assumptions may be. A whole spectrum of events and their consequences needs to be considered.

The GAO report has identified cascading tank failures due to heat or the contact of cryogenic liquid and carbon steel as another issue. The conditions under which these cascading tank failures may occur and resultant effects on the hazards are not clearly understood. Therefore, there are considerable uncertainties in describing the rate and quantity of LNG released and the form in which it may be released depending upon the locations and sizes of holes in the two hulls of the ship.

The vapor formed by the release of LNG (into or on water) is most likely to be ignited, close to the ship, from hot metals or electrical sparks (static or cut cables). In all current generation models it is assumed that all released LNG will form an expanding-vaporizing pool on the water surface sustaining a pool fire. Modeling the spread of the pool given the volume of the liquid LNG in the pool (or the rate of volume entering the pool) is reasonably well established. However, what is not known precisely is how much of the LNG flowing out of the tank actually pools on the surface. A large jet of LNG pouring out from an elevated hole plunging into water can penetrate the water column to a significant depth, fragment by both mechanical and thermal interaction with water, form small droplets of LNG most of which will vaporize[2] by the time they rise to the surface leaving only a fraction of the release to form a floating liquid pool. There are two main consequences of this. One is that the large vapor volume released could burn as a fireball near the ship. (A fireball puts out significantly higher heat (per unit area) but for a

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[2]   My own recent analysis of the phenomenon of a LNG jet plunging into deep water indicates that depending upon the LNG plunging velocity into the water surface 50% or higher fraction of the released liquid could vaporize in the immediate vicinity of the release leaving only a smaller volume of liquid to spread on the water surface.

considerably shorter duration than a pool fire). The second possible outcome is that the vapor produced within the water column together with the vapor produced by the spreading LNG pool on water burns in a pool fire. The diameter of this pool fire would be far less than if all released liquid pooled on the water surface. Both of these phenomena have direct effect on the calculated hazard distance. No experiments have been conducted to understand the effects of LNG jet plunging into the water and the consequent fireball, pool fire or other types of burning[3].

A fire poses hazards due to the emitted radiant heat. Radiant heat is the heat felt by a person (or an object) outside the fire and at some distance from the fire so that the heat is not due to direct contact with the hot gases in the fire. This is the "heat" that one experiences when facing a fire in a home fireplace. The radiant heat emission from a fire is generally quantified by a parameter called the "emissive power," which is the average amount of heat energy "leaving" a unit nominal surface area of the fire and is expressed in units of kW/m^2 or $Btu/hr\ ft^2$. The higher the emissive power the brighter a fire will appear and the farther one needs to be from the fire to be safe. The emissive power of LNG fires has been measured in relatively small-scale field tests. Most of these small fires burn bright (as seen in Exhibit 1). It is known that emissive power value is fire size dependent. A large body of current generation models used for LNG fire hazard distance evaluations assume that irrespective of the fire size the emissive power remains essentially the same (and high), leading to the prediction of uncomfortably large hazard distances from large spills of LNG.

As argued earlier (and shown in Exhibit 2), large LNG fires become smoky, very similar to other fuel fires. All smoky fires have a region close to the bottom where the smoke mantle has not formed and where the hot "bright" parts of the fire are visible from which can emanate high radiant heat fluxes. The height of this region decreases as the size of the fire increases. The black (cold) smoke mantle enveloping the fire absorbs the radiant heat emission from the inner regions of the fire resulting in substantially less radiant heat energy being released to the areas outside the fire. In the case of large LNG pool fire on water the burning regions close to the water could be hot but the overall emissive power will be less than that from a smaller size fire. In addition, the hot region close to the water will result in inducing high vaporization of water, locally. The water vapor thus formed just around the base of the fire may contribute to absorbing the radiant heat emission in addition to, being sucked into the fire and affecting the combustion chemistry to make the fire cooler and less radiative. None of these phenomena have been studied quantitatively in any controlled, large-scale experiments. We do not know how smoky very large LNG fires will be and what the height of the lower "bright' burning zone would be or what the mean emissive power will be. A theoretical model developed using the principles of combustion physics and validated against the best available data from the 35 m LNG fire experiments (the largest fire to date) seems to indicate that the mean emissive power of large LNG fires from ship spills may be only about 1/3 as radiative as smaller fires. If this is true, the hazard distances predicted from current models will have to be reduced by almost a factor of 2. Certainly, more research and large pool fire experiments on water are needed to get definitive data. I concur with the GAO recommendation on the need for this research.

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[3]   I, however, noticed in the China Lake tests that the higher the spill rate (in gpm) of LNG the higher was the burning rate, the taller was the fire and the quicker it went out.

Some people analyzing LNG hazards from ship releases are concerned with cascading failures of tanks due to external fires or interactions of the cryogenic LNG with metal structure of the ship. In fact, the GAO report recommends that research be conducted on this potential failure phenomenon. I agree with this recommendation, in principle, provided the types of research performed are realistic representations of the conditions following LNG release from a single tank. The heat from a pool fire may not result in further tank failures. The potential for cryogenic liquid-carbon steel interaction will depend upon a number of variables including the extent to which water is present, the location of contact between the hull plate and the liquid, whether such a contact will result in the immediate fracture of a part of the plate and the draining of the cryogenic liquid reducing the possibility of further contact, the engineered naval architectural designs that maintain the integrity of the ship structure even when a part of the structure fails, etc.

It is my opinion that heat from even a LNG pool fire impinging on the outer hull plate of the ship will be insufficient to cause further tank failures. This opinion is based on the following reasons; (i) there are at lest two historical records of incidents involving ships carrying refrigerated liquefied fuels which were exposed to intense and very long duration (hours) hydrocarbon fires impinging on the hulls and deck plates, yet suffered no failures of the cryogenic liquid tanks, (ii) the ships were of smaller size than current day LNG vessels; because of shorter dimensions, the smaller vessels are relatively more vulnerable to heat transfer from the fire to the tanks (and yet the tanks did not fail), (iii) the calculated lifetime of a LNG pool fire is of the order of minutes within which the total heat transfer to a massive ship structure would not affect the hull integrity (especially since the outer hull is also cooled by sea water), and (iv) the LNG and hydrocarbon fires have the same temperature as discussed earlier. The cases I cite are the incidents with "Yuyo Maru # 10" and the "Gaz Fountain."

In November 1974 the Yuyo Maru No10, a 47,300 m^3 tank capacity ship carrying refrigerated LPG in insulated tanks with ballast tanks filled with naptha (a fuel very similar to gasoline) was underway in Tokyo harbor. It was hit broadside by 15,500dwt steel products carrying ship "Pacific Ares," The collision resulted in one of the wing tanks of Yuyo Maru being punctured and releasing naptha on to both the water and the deck of the colliding ship[4]. The naptha pool ignited immediately and the resulting fire caused damage to both the LPG carrier and the colliding vessel. The naptha fire on the sea engulfed the ships for more than 4 hours. The LPG vapors were released through the normal relief valves and no boiling liquid expanding vapor explosion (BLEVE) occurred nor did a leak of liquid propane occur nor any tank failure.

The other incident refers to Gaz Fountain. This ship, designed to carry both LNG and LPG, was hit in the Persian Gulf during the Iran/Iraq war in October 1984 by three air-to-surface Maverick missiles, which caused extensive damage on the deck of the ship[5]. The ship at that time was carrying LPG. Intense and long lasting fire resulted on the deck. Propane vapors burned through a gash in the tank roof as a large vent fire. No tank failure or release of refrigerated liquid propane resulted nor did any of the tanks undergo a BLEVE type of failure.

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[4]   William de Barry Thomas, "Spectacle Blurs Issues," Hazardous Cargo Bulletin, p 23, October 1984.
[5]   J.A. Carter, "Salvage of Cargo from war damaged Gaz Fountain," paper presented at the 1985 Gastech Conference, Nice, France, 1985.

Other researchers have postulated the failure of LNG ship tanks due to fire heat exposure leading to a LNG tank explosion (due to BLEVE). As indicated above, no such explosions have occurred in tanks of ships carrying refrigerated liquefied petroleum gas (LPG) even after being subjected to intense fires on the outside. For a BLEVE to occur the liquid in a tank must be heated to temperatures well beyond its normal boiling temperature (and therefore higher pressure in the tank) and the tank has to be suddenly depressurized by, say, the sudden rupture of the tank wall. The rapid depressurization results in the production of large volumes of vapor, which may ignite and form a large fireball and the pressure waves created may hurl pieces of the tank to some distance. The higher the pressure in the tank at rupture the worse will be the effect of a BLEVE including the throw of the pieces of the tank to distances up to ¼ mile. BLEVE incidents have occurred in pressurized (LPG) rail tank cars or relatively small LPG storage tanks in which the pressure is normally about 105 psig and the tank will withstand pressures up to 375 psig before rupturing. Large tanks have not exhibited the BLEVE type of explosive rupture;The smaller the tank and the higher the pressure it can withstand the greater is the likelihood for the occurrence of a BLEVE.

One can conclude that a BLEVE is extremely unlikely in a LNG ship tank when one considers the conditions necessary for such an event to occur. First, the volume of liquid in each tank of a LNG carrier is large (25, 000 m^3). To heat such a massive amount of liquid to any temperature significantly higher than its normal boiling temperature requires significant amount of heat to be input. The calculated lifetime of a LNG pool fire (caused by the rupture of another tank) generally ranges from a few minutes to, at best, 15 minutes. Over this burning time it is difficult to transfer significant quantity of heat to the LNG in the tanks. Second, the LNG tanks are well insulated and separated from the outer hull by a large (at least 2 m wide) inter-hull ballast space, which impedes heat transfer from the fire to the tank wall. Third, the tanks are provided with relief valves, which will ensure that no significant rise in the pressure occurs. Further more, because of the size of the LNG tank the roof of the tank will not be able to withstand any significant increase in pressure () before being damaged. Last but not the least, actual experience with large ships carrying refrigerated fuels (LPG and butane) in tanks similar to those in LNG carriers indicates that even though they were subject to fires lasting several hours no BLEVE resulted. Therefore, in my opinion, the consideration of BLEVE as a potential public hazard phenomenon in the scenario of an accidental or intentional release from a LNG ship is addressing a non-problem.

4B   Areas that require additional research and why

Other research that may be as important as pool fire tests and modeling needs to be performed to determine the type and magnitude of other hazards, which may, under certain circumstances, become the dominant hazard scenario(s) rather than a pool fire. These include water-LNG interaction, water intrusion into LNG tanks and considerations of a fireball type of burning.

There are two most likely scenarios resulting from a large release from a LNG ship. These are (i) the formation of a LNG pool fire on water (initially expanding but reaching later a steady size) and, (ii) the potential formation of a large fireball type burning due to the immediate ignition of the large volume of vapor produced rapidly and locally from the LNG jet-water interaction. Whether such interaction could lead to localized and flameless rapid phase transition explosions,

(RPT), should be investigated. A RPT together with LNG jet penetration into the water column together with the occurrence of a RPT can result in a very large volume of vapor bring thrown high up in the air leading to the formation of a fireball if ignited. The recent GAO report has recommended the investigation of the radiant heat emission and smoke production characteristics of large LNG pool fires on water. I am in agreement with GAO on this recommendation. However, the results of a pool fire test series alone will not provide all of the knowledge required to perform a credible public safety assessment. Therefore, I recommend the conduct of the following types of experiments followed by modeling to properly estimate the potential hazard areas from different types of similar magnitude phenomena. (These recommendations are complementary to those of the GAO).

1   Large LNG pool fire of sizes up to 100 m in diameter on (deep) water– the objective of these tests should be to understand the variation of the fire dynamics, smoke production characteristics and radiant heat emission change from bottom to top of LNG fires as the fire size increases.

2   Plunging LNG jet interaction with water (of significant depth) to understand the phenomenon of depth of penetration, jet fragmentation, rate of vaporization and fraction of liquid spilled that will eventually pool on the water surface. This is an equally important phenomenon to consider since in some situations most of the spilled LNG may evaporate in the water column and the pool formed may be so small as to not pose significant pool fire hazard compared to, perhaps, other phenomena like a fireball type of burning.

3   Ignition tests with a plunging LNG jet into water to see if a fireball results (and if so the conditions under which it happens) or whether a fire similar to a pool fire but with substantially large fire plume results due to very high gas release rates in the "pool."

4   Viewing a LNG Pool fire (or even a large natural gas fire) from a distance of several hundreds of meters up to 2 km on a very large expanse of water and measuring the absorption of the radiant heat in the atmosphere. Current calculations of LNG heat absorption by the intervening atmosphere are based on the assumption that the fire radiates like an ideal black body. However, LNG fires are known to be band emitters of radiation in exactly the right frequency where the water vapor (and to some extent the carbon dioxide) in the atmosphere absorbs. Such a definitive test conducted on water will provide a basis for taking into consideration the beneficial (and mitigative) aspects of the atmosphere. Unfortunately, some of the models used in calculating hazard distances either incorrectly model the atmospheric absorption or do not consider it at all. Such omission is not excusable when the predicted hazard distances are in hundreds of meters (up to 2 km).

5   The interaction of the LNG outflow and the water inflow (simultaneously) to understand what may happen if the postulated hole location in the ship's tank is at or below the water line. The flow situation and the effects of large quantity of water intrusion into a tank filled with LNG are complex and need to be studied. Such a phenomenon may need to be considered in hazard calculations.

**5   Results from risk assessments rather than from a single postulated scenario should
         be the basis of policy decision making.**

Risk analysis as a tool is being increasingly utilized in the US for decision-making, but only in
bits and pieces. The single important reason for the lack of universal adoption of risk-based
decision making is the lack of standards for the levels of risk that are acceptable to society.

It is my opinion that policy decisions should be made after evaluating all possible scenarios of
releases, their likelihood of occurrence, the levels of consequences associated with each scenario
and considering the effects of either natural mitigation processes or man made technological or
procedural systems. Absent such an approach, the focus will always be on the largest, most
incredible types of releases, whether they have ever a chance of occurrence or not. Preparing for
and managing resources required to respond to emergencies involving events that occur with
very low probabilities is a misapplication of resources.

It is very commendable that the report by Sandia[6] recognizes that risk analysis must be the basis
of overall assessment rather than the consequences of a single worst-case event. In fact, this
report has provided a template on how one should perform a risk assessment; unfortunately,
since the process has not been quantified with a specific example, the public seems to be
focusing on the results from the theoretical assessment of the consequences only. Many other
federal agencies have long recognized the usefulness of risk-based approach. However, it has
been slow in "permeating" to the LNG industry regulations. The US Coast Guard requires the
performance of Waterway Suitability Assessment, for LNG ship passage to a port, based on a
risk consideration approach. The US DOT has in its Pipeline Integrity Management regulations
the requirements for performing risk based assessments. The NFPA LNG Committee is
considering providing, as an alternative Standard for compliance, a risk based standard[7]. The
European regulators have successfully used the risk-based approach to permitting LNG and other
petrochemical facility siting for over a decade.

One of the important recommendations I would offer this august body is to consider setting up
acceptability standards for levels of risk that are suitable for siting industrial activities and for
continuing such operations. Risk cannot be considered in a vacuum; it has to be based on
comparative scales. There is substantial body of literature on this topic.

7   Conclusions

   1   LNG industry has operated safely both in the US and worldwide for over six decades.
          There is no technical or operational reason why this exemplary record will not

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[6]   Hightower, M, L. Gritzo, A. Luketa-Hanlin, J. Covan, S.Tieszen, G. Wellman, M. Irwin, M. Kaneshige, B.
      Melof, C.Morrow, and D. Ragland, "Guidance on Risk Analysis and Safety Implications of a Large Liquefied
      Natural Gas (LNG) Spill Over Water," Sandia National Laboratory Rep.# SAND2004-6258, U.S. Department
      of Energy, Washington, DC, Dec 2004.

[7]   The full membership of this NFPA 59A Committee is considering this recommendation and verbiage provided
      by its sub-committee. If approved, this alternative standard would be incorporated into the 2009 edition of the
      NFPA 59A Standards.

continue. New technologies, application of results of careful research, and continued personnel training are expected to contribute to the enhancement of the safety record.

2   LNG burning properties are not very different compared to similar properties of other commonly used hydrocarbon fuels. Large LNG fires will be very similar in radiant heat emission characteristics to large fires of propane, gasoline, jet fuel, etc.

3   The models that are being currently used in LNG hazard assessment have layer upon layer of conservative calculations, making predicted distance to hazard substantially more than what it would likely be in reality. New sets of larger LNG pool fire tests will provide the necessary framework for the development of realistic models with which to assess the fire hazards from potential LNG release scenarios from ships.

4   Other research that may be as important as pool fire tests and modeling needs to be performed to determine the type and magnitude of other hazards, which may, under certain circumstances, become the dominant hazard scenario(s) rather than a pool fire. These include water-LNG interaction, water intrusion into LNG tanks and considerations of a fireball type of burning.

5   Focusing only on consequences of perceived worst cases rather than on the overall risk from an activity will result in poorly utilized and improperly allocated resources, not to speak of the economic penalties that may result.

6   Risk analysis as a tool is being increasingly utilized in the US for decision-making, but only in bits and pieces. The single important reason for the lack of universal adoption of risk-based decision making is the lack of standards for the levels of risk that are acceptable to society.

Mr. Chairman and Members of the Committee, I thank you for the opportunity to testify before your Committee.

Phani Raj, PhD.
President
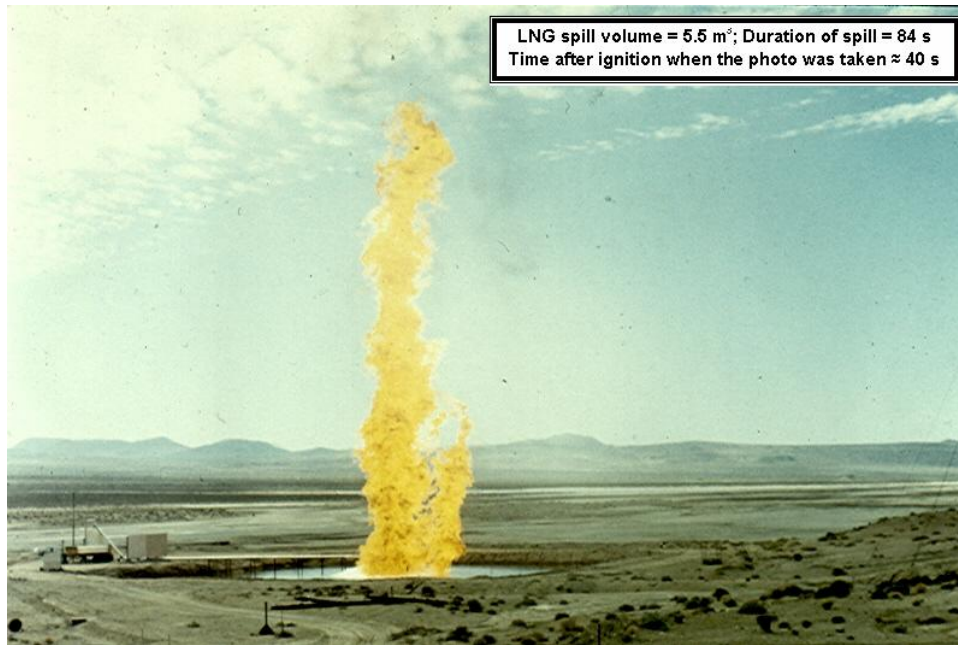Technology & Management Systems, Inc.
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Exhibit 1:   13 m diameter LNG pool fire on water

Exhibit 2:   35 m diameter LNG pool on an insulated concrete dike

Comparison of two LNG fires showing the effect of size on smoke formation (and consequent reduction in the magnitude of the emitted heat flux in the larger fire)