QUEST CONSULTANTS INC.®

October 2, 2001

Mr. Don Juckett
United States Department of Energy

VIA TELECOPY

Dear Mr. Juckett:

Quest Consultants Inc. has performed a series of release and dispersion calculations in an effort to quantify the potential flammable and radiant hazards following a release of liquefied natural gas (LNG). The releases were designed to simulate the "worst-case" dispersion and fire scenarios following large releases from a land-based LNG storage tank or a ship-borne LNG storage tank.

Several of the parameters defined in the analysis are listed below.

Composition of LNG	= 95% methane, 3% ethane, 2% propane
Pressure in storage vessel	= not to exceed 2 psig
Temperature of LNG	= -258°F

Land-based release scenario

Capacity of largest storage tank = 600,000 bbl (95,400 m^3)
Secondary confinement (diking) is available and remains intact following the release from the LNG storage tank.

Ship-based release scenario

Capacity of single storage tank = 25,000 m^3 (157,250 bbl)
This is the capacity of the single largest shipboard storage tank. Some LNG ships may have up to five tanks of this size on board.

Simulated hole diameter in storage tank = 5 m (16.4 ft) and 1 m (3.28 ft)

Atmospheric Conditions

Wind speed	= 1.5 m/s and 5 m/s for dispersion calculations
	= 9 m/s for pool fire radiation calculations
Relative humidity	= 70%
Air temperature	= 80°F
Water temperature	= 80°F

MAILING: P.O. BOX 721387 NORMAN, OK 73070-8069
SHIPPING: 908 26TH AVENUE NW, SUITE 103 NORMAN, OK 73069
TELEPHONE: (405) 329-7475 FAX: (405) 329-7734
E-mail: info@questconsult.com

Atmospheric stability = Pasquill-Gifford F (extremely stable) and Pasquill-Gifford D (neutral) [Atmospheric stability is classified by the letters A through F. In general, the most unstable atmosphere is characterized by stability class A. Stability A would correspond to an atmospheric condition where there is strong solar radiation and moderate winds. This combination of radiation and winds allows for rapid fluctuations in the air and thus greater mixing of the released gas with time. Stability D is characterized by fully overcast or partial cloud cover during both daytime and nighttime. The atmospheric turbulence is not as great during D conditions as during A conditions; thus, the gas will not mix as quickly with the surrounding atmosphere. Stability F corresponds to the most "stable" atmospheric conditions. Stability F generally occurs during the early morning hours before sunrise (thus, no solar radiation) and under low winds. The combination of low winds and lack of solar heating allows for an atmosphere which appears calm or still and thus restricts the ability to actively mix with the released gas.]

Flammable Dispersion Calculations

Release/dispersion calculations were made in order to examine the effect of atmospheric conditions and release hole size on the downwind travel of the flammable clouds. The dispersion calculations were performed until the lower flammable limit (LFL) was reached in the downwind direction.

The hazard zones resulting from the selected releases were evaluated to determine the extent and location of the flammable vapor cloud. When performing site-specific consequence analysis studies, the ability to accurately model the release, dilution, and dispersion of gases and aerosols is important if an accurate assessment of potential exposure is to be attained. For this reason, Quest uses a modeling package, CANARY by Quest®, that contains a set of complex models that calculate release conditions, initial dilution of the vapor (dependent upon the release characteristics), and the subsequent dispersion of the vapor introduced into the atmosphere. The models contain algorithms that account for thermodynamics, mixture behavior, transient release rates, gas cloud density relative to air, initial velocity of the released gas, and heat transfer effects from the surrounding atmosphere and the substrate. The release and dispersion models contained in the QuestFOCUS package (the predecessor to CANARY by Quest) were reviewed in a United States Environmental Protection Agency (EPA) sponsored study[1] and an American Petroleum Institute (API) study[2]. In both studies, the QuestFOCUS software was evaluated on technical merit (appropriateness of models for specific applications) and on model predictions for specific releases. A recent study prepared for the

[1]*Evaluation of Dense Gas Dispersion Models*. Prepared for the U.S. Environmental Protection Agency by TRC Environmental Consultants Inc., East Hartford, Connecticut, 06108, EPA Contract No. 68-02-4399, May, 1991.

[2]*Hazard Response Modeling Uncertainty (A Quantitative Method)*; Volume II, Evaluation of Commonly-Used Hazardous Gas Dispersion Models, S. R. Hanna, D. G. Strimaitis, and J. C. Chang. Study cosponsored by the Air Force Engineering and Services Center, Tyndall Air Force Base, Florida, and the American Petroleum Institute, and performed by Sigma Research Corporation, Westford, Massachusetts, September 1991.

Minerals Management Service [Gulf of Mexico OCS Region][3] reviewed models for use in modeling routine and accidental releases of flammable and toxic gases. CANARY by Quest received the highest possible ranking in the Science and Credibility areas. In addition, the report recommends CANARY by Quest for use when evaluating toxic and flammable gas releases. The specific models contained in the CANARY by Quest software package have also been extensively reviewed.

Results of the dispersion analysis are presented in Table 1. For the release scenarios, the maximum distances achieved would not remain at the maximum downwind distances for more than a few minutes. The cryogenic nature of LNG allows for a rapid vaporization rate at the beginning of the release event which then decays with time. As the vaporization rate starts to decay, the "size" of the cloud will begin to shrink and the hazard will begin to dissipate.

Table 1
Dispersion Results

Release From	Hole Size	Atmospheric Conditions	Liquid Impoundment?	Distance to LFL (ft) [miles]
600,000 bbl LNG tank	5 meters in diameter	1.5 m/s; F	yes	17,350 [3.25]
		5.0 m/s; D	yes	8,300 [1.6]
	1 meter in diameter	1.5 m/s; F	yes	5,740 [1.1]
		5.0 m/s; D	yes	1,010 [0.2]
25,000 m^3 Ship-borne LNG Tank	5 meters in diameter	1.5 m/s; F	no	13,375 [2.5]
		5.0 m/s; D	no	3,290 [0.6]
	1 meter in diameter	1.5 m/s; F	no	12,250 [2.3]
		5.0 m/s; D	no	2,570 [0.5]

It is important to keep in mind that several key assumptions are required in order for the flammable gas dispersion distances listed in Table 1 to be achieved.

Land-based release scenario

Whether the release is from a 5-meter or 1-meter diameter hole in the base of the LNG tank, the following conditions would have to be met.

1. The "hole" would have to be produced in the tank wall(s) in a manner such that no potential ignition sources were present in or around the release.

[3] *A Critical Review of Four Types of Air Quality Models Pertinent to MMS Regulatory and Environmental Assessment Missions*, Joseph C. Chang, Mark E. Fernau, Joseph S. Scire, and David G. Strimaitis. Mineral Management Service, Gulf of Mexico OCS Region, U.S. Department of the Interior, New Orleans, November, 1998.

2. The evolving gas cloud would overflow the dike walls, drift downwind under the atmospheric conditions specified, and not encounter an ignition source anywhere within its dispersion pattern in order to reach the maximum downwind distance listed.

Ship-based release scenario

Whether the release is from a 5-meter or 1-meter diameter hole in a single ship-based LNG tank, the following conditions would have to be met.

1. The "hole" would have to be produced in the tank wall(s) in a manner such that no potential ignition sources were present in or around the release.
2. The evolving gas cloud would evolve over the water surface and drift downwind under the atmospheric conditions specified and not encounter an ignition source anywhere within its dispersion pattern in order to reach the maximum downwind distance.

Fire Radiation Calculations

If the large release scenarios were to occur, the most likely outcome of such a release would be the near instantaneous ignition of the flammable vapors that would result in a rapid flash fire followed by a large pool fire. For the land-based scenario, the base of the flame is defined by the secondary containment (i.e., the diking around the storage tanks). In the case of a release onto the water, the size of the liquid pool, and subsequently the base of the fire, is defined by the rate at which the LNG spreads on the water surface. For the purposes of these calculations, the maximum LNG pool diameter on the water surface was used to define the base of the water-based pool fire.

Unlike dispersion calculations, the worst-case atmospheric conditions for pool fires are during high winds. The winds allow the flame to bend, thus moving the flame further downwind. This results in higher downwind flux levels than those achieved under low-wind conditions.

Pool fire radiation calculations were made in order to determine the distance to specified radiant flux levels following the ignition of the cloud when the liquid pool had reached its maximum size. Three radiant flux levels were chosen for evaluation. The definitions of the three levels evaluated are:

7,000 Btu/hr·ft^2 (22.1 kW/m^2) = At this flux level, structural steel weakens after prolonged exposure.

4,000 Btu/hr·ft^2 (12.6 kW/m^2) = At this flux level, the piloted ignition of wood is possible (the vapors evolving off the wooden structure would ignite).

1,500 Btu/hr·ft^2 (4.73 kW/m^2) = At this flux level, second-degree skin burns are possible after 30-second exposure.

The results of the pool fire analysis are presented in Table 2.

Table 2
Pool Fire Results

Release From	Hole Size	Atmospheric Conditions	Liquid Impoundment ?	Distance to Radiant Flux Levels* (ft)		
				7,000 Btu/hr-ft^2	**4,000 Btu/hr-ft^2**	**1,500 Btu/hr-ft^2**
600,000 bbl LNG tank	5 meters in diameter	9 m/s	yes	1,165	1,420	2,010
	1 meter in diameter	9 m/s	yes	1,165	1,420	2,010
25,000 m^3 Ship-borne LNG Tank	5 meters in diameter	9 m/s	no	1,020	1,260	1,770
	1 meter in diameter	9 m/s	no	835	1,020	1,420

*measured from center of pool

I believe this is the information you requested. Should you have any questions or require any other information, please give me a call.

Sincerely,

John B. Cornwell
Principal Engineer

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