QUEST
CONSULTANTS INC.®

October 3, 2001

Mr. Don Juckett
United States Department of Energy

VIA TELECOPY

Dear Mr. Juckett:

As you requested during our telephone conversation this morning, we are providing additional information on some of the modeling techniques and assumptions used in the evaluation of several LNG spills reported in our letter of October 2, 2001.

Perhaps the single most important issue to be addressed is the modeling of the release of LNG and its subsequent vaporization. In our modeling, we assumed that a one-meter or five-meter diameter hole would be made in either LNG storage vessel. Once the large diameter hole is present, LNG will rapidly drain out of the vessel. The larger the hole, the more rapid the vessel empties. However, any reasonably sized hole does not instantaneously empty the vessel. This is an important assumption for the following reasons.

> If an instantaneous release were to occur, the entire volume of LNG (either 600,000 bbls for the land based storage or 25,000 m3 for the ship based storage) would have to "slump" to grade. The only way this could occur is if the containment vanished without impacting the liquid.

There have been several instantaneous release, spreading, and vaporization models published over the years. Many are based on several similar assumptions and produce similar results. A short review of those models (identified by their primary author), and some of the results obtained are listed in Table 1. The results are for an instantaneous release of 25,000 $m^3$ (882,750 $ft^3$) of LNG onto water. A representative LNG vaporization rate of 1.0 inch/min was used in each model.

Table 1 lists the maximum radius of the liquid pool on water, the maximum vaporization rate of the LNG, and the total time that is required to vaporize the entire 25,000 $m^3$. Using the model by Fay as an example, the liquid pool would spread to a radius of 1,411 ft, and be completely vaporized in 5.3 minutes. It should be kept in mind that all the models listed are based on several small-scale experiments. Thus, the model predictions are well outside the available experimental data.

The last column in Table 1 defines the thickness of the liquid pool. This thickness was calculated by dividing 25,000 $m^3$ by the maximum pool area. This calculation assumes that none of the LNG vaporized before the pool reached its maximum radius. In short, if we make this assumption, then we would have a pool of LNG 2,822 feet in diameter and 1.7 inches thick (Fay model results, assuming uniform thickness). In reality,

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

**Table 1**
**Summary of Instantaneous Spill Model Results**
**LNG Spreading on Water**

Spill volume = 25,000 $m^3$ (882,750 $ft^3$)
Evaporation rate = 1.0 inch/min (0.0382 lb/sec·$ft^2$)
LNG density = 27.5 lb/$ft^3$

| Model | Maximum Radiation (ft) | Evaporation Time (min) | Maximum Boil-off (lb/sec) | Thickness (inch)* |
|---|---|---|---|---|
| Fay | 1,411.0 | 5.3 | 238,897.0 | 1.7 |
| Hoult | 1,238.8 | 4.0 | 184,151.0 | 2.2 |
| Otterman | 1,289.7 | 6.3 | 199,597.7 | 2.0 |
| Raj/Kelelkar | 1,255.8 | 4.5 | 189,230.8 | 2.1 |
| Muscari | 1,539.2 | 5.4 | 284,277.0 | 1.4 |

* Calculated as total volume divided by maximum area covered.

the thickness would be less since some of the LNG would have vaporized before reaching the maximum radius. If the liquid pool were to have variable thickness (i.e., thicker in the center and thinner at the edges), then the thickness at the edges would have to be very thin indeed. As you can see from Table 1, all five of the instantaneous release, spreading, and vaporization models produce similar results.

A direct result of using such a model is the use of extremely high vaporization rates. As we discussed, a large body of water such as an ocean or bay would be considered an infinite heat source. The water would be able to transfer heat to the LNG pool for an unlimited amount of time. The maximum vaporization rates listed in Table 1 would occur when the pool reached it maximum radius. These extremely high rates (up to 142 tons per second) are the inputs into the dispersion models.

This is one of the main reasons the earlier studies employing DEGADIS and other models produced such large dispersion distances to the LFL. Although DEGADIS and other heavier-than-air dispersion models were developed and tested against much smaller test programs involving releases of LNG (e.g., 40 $m^3$ of LNG), there isn't anything that would preclude their use in this application.

Quest's release, spreading, and vaporization models are not based on an instantaneous release of LNG. The models calculate the rate at which the LNG drains out of the one- or five-meter hole, spreads over the substrate, vaporizes, and cools the substrate (in the case of earthen or concrete substrates, thus altering the future heat transfer ability of the substrate). In the case of spills onto water, the water is treated as an infinite heat source. Work performed by the Safety and Reliability Directorate (SRD)[1] and others[2,3,4] has allowed us to develop a relationship between the volume of the LNG available at any instant and the shape of the liquid pool. The models have been tested against the available data and have performed satisfactorily.

When this model is used to calculate the vaporization history following a release from a five-meter diameter hole in a 25,000 $m^3$ tank onto water, the following results are found.

Maximum LNG pool diameter = 470 feet
Maximum LNG vaporization rate = 7,600 lb/sec

As you can see, this maximum vaporization rate is significantly less than those produced by the instantaneous models. This is the primary reason why the dispersion distances are shorter than those that would be predicted if the vaporization rates in Table 1 were used.

I believe this answers some of the questions you had. Please contact me if you require any additional information.

Sincerely,

John B. Cornwell
Principal Engineer

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[1] Shaw, P., and F. Brisco, *Evaporation from Spills of Hazardous Liquids on Land and Water*. . Safety and Reliability Directorate, United Kingdom Atomic Energy Authority, SRD R 100, May, 1978.

[2] Raj, Phani K., "Models for Cryogenic Liquid Spill Behavior on Land and Water." *Journal of Hazardous Materials*, Volume 5, 1981: pp. 111-130.

[3] Otterman, B., "Analysis of Large LNG Spills on Water - Part 1: Liquid Spread and Evaporation.." *Cryogenics*, Volume 15, August, 1975: pp. 455-460.

[4] Waite, P. J., R. J. Whitehouse, E. B. Winn, and W. A. Wakeham, "The Spread and Vaporisation of Cryogenic Liquids on Water." *Journal of Hazardous Materials*, Volume 8, 1983: pp. 165-184.