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An Analysis of the Risks of a Terrorist Attack on LNG Receiving Facilities in the United States

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An Analysis of the Risks of a Terrorist Attack on LNG Receiving Facilities in the United States



3-D Aerial View from Proposed SES LNG Receiving Facility Site to Downtown Long Beach [White line is 2 miles long.] Graphic produced by Google Earth.

Abstract:

The placement of liquefied natural gas (LNG) receiving facilities in areas of high population or critical infrastructure densities within the United States is a concern because such facilities house flammable materials in quantities sufficient to be potential targets for terrorism. Mitsubishi has proposed the development of an LNG receiving facility in Long Beach, California, the state's fifth most populous city. A comprehensive risk analysis is needed to evaluate the impacts of this facility on this major urban area. This paper presents a terrorism risk analysis that includes an examination of the Pareto optimality of siting, containment, and defense options based on the dominance-based fitness of expected losses versus conditional expected losses, looks beyond the specific Long Beach problem to the potential national threat of LNG receiving facilities and terrorism generally, and provides national policy recommendations with respect to the siting, containment, and defense of LNG receiving facilities.

Carl Southwell
University of Southern California
November 9, 2005

Introduction

The renewed interest in establishing liquefied natural gas (LNG) receiving facilities in the United States (U.S.) arises from the opening of the Trinidad LNG liquefaction plant in 1999, the continuing increase in demand for natural gas in the U.S., and the resurgence of U.S. natural gas prices since 2000. As a result, two mothballed LNG receiving terminals were reactivated in 2001 and 2003, interest in siting and building new U.S. LNG receiving facilities has intensified, and the Energy Policy Act of 2005¹ has paved the way to relatively streamlined approvals of proposed LNG receiving terminals. For example, Sound Energy Solutions (SES), a subsidiary of Mitsubishi Corporation, has applied² to construct, install, and operate an LNG receiving facility on 25 acres of Pier T in the Port of Long Beach, California. This proposed facility would be approximately two miles from downtown Long Beach, a densely populated coastal city with a population approaching 500,000.

Despite an intensification of demand and the desire to build such facilities adjacent to large population centers (and customer bases), the siting of LNG receiving facilities continues to be a concern because LNG is a hazardous material. The primary safety concerns about LNG arise from the potential consequences of an LNG spill.³ The extreme cold of LNG can directly cause injury or damage such as freezer burns from dermal contact or the cracking of certain metals, such as copper or steel. Exposure to an LNG vapor cloud, although non-toxic, can cause asphyxiation due to the displacement of oxygen. Moreover, LNG vapor clouds can ignite in the presence of an ignition source within any portion of the vapor cloud where the concentration of natural gas is between five and 15 percent of air by volume. An ignited LNG vapor cloud is very dangerous because of its tremendous radiant heat output. As the vapor cloud burns, its flame could burn back toward the evaporating pool of liquid, ultimately burning the quickly evaporating natural gas immediately above the pool giving the appearance of a burning pool or “pool fire.” An ignited vapor cloud or a large LNG pool fire can cause extensive damage to life and property.

It is important that LNG receiving facility safety and security issues be defined clearly in terms of decision and cost-benefit analyses. For LNG receiving terminals, the economic benefits of a

relatively cheap and reliable source of natural gas are clear. The confounding questions that remain for its neighboring residents and businesses are “*What is a reasonable worst case fire as a result of an intentional LNG spill?*” and “*What are its negative consequences?*” For these reasons, it is vital that risk analyses supplement traditional cost-benefit analyses.

Proposed U.S. LNG receiving facility projects require detailed risk assessments to design and develop site-specific, comprehensive risk management plans. This work involves the modeling of potentially hazardous situations, including ship movements, vapor cloud dispersions, pool fires, and deliberate attacks such as terrorist events. Such risk assessments include three-step processes—hazards assessments, expected loss assessments, and conditional expected loss assessments. *Hazard assessments* for LNG facilities identify shipping-related and land-based risks. *Expected loss assessments* attempt to determine the likelihood of specific events⁴ happening based on the history of mechanical failures, accident rates, and other factors such as the probability of a terrorist event. Negative events are evaluated in terms of their probabilities of occurrence. In practice, significant potential risks are justified as acceptable because the likelihood of these risks occurring is sufficiently small (e.g., one in one million) as to be considered nearly implausible. Finally, *conditional expected loss assessments* [i.e., worst-case events (given that the events have occurred)] are evaluated to determine the potential for severe consequences such as loss of life, injury, and property based on site- and situation-specific decisions.

In this essay, we explore the final two stages of this process—an *expected loss assessment* and a *conditional expected loss⁵ assessment*—for the proposed Long Beach SES LNG Receiving Facility as well as siting and defense options. A juxtaposition of expected losses versus conditional expected losses based on various siting and defense options will define a border of Pareto optimal options based on their dominance relationships. In addition, we will provide some examples that consider the technology transference effect and more widespread impacts of this examination in evaluating the Everett (Boston, MA) Distrigas LNG Receiving Facility and the Providence (RI) KeySpan LNG Receiving Facility.

From a public policy perspective, the value of these analyses is two-fold: given certain expectations of a high severity and low frequency negative event. First, is the siting of each facility appropriate? Second, are there countermeasures or an alternative siting with respect to each facility that might be more appropriate? Within such a delimited decision arena, a severity scale of sites can be constructed, and a bordereau of recommendations concerning LNG containment, siting, and defense countermeasures can be crafted.

Defining the Problem

What is LNG?

LNG is the natural gas used in residences and businesses everyday [basically, methane (CH_4) with small proportions of other, heavier flammable gases such as ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), and even smaller proportions of inert gases and water], except that it has been refrigerated to minus 259 degrees Fahrenheit at which point it has become a clear, colorless, and odorless liquid. As a liquid, natural gas occupies approximately one six-hundredth of its gaseous volume and can be transported relatively economically between continents in special tankers. And, LNG weighs slightly less than half as much as water, so it floats.

When LNG comes in contact with any much warmer surface such as water or air,⁶ it evaporates very rapidly (“boils”), returning to its original, gaseous volume. As the LNG vaporizes, a vapor cloud resembling ground fog forms under relatively calm atmospheric conditions. The vapor cloud is initially heavier than air since it is so cold, but as it absorbs heat, it becomes lighter than air, rises, and can be carried away by the wind. An LNG vapor cloud cannot explode in the open atmosphere, but it can burn when it constitutes between five and 5 percent of air by volume and in the presence of an ignition source.

History of LNG

LNG dates to 1873 when British scientist Michael Faraday experimented with liquefying different types of gases, including natural gas, and German engineer Karl Von Linde built the first practical refrigeration compressor. The first LNG plant was built in West Virginia in 1912 and began operation in 1917. The first commercial LNG plant was built in Cleveland, Ohio, in 1941.⁷

The liquefaction of natural gas enabled the possibility of its long-range transport. In January 1959, the world’s first LNG tanker, *The Methane Pioneer*, a converted World War II liberty freighter, carried an LNG cargo from Lake Charles, Louisiana, to Canvey Island, United Kingdom. This event demonstrated that LNG could be transported safely across the ocean. Following the success of *The Methane Pioneer*, the British Gas Council implemented a commercial project to import LNG from Venezuela, but, nearly simultaneously, natural gas fields were discovered in Libya and Algeria—only half the distance to England as Venezuela. Thus, with the start-up of the 260 million cubic feet per day (MMcfd) Arzew GL4Z field in 1964, the United Kingdom became the world's first LNG importer nation and Algeria the first LNG exporter nation.

Soon, additional LNG liquefaction plants and import receiving terminals were constructed. Four marine terminals were built in the United States between 1971 and 1980. These facilities are in Lake Charles, Louisiana, Everett, Massachusetts, Elba Island, Georgia and Cove Point, Maryland. After reaching a peak import volume of 253 billion cubic feet (Bcf) in 1979 that represented 1.3 percent of U.S. gas demand, LNG imports declined because of gas surpluses in North America and price disputes with Algeria. The Elba Island and Cove Point receiving terminals were closed in 1980, and the Lake Charles and the Everett terminals had very low utilization. Currently, there are five LNG receiving facilities in the United States (see **Exhibit 1**).

Exhibit 1

Current U.S. LNG Receiving Facilities and their Annual Gas Imports (in Billions of Cubic Feet)⁸

Facility Importer(s)	Location	Annual Current Import Capacity (Bcf)
Distrigas	Everett, Massachusetts	191
Southern Energy Company	Elba Island, Georgia	111
BG LNG	Lake Charles, Louisiana	133
BP Energy/Shell NA LNG/Statoil LNG	Cove Point, Maryland	234
Excelerate Energy, LLC	Gulf of Mexico (116 miles offshore of Louisiana)	248

Modern LNG Transport and Receiving Facility Design

LNG spill prevention and response are major factors in the design of LNG tankers and receiving facilities. LNG tanker and receiving facility design features safety and security.

Tankers

Ocean-going tankers transport large amounts of LNG from liquefaction plants⁹ to receiving terminals. These ships are equipped with up to five LNG-cargo tanks housed inside double-walled hulls. Each cargo tank can store thousands of cubic meters of LNG. These ships are up to 1,000-foot long and require a minimum water depth of 40 feet.

LNG tankers are equipped with specialized systems for handling the cryogenic gas and for addressing the hazards associated with spills and fire. The ship's safety systems are divided into *ship handling* and *cargo system handling*. The ship-handling safety features include radar and GPS that alert the crew to other traffic and hazards around the ship, and automatic distress systems and beacons that transmit signals if the ship is in trouble. Cargo-system safety features include an instrumentation package that shuts down the system if it operates out of predefined parameters and gas- and fire-detection systems.

Receiving Terminals

Shore-based LNG terminals—consisting of a docking facilities, LNG-storage tanks, LNG-vaporization and odorization equipment and vapor-handling systems—occupy approximately 25 to 40 acres of land apiece. The location of an LNG terminal requires roads, electric transmission lines, and gas and water lines. The docking facility must be designed to accommodate the sizes of the anticipated LNG tankers. It usually consists of a pier or jetty about 1,800-foot long and 30-foot wide with moorings and off-loading facilities. Moorings connect the tanker securely to the jetty so that the LNG can be transferred from the ship's tanks to the onshore piping.

While unloading their cargoes, LNG tankers are subject to tidal, wind, and wave forces that can jeopardize the integrity of the ship-to-shore interface. Thus, LNG ports and jetties must have built-in safety features to prevent releases of LNG during these transfers. A ship-to-shore emergency shutdown (ESD) system and associated shut-off valves allow rapid and safe shutdown of an LNG

transfer. An ESD system will stop the ship's unloading pumps and close flow valves both on the ship and shore within 30 seconds. Moreover, quick-release couplings automatically disconnect the unloading arms during emergencies.

Transfer piping used to unload the cryogenic liquid from the ship's tanks can withstand up to a 360 degree Fahrenheit temperature drop once LNG pump-out begins. Normally, the cryogenic piping is made of stainless steel with a nine-percent nickel content. Expansion loops and expansion bellows are built-in safety features that compensate for pipeline contraction.¹⁰

LNG is stored on land in specially designed storage tanks while it awaits regasification. The failure of one or more tanks can release an enormous volume of LNG (e.g., more than 100,000 cubic meters) with potentially disastrous consequences due to the size of the resulting vapor cloud and potential fire. Over time and in response to this hazard, the design of modern storage facilities has improved from earlier designs.¹¹

Three types of LNG storage tanks are used today as follows:

- 1 **Single-containment** tanks are double-walled. An interior tank is made of nine percent nickel with an outer tank made of carbon steel.
- 2 **Double-containment** tanks have a primary nine percent nickel tank and a secondary tank. The secondary tank, typically a concrete wall, is located within twenty feet of the primary tank. In the event of a leak, the secondary tank contains the cryogenic liquid and limits the surface area and vaporization from the LNG liquid pool.
- 3 **Full-containment tanks** have a nine percent nickel inner tank, plus a pre-stressed concrete outer tank. The outer tank, which includes a reinforced concrete roof and floor lined with carbon steel, can be designed to withstand most impacts from missiles or flying objects. These modern storage tanks have no side or bottom openings. All penetrations, including those for LNG transfer, are through the roof. This design reduces the amount of LNG spilled in the event of a rupture or leakage.

In addition, LNG storage tanks contain instruments to monitor the pressure, temperature, and density of the LNG along the entire height of the liquid column, and in-tank cameras enable plant operators to assess tank damage, for example, in the event of an earthquake and to visually inspect the tank contents in the event of unusual instrument readouts.

Fire detection and response systems are also in place. Facility operators use low-temperature, gas, fire, and smoke detectors. Fireproofing of structures and equipment are mandatory safety features within LNG facilities.

LNG facilities are designed to assure adequate distances between LNG storage tanks, storage areas, jetties and docks, vaporization process areas, and other parts of the facility. LNG facilities have exclusion zones—the area surrounding an LNG facility in which an operator legally controls all activities. These zones assure that public activities and structures outside the immediate LNG facility boundary are not at risk in the event of an on-site LNG fire or a release of a flammable vapor cloud. Federal regulations identify two types of exclusion zones: *thermal-radiation protection* (from LNG fires) and *flammable vapor-dispersion protection* (from LNG clouds that have not ignited but could migrate to an ignition source).

Thermal-radiation exclusion distances are determined by using the National Fire Protection Association (NFPA) standard for the production, storage, and handling of LNG, or by using a computer model that accounts for facility-specific and site-specific factors, including wind speeds, ambient temperature, and relative humidity. The required distances should assure that heat from an LNG fire inside the dikes, for example, would not be severe enough at the property line to cause death or third degree burns.

Safe distances from dispersing LNG vapor clouds are determined by the same NFPA standards or by a computer model (for example, ALOHA¹²) that considers average gas concentration in air, weather conditions, and terrain roughness. The permitting authority, the Federal Energy Regulatory Commission (FERC), in cooperation with the DOT-Office of Pipeline Safety and the Coast Guard,

determines the exclusion zones for LNG tankers and port facilities. In addition, the Coast Guard deploys sea marshals to oversee “high-interest vessels” such as LNG tankers.

Risk Analysis—A Conditional Expected Losses Approach

The Long Beach SES LNG Receiving Facility

A risk analysis of the Long Beach SES LNG Receiving Facility is a decision analysis of alternatives for Long Beach in terms of siting, hardening, and defense.

In Long Beach, SES has applied to construct, install, and operate LNG receiving facilities on 25 acres of Pier T in the Port of Long Beach, a LNG ship berth with LNG unloading arms and two full containment LNG receiving tanks, each with a gross liquid volume of 160,000 cubic meters (1,006,000 barrels), the regasified equivalent of 3.5 billion cubic feet (Bcf). The facility has two spheres or tanks containing LNG that are comprised of five layers. The first layer or the inner tank is “the primary containment barrier (...and) consists of 9% nickel/steel alloy.” The second important layer is the outer tank that is made of “3 feet of pre-stressed reinforced concrete, the strongest type of concrete available.” And, a 20-foot outer reserve wall “completely surrounds the LNG tank.” Our assumptions include an attack from a large jet such as a Boeing 717-class airliner¹³ or larger¹⁴ used as a missile projected into the containers or the docked LNG ship. To improve the probability of success from the terrorists’ points of view, two planes might be used. Any jet of comparable size and capable of comparable speed will likely be acquired out of Los Angeles International Airport (LAX), Long Beach Airport (LGB) or (less frequently, but with an increased probability of success) out of Torrance Zamperini Airport or Santa Monica Airport.

Probabilities of a catastrophic attack by terrorists are assumed to be correlated negatively and strongly with additional concentration on remote siting (with respect to the distance from the local built environment and population), hardening (as a barrier to intrusion by missiles or explosives), and aerial defense (as a deterrent to air assaults) of the facility. **Scenarios 1 through 6** model an aerial assault by terrorists on this facility utilizing differing decisions with respect to siting, hardening, and defense.

We modeled six possible fire scenarios resultant from various counter-terrorism preparedness decisions and planned terrorist attacks perpetrated by an Al Qaeda-like organization. The first two scenarios consider an attack on the actual, proposed Long Beach SES LNG receiving facility during different seasons, and the second four scenarios consider an attack at the proposed facility with altered siting, containment, and/or aerial defense countermeasures in the Long Beach harbor area and during different seasons. Based on the specific attack scenarios, simple cause-and-effect models were utilized. Essentially, each analysis was broken down into the following steps: First, the attack mode for the target includes an aircraft collision with a tank or a ship, the release of cryogenic liquid, and a fire. Second, prevention and mitigation efforts including, but not limited to, hardening of the facility, anti-aircraft technology, and remote siting of the facility or its LNG ship dock affected the probability of success or failure. Third, consequences of an attack included deaths, injuries, destroyed property, and business interruption economic damage.¹⁵

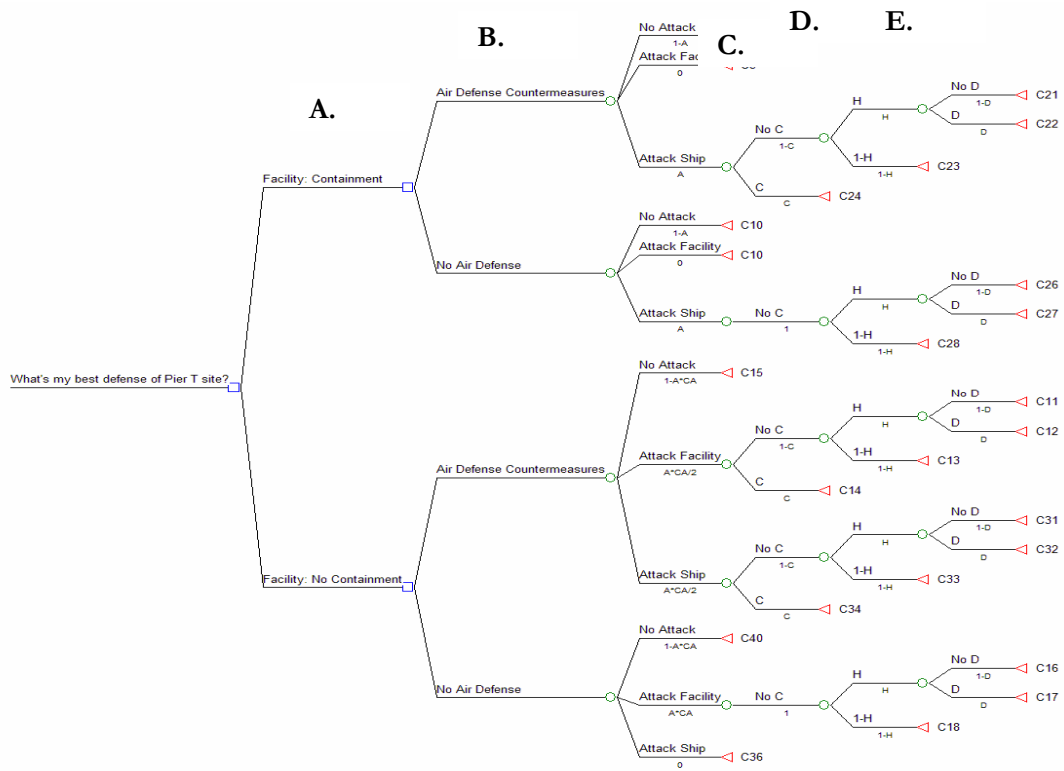
The procedures for estimating the worst-case consequences of a disaster at the Long Beach SES LNG receiving facility are relatively simple—(a) assume it is intentional (i.e., a terrorist event) and (b) assume it is catastrophic (i.e., a near-instantaneous complete release of the LNG due to trauma {e.g., using a jet as a missile to breach the LNG tanks}). Using the capacity of its LNG tanks as the spill size and assuming a catastrophic breach, we employed the software package CAMEO¹⁶ to model a 5% methane cloud's extent or thermal radiation exclusion distance, assuming typical, local atmospheric and landscape conditions. Our model assumes a leak from a ten-foot diameter hole in a spherical tank containing 200 million pounds of LNG.¹⁷ The resultant plume extends four miles from the LNG tank, covering the entire downtown Long Beach area and impacting thousands of residents and workers.

A rough estimate of potential damage can be calculated as a result of the potential vapor cloud fire (VCF). If the plume encounters an ignition source, then a VCF may result. VCF's are significant because, assuming no or limited confinement, there is the possibility of escalation. It is highly likely

that secondary fires may start as a result of the fire, and there is a significant probability that, following a VCF, there will be a steady fire.¹⁸

In order to evaluate the likeliest course of action by possible terror cells, we modeled a range of decision trees, sensitivity analyses including tornado diagrams, and CAMEO plumes to review the outcomes of various decisions. The decision trees represent the choices involved in an attack given employed countermeasures and, given these choices, the attacks' probabilities of success or failure. *For example, does choosing full containment of the LNG tanks matter with respect to the probability of an attack? Given that a facility's tanks are fully contained, does a terrorist choose to attack a docked LNG ship instead? If there's an air defense battery at the LNG facility, how does this affect the probability of an attack's success? Given an air defense battery, what's the probability of an effective use of countermeasures given an attack? Given an ineffective use of countermeasures, what's the probability of a miss? And, given a hit, what's the probability of a direct hit versus a deflected hit (and what's the impact in terms of consequences, of these contingencies)?*

Exhibit 2



Long Beach SES LNG Receiving Facility Decision Tree—Scenario 1 Proposed Location

Exhibit 2 displays a decision tree from the terrorists' perspective with respect to this attack. The answers to five consecutive decision questions help determine the optimal solution to minimize damage as follows: **A.** (from **Exhibit 2**)¹⁹ *Are the tanks full containment vessels?* **B.** *Is the facility protected by an air defense battery?* **C.** *Given an attack, will there be sufficient time to use effective countermeasures?* **D.** *Regardless, will the jet hit its intended target?* **E.** *If the target is hit, will the hit be direct and most effective, or will it be a less damaging deflected hit?*

In examining this decision tree, there are several relative probability-related observations one can make. If the LNG tanks at the facility are not contained and the facility is located such that it could potentially cause much damage, an attack on the LNG tanks is preferred from the terrorists' perspective. If the LNG tanks at the facility are contained and the facility is located such that it could potentially cause much damage, an attack on the LNG ship (close to the time it docks and is still fully loaded) is preferred from the terrorists' perspective. If aerial defenses are utilized, the probability of an attack, regardless of its type, is reduced.

Exhibit 3 displays the base assumptions and ranges for thirty variables used in the **Exhibit 2** decision tree. For example, for *variable 1*, assuming that among the 100 most probable targets nationwide (with a one percent conditional probability of an incident), the LNG receiving facility and its docked LNG tanker would be among the five most probable local targets (with a twenty percent conditional probability), we estimated that based on MIPT database reports of terrorist attacks, a reasonable selected probability for the Port of Los Angeles and Long Beach was 1 in 230 per five years, and, for the LNG facility, 1 in 1150 per five years with a range between 1 in 10,000 and 1 in 101 (also, see endnote 18). Judgmentally, we estimated that the increase in the probability of an attack on an LNG tank would be twenty-fold (with a range between no increase and 100 times). The value of a life was selected as \$5 million; the value of an injury, \$100,000. The estimated number of fatalities given an unimpeded, catastrophic attack was selected as 5000, and the number of injuries was selected as 25,000. Similar costs, factors, and numbers as well as their ranges were selected

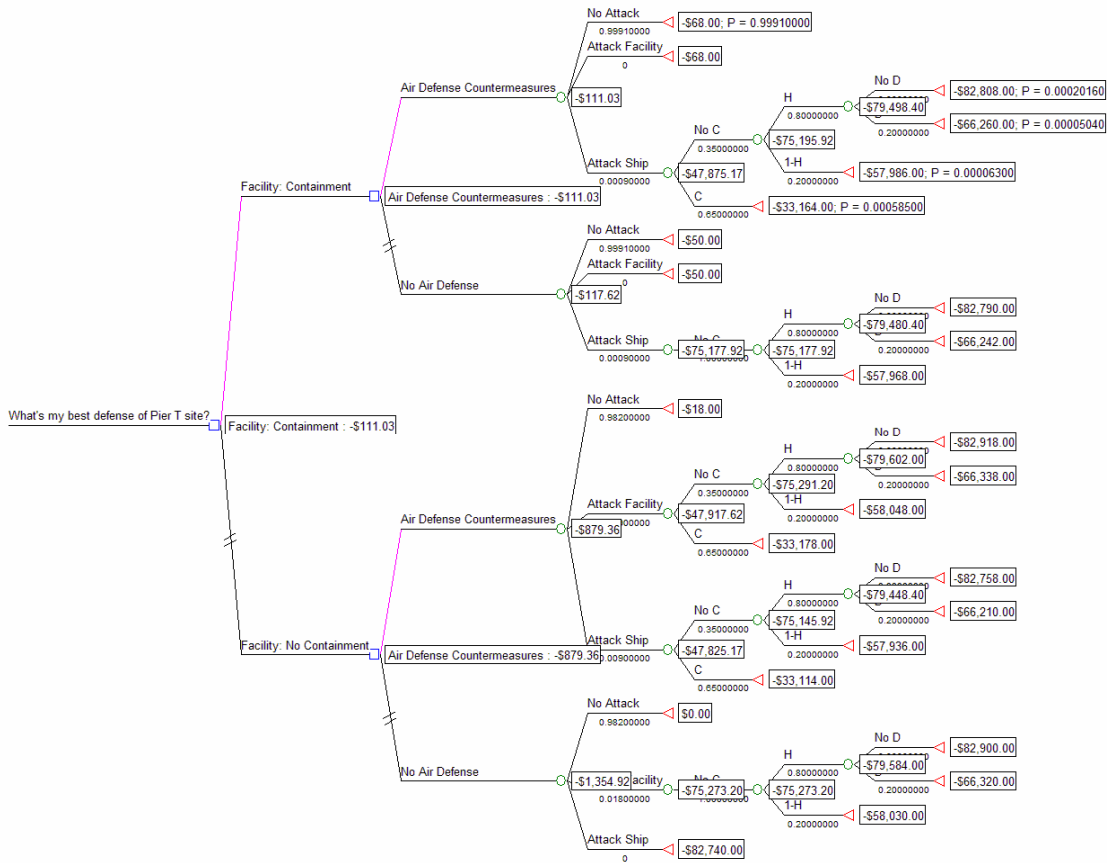
largely judgmentally and based on reasonability constraints given the local built environment and population.

Exhibit 3

Long Beach SES LNG Receiving Facility Decision Tree Variables

<u>No.</u>	<u>Variable</u>	<u>Base</u>	<u>Minimum</u>	<u>Maximum</u>
1	Probability of Attack as proposed (A)	0.0009	0.0001	0.0099
2	Probability of Counterattack Defenses	0.65	0	0.8
3	Increase in Pr(Attack) due to non-containment	20	1	100
4	Cost of Containment (\$Mlns)	50	0	150
5	Probability of Deflection Hit	0.2	0	0.8
6	Cost of Defenses - Antiaircraft (\$Mlns)	18	0	200
7	Factor Savings from Deflected Hit	0.2	0	0.4
8	Factor Savings due to Defenses	0.6	0	1
9	Probability of Hit Ineffective Defenses	0.8	0	1
10	Factor Savings from Missed Antiaircraft Defense	0.3	0	0.5
11	Value of Life (\$)	5,000,000	0	10,000,000
12	Value of Injury (\$)	100,000	0	250,000
13	Probability of Attack at Pier J as a Factor of A	3	1	100
14	Probability of Attack at Quasi-offshore as a Factor of A	6	1	100
15	Probability of Attack at Pier T/Breakwater as a Factor of A	6	1	100
16	Probability of Attack at Pier J/Breakwater as a Factor of A	6	1	100
17	Property Damages total costs (\$Mlns)	5,000	0	10,000
18	Economic Damages total costs (\$Mlns)	50,000	0	200,000
19	Other Damages total costs (\$Mlns)	0	0	10,000
20	Other Costs (jetty-pipeline with original) total costs (\$Mlns)	200	0	10,000
21	Other Costs (jetty with Pier J) total costs (\$Mlns)	135	0	10,000
22	Other Costs (jetty and island) total costs (\$Mlns)	225	0	10,000
23	Facility total costs (\$Mlns)	400	0	500
24	Ship total costs (\$Mlns)	240	0	250
25	Factor Savings of Costs by moving from proposed to Pier J	0.5	0	1
26	Factor Savings of Costs by moving from proposed to offshore	0.1	0	1
27	Number of Fatalities	5000	0	100,000
28	Number of Injuries	25,000	0	200,000
29	Factor Savings of Fatalities/Injuries by moving from proposed to Pier J	0.1	0	1
30	Factor Savings of Fatalities/Injuries by moving from proposed to offshore	0.01	0	1

Exhibit 4



**Long Beach SES LNG Receiving Facility Decision Tree
Scenario 1 Proposed Location (Rolled Back given Base Assumptions)**

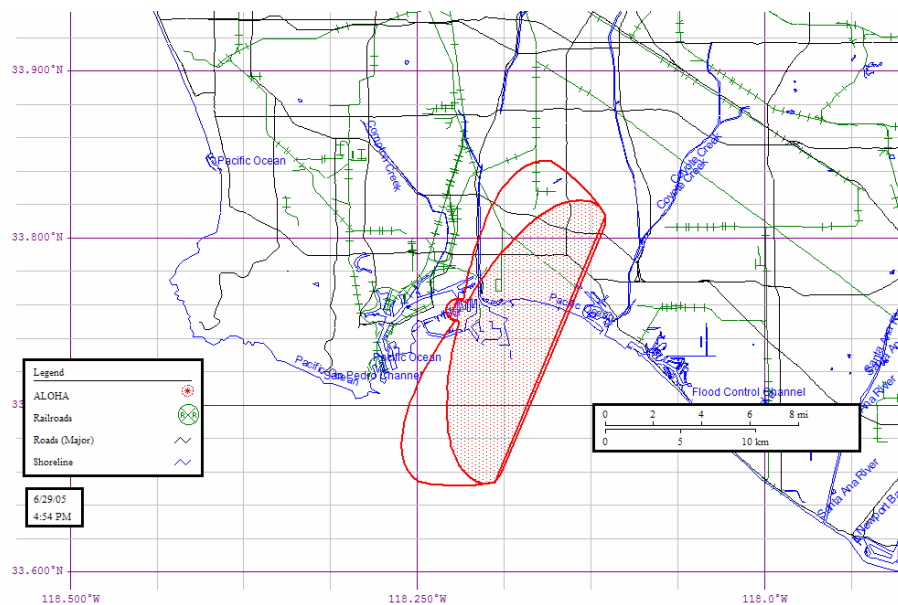
Exhibit 4 displays Exhibit 2 in its “rolled back” state using Exhibit 3 base assumptions.

Rolling back a decision tree calculates the optimal decision based on particular outcomes. To roll back a decision tree, from right to left, you multiply the probability of particular outcomes by those outcomes’ consequences, and then add all of the products for a particular consequence. For **Scenario 1**, the “optimal” decision from the public’s perspective is to have full containment tanks with an aerial defense battery (see also Exhibit 14). Taking into account factors such as the expected probability of a terrorist attack on the LNG facility given tanks that are fully contained, the expected increase in the probability of such an attack given that full containment is not in place, the probability of a defensive counterattack given that defenses are in place, the probability of a successful attack

despite defenses, the probability of a deflected hit on the facility despite a successful attack, the costs of defenses and containment, the choice between attacking the fixed tanks or the docked tanker.²⁰ and the savings expected by the various mitigating circumstances, the decision tree graphically displays the discrete expected and cumulative values at each state of the conditional sequences of events. **Exhibit 5** displays the expected methane plume from this event.

Exhibit 5

**Simulated Terrorist Attack on Proposed Long Beach LNG Receiving Facility
 Maximum Extent of 5% Methane Plume Assuming No Ignition Source
 Unshaded Plume Areas Indicate 95th Percentile Expected Plume Range
 Long Beach, CA during a typical winter, spring, or fall day
 Full breach of either facility tanks or LNG ship**



Atmospheric conditions:

Wind: 6 mph from WNW at 3 meters height; Atmospheric stability Class: C
 Air Temperature: 70° F; Relative Humidity: 50%
 Ground Roughness: urban; Cloud Cover: 50%

Spill information: Chemical: METHANE; Molecular Weight: 16.04 g/mol
 TEEL-3: 50000 ppm

Normal Boiling Point: -258.7° F; Chemical Mass in Tank: 200,000,000 pounds
 Circular Opening Diameter: 10 feet; Opening is 25 feet from tank bottom
 Release Duration: 40 minutes (Heavy Gas Model—Two Phase Flow)
 Max Average Sustained Release Rate: 7.79e+06 pounds/min
 Max Threat Zone: 4.3 miles

Expected losses from such an event (see **Exhibit 6**) include 5000 fatalities, 25,000 injuries, and a total economic impact of about \$83 billion²¹. The \$83 billion total economic impact was estimated

by valuing each fatality at \$5 million, each injury at \$100,000, the LNG facility at \$400 million, an LNG ship at \$240 million, local property damage at \$4.36 billion, and ongoing economic impacts at \$50 billion (primarily in terms of short- and medium-term reduced port trade).

Exhibit 6

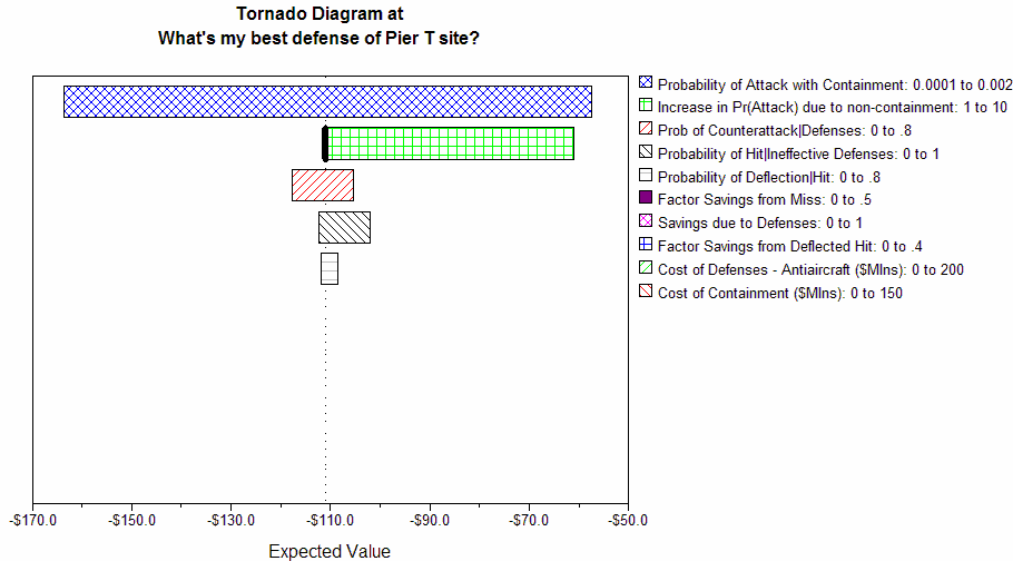
2005 Demographic Profile of Area within Various Distances of Long Beach SES LNG Facility

	2-mile Radius	3-mile Radius	5-mile Radius	95th percentile Plume extent
Total Population	7,743	85,124	408,860	275,000
Total Households	3,033	29,246	136,051	90,000
Median Household Income	\$26,547	\$27,037	\$37,150	n/a
Majority Ethnic Group	Hispanic 55.4%	Hispanic 65.2%	Hispanic 54.4%	n/a
Total Businesses	893	3,822	11,235	8,000
Total Employees	16,085	44,037	113,855	85,000
Total Estimated Fatalities from Attack (% Population)	n/a	n/a	n/a	5,000 (1.8%)
Total Estimated Injuries from Attack (% Population)	n/a	n/a	n/a	25,000 (9.1%)
Total Economic Losses from Attack (excluding Fatalities and Injuries)	n/a	n/a	n/a	\$54.36 billion

Sources: Safety Advisory Report On the Proposed Sound Energy Solutions Liquefied Natural Gas Terminal at the Port of Long Beach, California, Staff Paper, California Energy Commission Publication Number CEC-600-2005-033, September 7, 2005 (p. 8) and author.

Exhibit 7 is a tornado diagram of the decision tree. A tornado diagram is a representation that depicts the most sensitive precedent variables of a decision tree along with their impacts on the overall result. **Exhibit 7** shows that the probability of an attack on a facility and the increase in the probability due to non-containment of the fixed storage tanks dominate the sensitivity of its results. The selected five-year frequency probability range of 0.0001 (1 in 10,000) to 0.0099 (1 in 101) accounts for most of the variability among expected consequences.

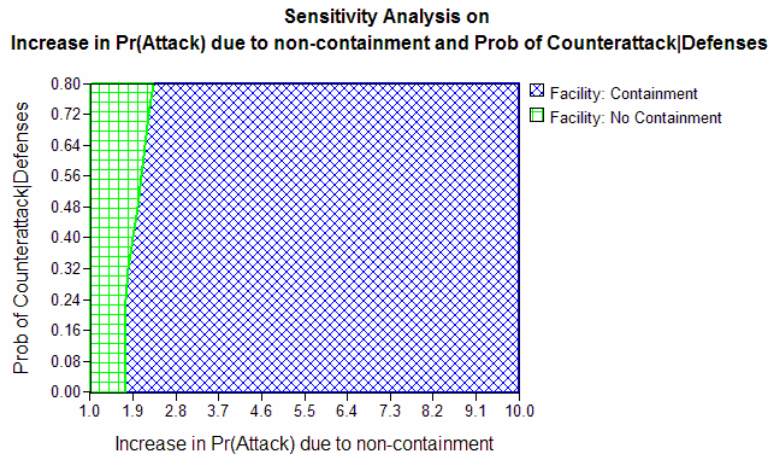
Exhibit 7



Tornado Diagram—Long Beach SES Receiving Facility Decision Tree

As is further illustrated in **Exhibit 8**, as long as full containment decreases the probability of attack by at least half, it is always preferred to non-containment. This supports the validity of SES’s proposal to fully contain the tanks although this does not account for the substitution potential of the LNG ship at dockside and before unloading.

Exhibit 8

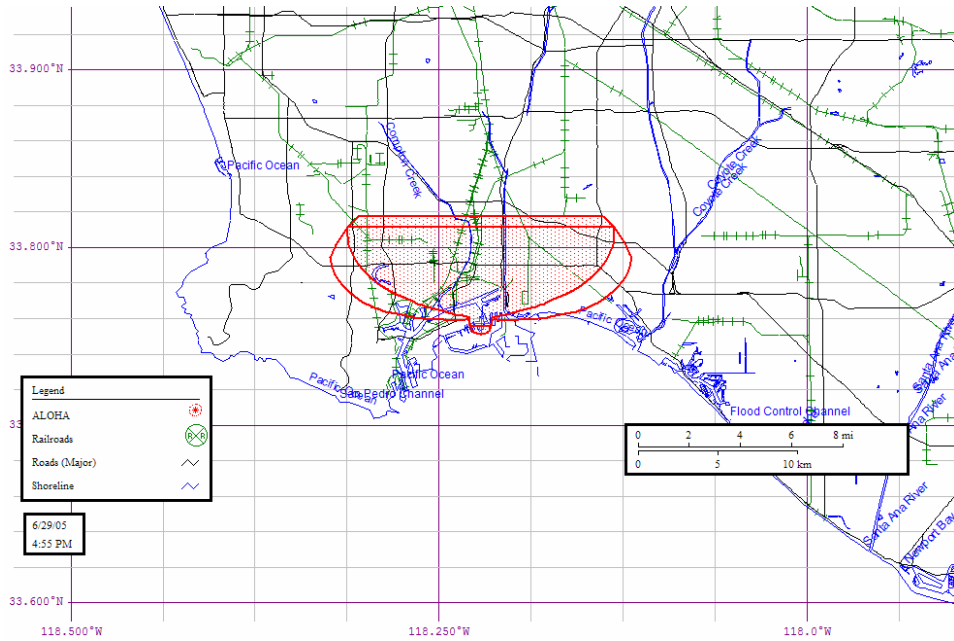


2 Way Sensitivity Diagram—Long Beach SES Receiving Facility Decision Tree

Scenario 2 repeats **Scenario 1**, except that it assumes the event occurs in the summertime with an expected plume as displayed in **Exhibit 9**. For purposes of the Long Beach facility, we have assumed that total economic impacts are approximately equal to those incurred in **Scenario 1**.

Exhibit 9

**Simulated Terrorist Attack on Proposed Long Beach LNG Receiving Facility
Maximum Extent of 5% Methane Plume Assuming No Ignition Source
Unshaded Plume Areas Indicate 95th Percentile Expected Plume Range
Long Beach, CA during a typical summer day
Full breach of either facility tanks or LNG ship**



Atmospheric conditions:

Wind: 7 mph from S at 3 meters; Atmospheric stability Class: D
Air Temperature: 70° F; Relative Humidity: 50%
Ground Roughness: urban; Cloud Cover: 50%

Spill information:

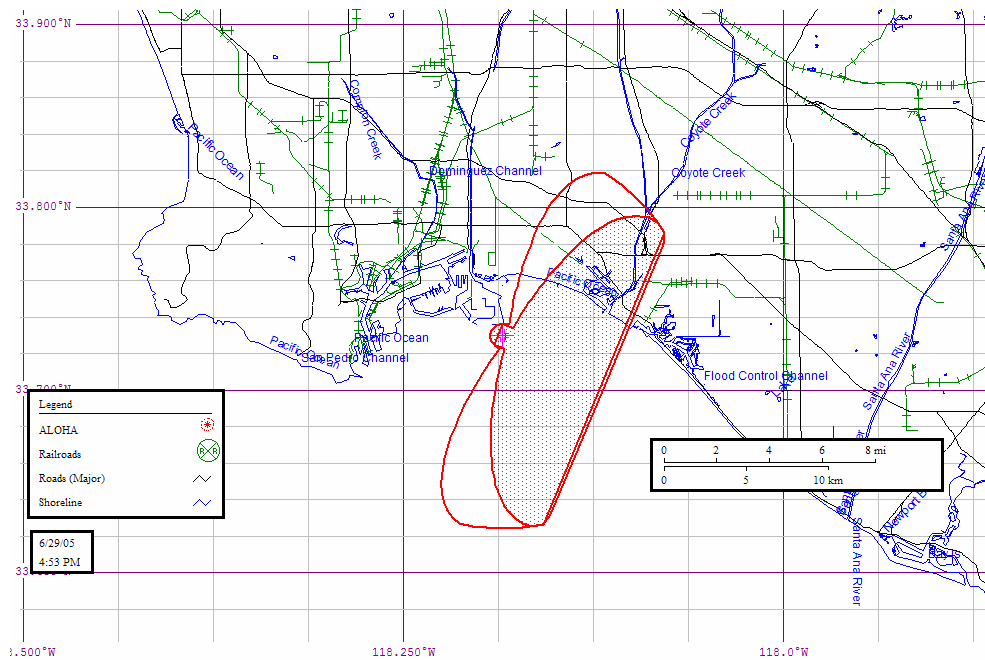
Chemical: METHANE; Molecular Weight: 16.04 g/mol
TEEL-3: 50000 ppm
Normal Boiling Point: -258.7° F; Chemical Mass in Tank: 200,000,000 pounds
Circular Opening Diameter: 10 feet; Opening is 25 feet from tank bottom
Release Duration: 40 minutes
Max Average Sustained Release Rate: 7.79e+06 pounds/min (averaged over a minute or more)
Total Amount Released: 1.95e+008 pounds; Max Threat Zone: 4.2 miles

Scenario 3 and **4** repeat the first two's assumptions, except that the facility siting is moved from Pier T to Pier J (away from downtown Long Beach, see **Exhibit 10** and **Exhibit 11**). Expected losses from such events include 500 fatalities, 2500 injuries, and a total economic impact of about

\$31 billion. The reduction is primarily due to moving the facility away from the population and densely-built central city.

Exhibit 10

**Simulated Terrorist Attack on Long Beach LNG Receiving Facility at Pier J Alternative Site During a Typical Winter, Spring, or Fall Day
Maximum Extent of 5% Methane Plume Assuming No Ignition Source
Unshaded Plume Areas Indicate 95th Percentile Expected Plume Range
Full breach of either Facility Tanks or LNG Ship**



Atmospheric conditions:

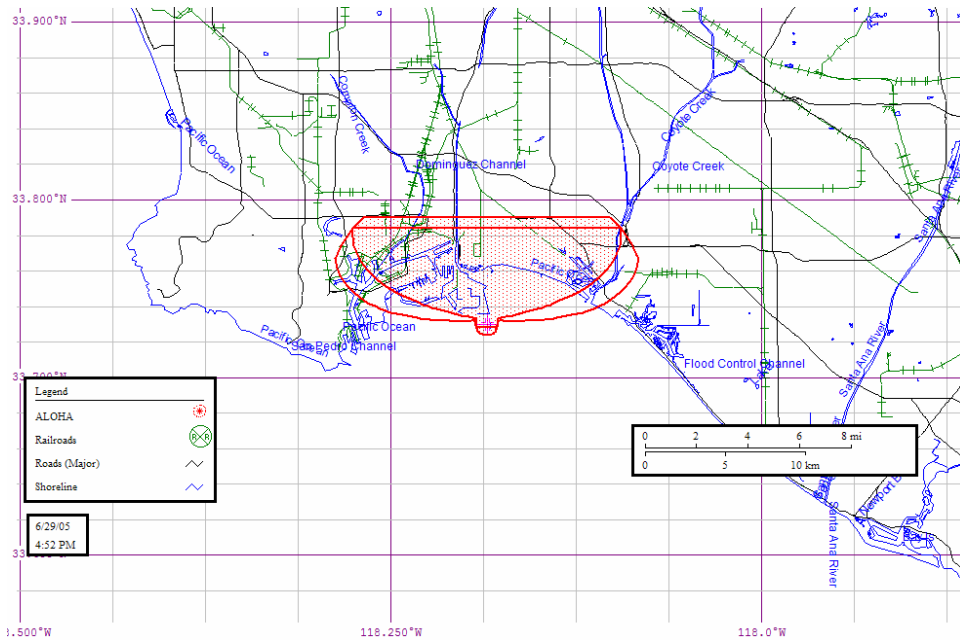
Wind: 6 mph from WNW at 3 meters height; Atmospheric stability Class: C
Air Temperature: 70° F; Relative Humidity: 50%
Ground Roughness: urban; Cloud Cover: 50%

Spill information:

Chemical: METHANE; Molecular Weight: 16.04 g/mol
TEEL-3: 50000 ppm
Normal Boiling Point: -258.7° F; Chemical Mass in Tank: 200,000,000 pounds
Circular Opening Diameter: 10 feet; Opening is 25 feet from tank bottom
Release Duration: 40 minutes (Heavy Gas Model—Two Phase Flow)
Max Average Sustained Release Rate: 7.79e+06 pounds/min
Max Threat Zone: 4.3 miles

Exhibit 11

**Simulated Terrorist Attack on Long Beach LNG Receiving Facility
at Pier J Alternative Site During a Typical Summer Day
Maximum Extent of 5% Methane Plume Assuming No Ignition Source
Unshaded Plume Areas Indicate 95th Percentile Expected Plume Range
Full breach of Either Facility Tanks or LNG Ship**



Atmospheric conditions:

Wind: 7 mph from S at 3 meters; Atmospheric stability Class: D

Air Temperature: 70° F; Relative Humidity: 50%

Ground Roughness: urban; Cloud Cover: 50%

Spill information:

Chemical: METHANE; Molecular Weight: 16.04 g/mol

TEEL-3: 50000 ppm

Normal Boiling Point: -258.7° F; Chemical Mass in Tank: 200,000,000 pounds

Circular Opening Diameter: 10 feet; Opening is 25 feet from tank bottom

Release Duration: 40 minutes

Max Average Sustained Release Rate: 7.79e+06 pounds/min (averaged over a minute or more)

Total Amount Released: 1.95e+008 pounds

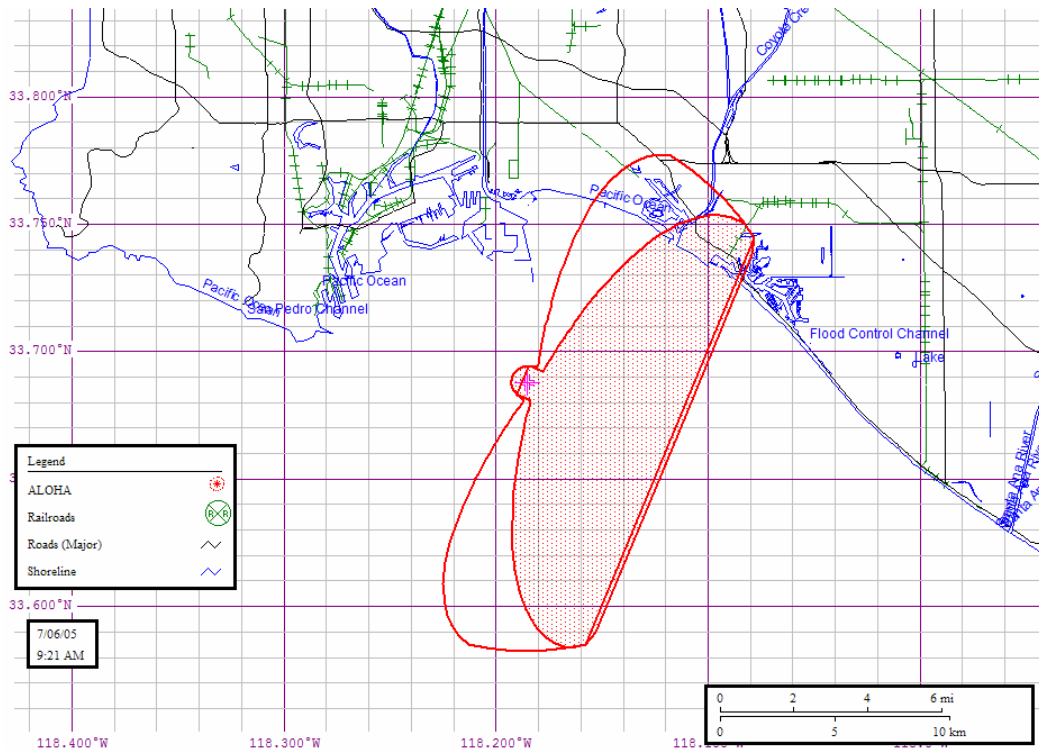
Max Threat Zone: 4.2 miles

Scenaria 5 and **6** similarly repeat the first two scenaria's assumptions, except that, in these scenaria, a three-mile long jetty²² is built south of Pier J, and the facility is sited at Pier J with its docking facility located at the ocean end of the jetty (see **Exhibit 12** and **Exhibit 13**). Expected losses from such an event include 50 fatalities, 250 injuries, and a total economic impact of about \$6 billion. This further reduction is due to the relative futility of attacking the contained LNG tank and

the further distance from the more probable LNG ship target to the populated and heavily built infrastructure zones.

Exhibit 12

**Simulated Terrorist Attack on Long Beach LNG Receiving Facility
at Offshore Island or Jetty with Pier (3 mi S of Pier J) Alternative Site During a Typical
Winter, Spring, or Fall Day
Maximum Extent of 5% Methane Plume Assuming No Ignition Source
Unshaded Plume Areas Indicate 95th Percentile Expected Plume Range
Full Breach of either Facility Tanks or LNG Ship**



Atmospheric conditions:

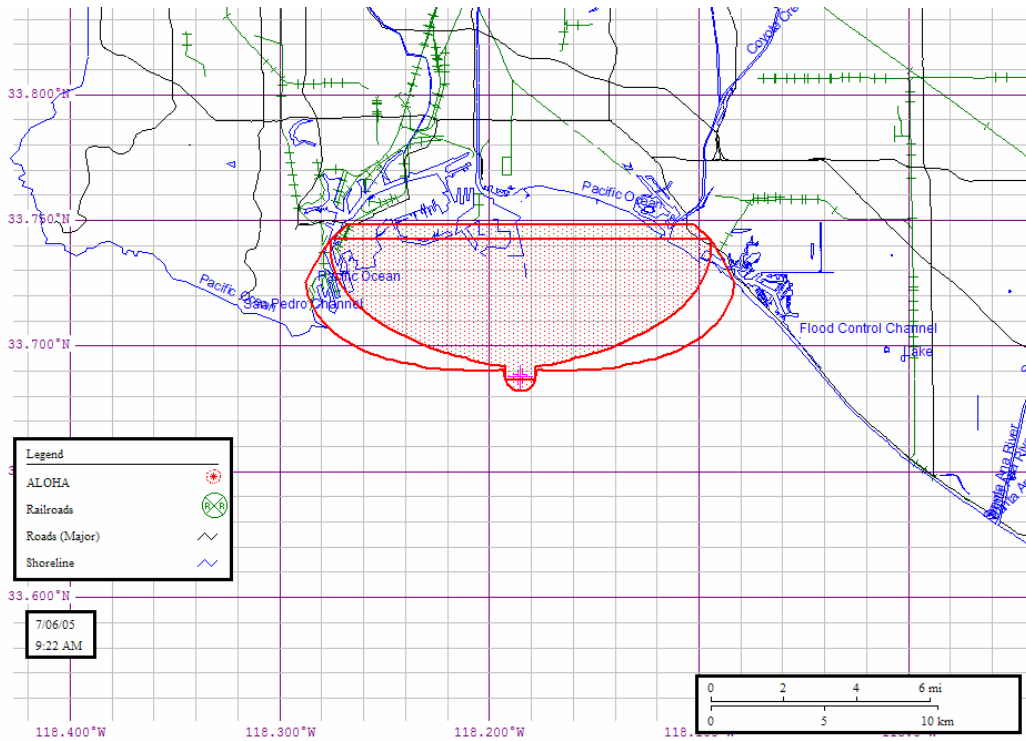
Wind: 6 mph from WNW at 3 meters height; Atmospheric stability Class: C
Air Temperature: 70° F; Relative Humidity: 50%
Ground Roughness: urban; Cloud Cover: 50%

Spill information:

Chemical: METHANE; Molecular Weight: 16.04 g/mol
TEEL-3: 50000 ppm
Normal Boiling Point: -258.7° F; Chemical Mass in Tank: 200,000,000 pounds
Circular Opening Diameter: 10 feet; Opening is 25 feet from tank bottom
Release Duration: 40 minutes (Heavy Gas Model—Two Phase Flow)
Max Average Sustained Release Rate: 7.79e+06 pounds/min
Max Threat Zone: 4.3 miles

Exhibit 13

**Simulated Terrorist Attack on Long Beach LNG Receiving Facility
at Offshore Island or Jetty with Pier (3 mi S of Pier J) Alternative Site During a Typical
Summer Day
Maximum Extent of 5% Methane Plume Assuming No Ignition Source
Unshaded Plume Areas Indicate 95th Percentile Expected Plume Range
Full Breach of either Facility Tanks or LNG Ship**



Atmospheric conditions:

Wind: 7 mph from S at 3 meters; Atmospheric stability Class: D
 Air Temperature: 70° F; Relative Humidity: 50%
 Ground Roughness: urban; Cloud Cover: 50%

Spill information:

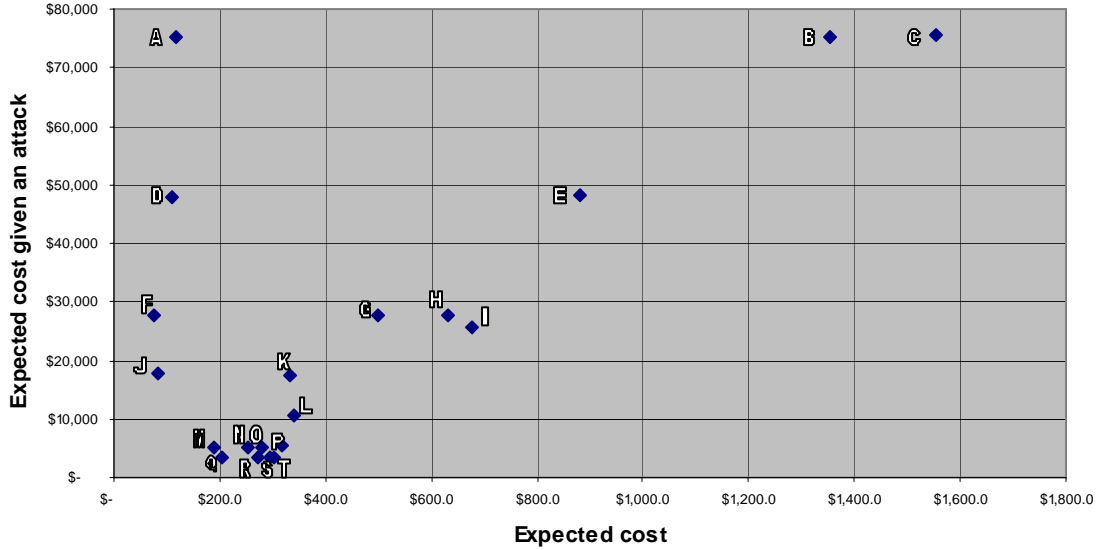
Chemical: METHANE; Molecular Weight: 16.04 g/mol
 TEEL-3: 50000 ppm
 Normal Boiling Point: -258.7° F; Chemical Mass in Tank: 200,000,000 pounds
 Circular Opening Diameter: 10 feet; Opening is 25 feet from tank bottom
 Release Duration: 40 minutes
 Max Average Sustained Release Rate: 7.79e+06 pounds/min (averaged over a minute or more)
 Total Amount Released: 1.95e+008 pounds
 Max Threat Zone: 4.2 miles

Exhibit 14 succinctly summarizes **Scenario 1** to **6**. The first three columns of this table outline the Long Beach site description, whether or not the fixed tanks are fully contained, and whether or not aerial defenses are in place. The fourth column expresses the annualized, expected cost of the set

of assumptions wherein the cost is the combination of the annualized expected value of a terrorist attack plus the cost of containment and countermeasures. The fifth column lists the expected cost of a terrorist attack in the given scenario, assuming that a successful attack, from the terrorists' perspective, occurs. **Exhibit 15** summarizes **Exhibit 14** by presenting its dominant strategies (i.e., the pairings of lowest annualized costs and lowest expected value of terrorist attack, assuming that a successful attack, from the terrorists' perspective, occurs). The dominant strategies represent the Pareto optimal choices that incorporate both expected and contingent expected losses. Choices 1 through 8, respectively, represent reasonable siting, containment, and countermeasure strategy options for policymakers' consideration.

Exhibit 14

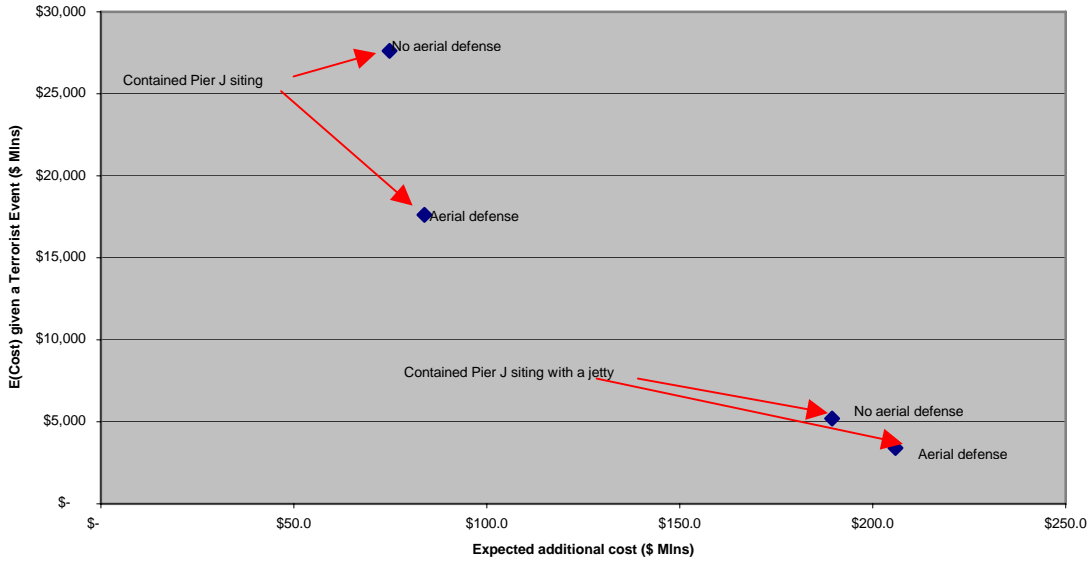
Expected cost | terrorist attack (\$ Millions)



Scenario	Facility containment?	Aerial defenses?	Expected value (\$ Millions)	Expected cost terrorist attack (\$ Millions)	Chart Label
Pier T (current proposal)	Y	Y	\$ 111.0	\$ 47,875	D
Pier T (current proposal)	Y	N	\$ 117.6	\$ 75,178	A
Pier T (current proposal)	N	Y	\$ 879.4	\$ 48,372	E
Pier T (current proposal)	N	N	\$ 1,354.9	\$ 75,273	B
Pier J	Y	Y	\$ 83.8	\$ 17,616	J
Pier J	Y	N	\$ 74.8	\$ 27,626	F
Pier J	N	Y	\$ 334.3	\$ 17,589	K
Pier J	N	N	\$ 497.7	\$ 27,649	G
Artificial Island	Y	Y	\$ 295.9	\$ 3,480	R
Artificial Island	Y	N	\$ 279.5	\$ 5,283	N
Artificial Island	N	Y	\$ 301.2	\$ 3,476	T
Artificial Island	N	N	\$ 317.8	\$ 5,378	P
Pier J with a jetty	Y	Y	\$ 205.9	\$ 3,390	Q
Pier J with a jetty	Y	N	\$ 189.5	\$ 5,193	M
Pier J with a jetty	N	Y	\$ 340.0	\$ 10,544	L
Pier J with a jetty	N	N	\$ 632.7	\$ 27,784	H
Pier T with a jetty/pipeline	Y	Y	\$ 270.9	\$ 3,455	S
Pier T with a jetty/pipeline	Y	N	\$ 254.5	\$ 5,258	O
Pier T with a jetty/pipeline	N	Y	\$ 677.8	\$ 25,762	I
Pier T with a jetty/pipeline	N	N	\$ 1,554.9	\$ 75,473	C

Exhibit 15

Dominant Strategies given Base Assumptions



Indicated Strategies

Choice	Scenario	Facility containment?	Aerial defenses?	Expected cost (\$ Millions)	Expected cost terrorist attack (\$ Millions)
1	Pier J with a jetty	Y	Y	\$205.9	\$3,390.0
2	Pier J with a jetty	Y	N	\$189.5	\$5,193.0
3	Artificial Island	Y	Y	\$265.9	\$3,450.0
4	Pier T with a jetty/pipeline	Y	Y	\$270.9	\$3,455.0
5	Artificial Island	Y	N	\$249.5	\$5,253.0
6	Pier T with a jetty/pipeline	Y	N	\$254.5	\$5,258.0
7	Pier J	Y	Y	\$83.8	\$17,615.0
8	Pier J	Y	N	\$74.8	\$27,625.0

In order to gauge consequences, CAMEO, a software program developed by the Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration Office of Response and Restoration (NOAA) to assist in chemical emergencies, was used to determine the height, width, and relative distance of the methane plume from point of impact to its 95th percentile extent at 50,000 ppm (or a 5% concentration of the atmosphere) or the Lower Explosive Limit (LEL) of methane²³. Such plumes represent reasonable theoretical maximums for the extents of catastrophic fires as a result of these simulated terrorist events.

Boston Distrigas LNG Receiving

Facility



Coast Guard oversees an LNG tanker entering Boston harbor

Source: http://www.ferc.gov/images/photogallery/lng_coast_guard.jpg

The seventh and eighth scenarios consider the Everett, Massachusetts Distrigas LNG receiving facility utilizing the Long Beach SES LNG methodology. Use of such decision

analysis enables the analyst to consider containment and aerial defense countermeasures that may enhance the security of an extant facility.

The Distrigas facility in Everett, Massachusetts is located on the Mystic River close to Boston Harbor and near the Tobin Bridge. Its proximity to the Boston area has heavily influenced transportation security since September 11, 2001.

Since this facility currently operates, its existing security procedures are known. For example, the United States Coast Guard (USCG) is the lead agency that controls the transport of LNG vessels agencies and establishes the time of delivery and the sequence of security activities. A Unified Command Post is established at the USCG Station, Boston Group, before the arrival of each LNG tanker. The Command Post is made up of members of USCG, the Massachusetts State Police, the Boston Police Department, the Environmental Police, and the Boston Fire Department. Each agency deploys its appropriate assets. The Massachusetts State Police Criminal Investigative Division deploys two undercover officers to observe the docking site. These officers stay in position for approximately one day. Eleven members of the Massachusetts State Police Dive Team inspect the wharf as well as sections of the river bottom each time a tanker docks. When a tanker gets within approximately two miles of the harbor, five USCG vessels meet it and establish a 500-yard perimeter. Two forward vessels are equipped to ram an offending vessel, if needed, and are charged with herding suspect vessels away from the tanker. Two aft USCG vessels are equipped with heavy

weaponry and are charged with dismantling a suspect vessel if the forward USCG vessels fail to stop its advance. A fifth USCG vessel is the command vessel from where all decisions regarding the transport security are made. This vessel is free to move wherever it desires, but generally stays aft of the transport tanker.

Another perimeter is established at the 1000-yard mark from the transport tanker. This 1000-yard perimeter is comprised of four Massachusetts State Police boats (two forward and two aft), one Boston Police Department boat to the port side, and one Environmental Police boat to the starboard side. These vessels can intercept suspect vessels and operate under the existing rules of engagement with respect to the use of deadly force established by their respective agencies.

In addition to water operations, the Massachusetts State Police shuts down traffic on the Tobin Bridge while the tanker is close to it. A State Police Helicopter hovers and provides observation from the time the tanker is met outside the Harbor until it is docked. Boston Police Department has the responsibility of closing all adjacent roads and wharfs that lead to the harbor. There are police units stationed at each of these access points from the time the tanker enters the Harbor to the time it docks, approximately two hours. The Boston Police Department estimates that it uses twenty to thirty staff members per inbound and outbound LNG tanker trip.

The Boston Fire Department devotes one person to the Unified Command Post. If there is an incident, Boston Fire has a mutual aid pact with the adjacent towns. The fire departments involved would call for every available asset and would use water and foam to put out the fire. While docked, security measures fall to the Distrigas Facility private security firm, the Everett Fire Department, and the Everett Police Department. Five members of the Everett Police Department maintain a visible presence while the tanker is in port and unloading. The typical offload takes 24 hours. On the outbound trip, a USCG boat (aft) and one State Police boat (foreword) maintain the 1000-yard perimeter while three USCG boats maintain the 500- yard reaction zone. Additionally, traffic on the Tobin Bridge is reduced to center lanes only.

For **Scenario 7**, the “optimal” decision from the public’s perspective is to have full containment tanks with an aerial defense battery at the Distrigas facility. Taking into account factors such as the expected probability of a summertime terrorist attack on the LNG facility given tanks that are fully contained, the expected increase in the probability of such an attack given that full containment is not in place, the probability of a defensive counterattack given that defenses are in place, the probability of a successful attack despite defenses, the probability of a deflected hit on the facility despite a successful attack, the costs of defenses and containment, the choice between attacking the fixed tanks or the docked tanker, and the savings expected by the various mitigating circumstances, expected losses from such an event include 7000 fatalities, 36,000 injuries, and a total economic impact of \$51 billion (see **Exhibit 16**). **Exhibit 17** displays the expected methane plume from this event.

Exhibit 16

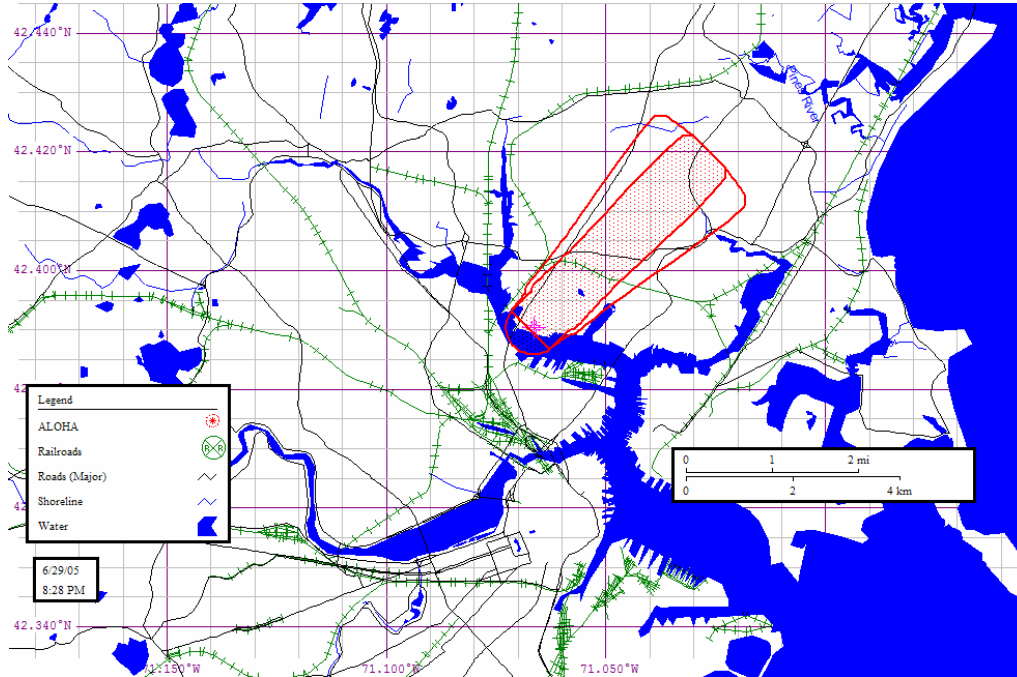
2000 Demographic Profile of Area within Various Distances of Everett Distrigas LNG Facility

	2-mile Radius	3-mile Radius	5-mile Radius	95th percentile Plume extent
Total Population	162,205	375,690	788,600	50,000
Total Households	66,843	156,778	333,356	20,000
Majority Ethnic Group	White 75.9%	White 73.3%	White 73.2%	n/a
Total Employees	81,134	198,288	413,723	25,000
Total Estimated Fatalities from Attack (% Population)	n/a	n/a	n/a	7,000 (14%)
Total Estimated Injuries from Attack (% Population)	n/a	n/a	n/a	36,000 (72%)
Total Economic Losses from Attack (excluding Fatalities and Injuries)	n/a	n/a	n/a	\$12.4 billion

Source: Landview 6 Census 2000 Population Estimator.

Exhibit 17

**Simulated Terrorist Attack on Boston LNG Receiving Facility
Maximum Extent of 5% Methane Plume Assuming No Ignition Source During a Typical
Summer Day
Unshaded Plume Areas Indicate 95th Percentile Expected Plume Range
Full breach of either Facility Tank or LNG Ship at Mooring**



Atmospheric conditions:

Wind: 14 mph from SW at 2 meters height; Atmospheric stability Class: D

Air Temperature: 75° F; Relative Humidity: 50%

Ground Roughness: urban; Cloud Cover: 50%

Spill information:

Chemical: METHANE; Molecular Weight: 16.04 g/mol

TEEL-3: 50000 ppm

Normal Boiling Point: -258.7° F; Chemical Volume in Tank: 42 million gallons

Circular Opening Diameter: 5 meters; Opening is 77.2 feet from tank bottom

Release Duration: 49 minutes (Heavy Gas Model—Two Phase Flow)

Max Average Sustained Release Rate: 1.39e+07 pounds/min

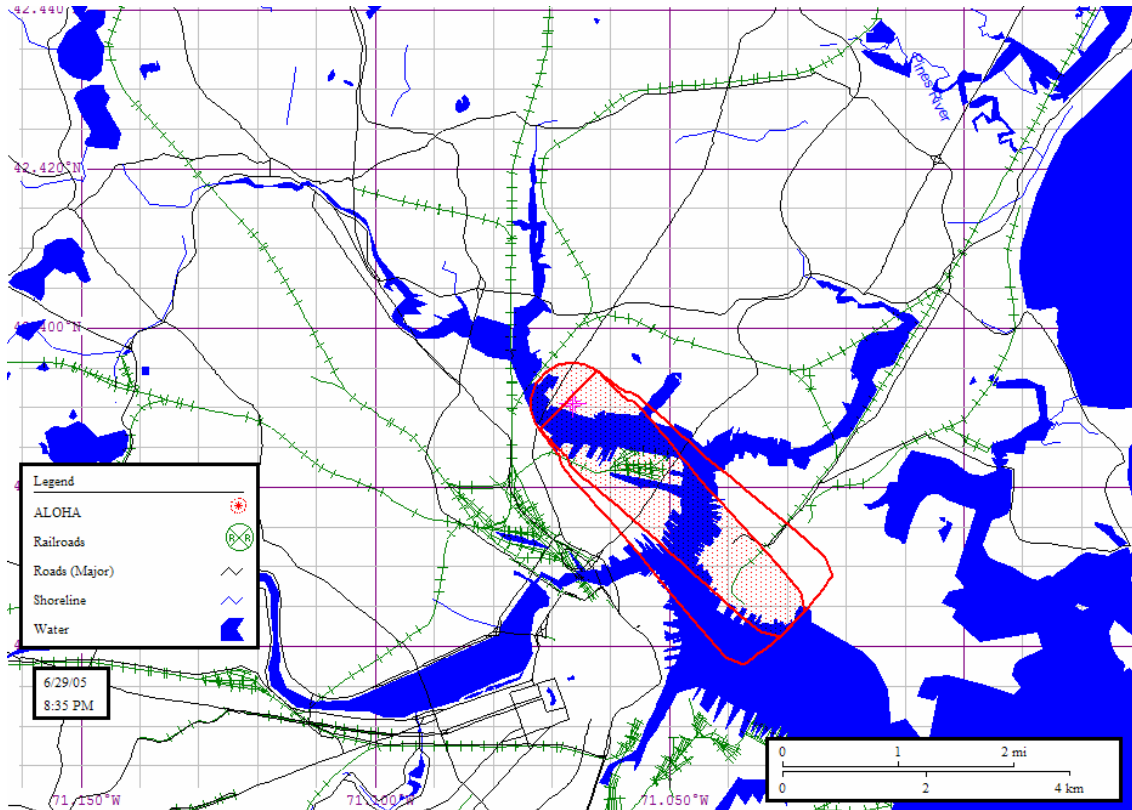
Total Amount Released: 1.07e+008 pounds

Max Threat Zone: 2.9 miles

Scenario 8 repeats **Scenario 7**, except that it assumes the event occurs in the wintertime with an expected plume as displayed in **Exhibit 18**. For purposes of the Boston facility, the expected losses from such an event include 750 fatalities, 3750 injuries, and a total economic impact of \$16 billion.

Exhibit 18

**Simulated Terrorist Attack on Boston LNG Receiving Facility
Maximum Extent of 5% Methane Plume Assuming No Ignition Source
Unshaded Plume Areas Indicate 95th Percentile Expected Plume Range
Full Breach of either Facility Tank or LNG Ship at Mooring during a Typical Winter Day**



Atmospheric conditions:

Wind: 11 mph from NW at 2 meters height; Atmospheric stability Class: D
Air Temperature: 40° F; Relative Humidity: 50%
Ground Roughness: urban; Cloud Cover: 50%

Spill information:

Chemical: METHANE; Molecular Weight: 16.04 g/mol
TEEL-3: 50000 ppm
Normal Boiling Point: -258.7° F; Chemical Volume in Tank: 42 million gallons
Circular Opening Diameter: 5 meters; Opening is 55.1 feet from tank bottom
Release Duration: 47 minutes (Heavy Gas Model—Two Phase Flow)
Max Average Sustained Release Rate: 1.45e+07 pounds/min
Total Amount Released: 1.25e+008 pounds
Max Threat Zone: 2.7 miles

Providence KeySpan LNG Receiving Facility

The final two scenaria consider the Providence, Rhode Island KeySpan LNG facility that was rejected on June 30, 2005, by FERC (and appealed on August 4, 2005, to FERC) by once again

utilizing the Long Beach SES LNG methodology. Use of such decision analysis enables the analyst to consider upgrade countermeasures that may enhance this facility's security.

KeySpan LNG, L.P. proposes to construct and operate upgrades to its existing Providence, Rhode Island LNG facility, and Algonquin Gas Transmission, L.L.C. proposes to site, construct, and operate a new natural gas pipeline and ancillary facilities in Providence. The activities proposed by KeySpan LNG and Algonquin are known as the KeySpan LNG Project. The KeySpan LNG Project would allow for the receipt of marine LNG deliveries at the existing KeySpan LNG facility, augment LNG supplies for truck deliveries to LNG storage tanks in the region, and supply up to 375 million cubic feet per day (MMcfd) of imported LNG to the New England region.

The KeySpan LNG facility would also continue to deliver up to 150 MMcfd of vaporized LNG to the New England Gas Company distribution system. In order to provide these services, the KeySpan LNG Project has requested authorization to construct, install, and operate a ship unloading facility with a single berth capable of receiving LNG ships with cargo capacities of up to 145,000 cubic meters, two 16-inch-diameter liquid unloading arms, a 24-inch-diameter liquid unloading line from the arms to the LNG storage tank, two vapor return blowers, a 12-inch-diameter vapor arm, an 8-inch-diameter vapor return line, four boil-off-gas compressors, a boil-off gas condenser, a two-stage LNG pumping system, an indirect fired vaporizer system with a capacity of 375 MMcfd, operations control buildings, ancillary utilities, and LNG facilities.

For *Scenario 9*, the Pareto optimal decision from the public's perspective with respect to the KeySpan LNG Project is to have full containment tanks with an aerial defense battery. Taking into account factors such as the expected probability of a summertime terrorist attack on the LNG facility given tanks that are fully contained, the expected increase in the probability of such an attack given that full containment is not in place, the probability of a defensive counterattack given that defenses are in place, the probability of a successful attack despite defenses, the probability of a deflected hit on the facility despite a successful attack, the costs of defenses and containment, the choice between attacking the fixed tanks or the docked tanker, and the savings expected by the various mitigating

circumstances, expected losses from such an event include 2000 fatalities, 10,000 injuries, and a total economic impact of \$18.3 billion²⁴ (see **Exhibit 19**). **Exhibit 20** displays the expected methane plume from this event.

Exhibit 19

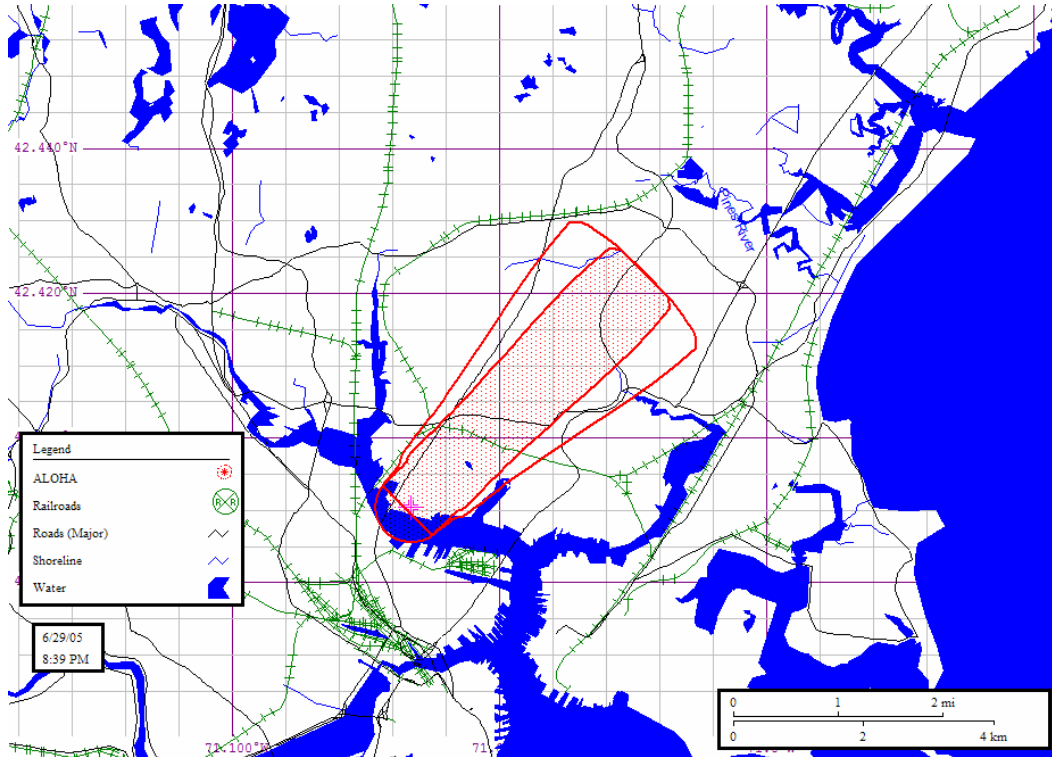
2000 Demographic Profile of Area within Various Distances of Providence KeySpan LNG Facility

	2-mile Radius	3-mile Radius	5-mile Radius	95th percentile Plume extent
Total Population	71,784	162,875	356,832	33,000
Total Households	26,589	61,425	136,782	10,000
Majority Ethnic Group	White 56.5%	White 62.9%	White 71.7%	n/a
Total Employees	29,266	69,964	157,148	12,000
Total Estimated Fatalities from Attack (% Population)	n/a	n/a	n/a	2,000 (6.1%)
Total Estimated Injuries from Attack (% Population)	n/a	n/a	n/a	10,000 (30.3%)
Total Economic Losses from Attack (excluding Fatalities and Injuries)	n/a	n/a	n/a	\$7.3 billion

Source: Landview 6 Census 2000 Population Estimator.

Exhibit 20

**Simulated Terrorist Attack on Rhode Island LNG Receiving Facility
Maximum Extent of 5% Methane Plume Assuming No Ignition Source
Unshaded Plume Areas Indicate 95th Percentile Expected Plume Range
Full Breach of either Facility Tank or LNG Ship at Mooring during a Typical Summer Day**



Atmospheric conditions:

Wind: 14 mph from SW at 2 meters height; Atmospheric stability Class: D

Air Temperature: 75° F; Relative Humidity: 50%

Ground Roughness: urban; Cloud Cover: 50%

Spill information:

Chemical: METHANE; Molecular Weight: 16.04 g/mol

TEEL-3: 50000 ppm

Normal Boiling Point: -258.7° F; Chemical Volume in Tank: 50 million gallons

Circular Opening Diameter: 5 meters; Opening is 81.8 feet from tank bottom

Release Duration: 56 minutes (Heavy Gas Model—Two Phase Flow)

Max Average Sustained Release Rate: 1.5e+07 pounds/min

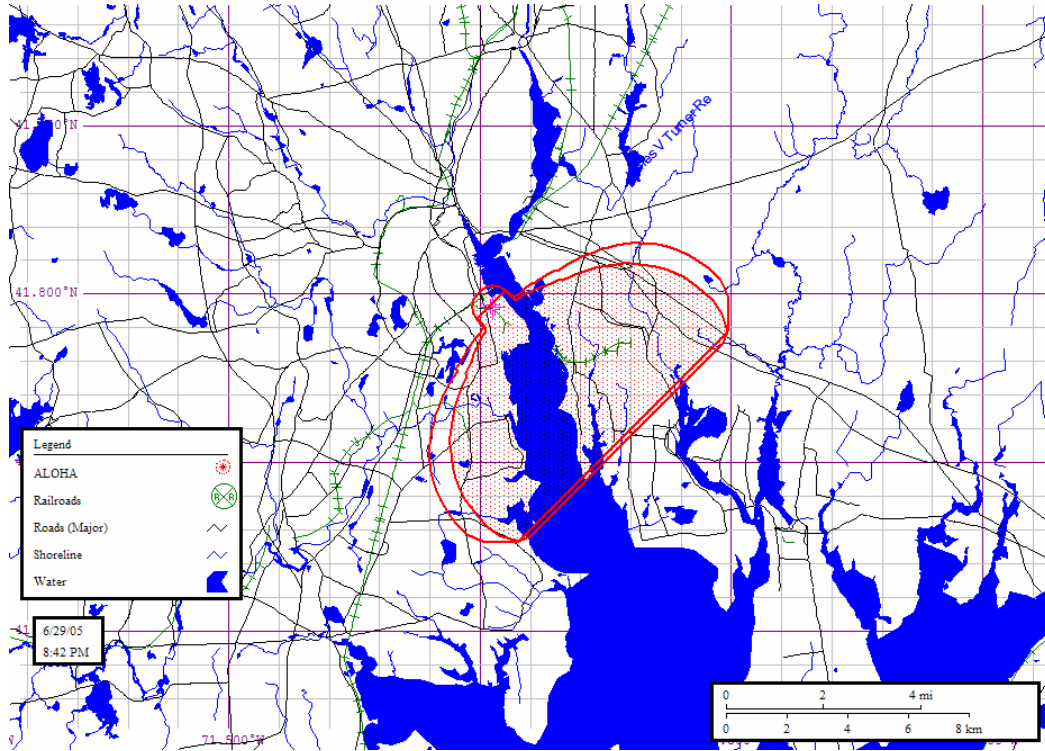
Total Amount Released: 1.07e+008 pounds

Max Threat Zone: 3.2 miles

Scenario 10 repeats **Scenario 9**, except that it assumes the event occurs in the wintertime with an expected plume as displayed in **Exhibit 21**. For purposes of the Providence facility, the expected losses from such an event include 500 fatalities, 2500 injuries, and a total economic impact of \$10 billion.

Exhibit 21

**Simulated Terrorist Attack on Rhode Island LNG Receiving Facility
Maximum Extent of 5% Methane Plume Assuming No Ignition Source
Unshaded Plume Areas Indicate 95th Percentile Expected Plume Range
Full Breach of either Facility Tank or LNG Ship at Mooring During a Typical Winter Day.**



Atmospheric conditions:

Wind: 11 mph from NW at 2 meters height; Atmospheric stability Class: D
Air Temperature: 40° F; Relative Humidity: 50%
Ground Roughness: urban; Cloud Cover: 50%

Spill information:

Chemical: METHANE; Molecular Weight: 16.04 g/mol
TEEL-3: 50000 ppm
Normal Boiling Point: -258.7° F; Chemical Volume in Tank: 50 million gallons
Circular Opening Diameter: 5 meters; Opening is 58.4 feet from tank bottom
Release Duration: 14 minutes (Heavy Gas Model—Two Phase Flow)
Max Average Sustained Release Rate: 1.92e+07 pounds/min
Total Amount Released: 1.49e+008 pounds
Max Threat Zone: 3.9 miles

Observations and Recommendations

Post-September 11, 2001, the possibility of a terrorist event at critical infrastructure in densely populated areas must always be considered. In particular, attention should be paid to scenarios that can wreak both emotional and economic havoc in the event of an attack..

Our decision analysis models show that the probability of attack on an LNG facility is the primary variable of interest since the attractiveness of the LNG as a fuel for fire drives the terrorists' decision-making. Tank containment is also an important factor in shifting the target of interest-attack probability to the LNG tanker. In other words, the increase in the probability of an attack due to non-containment can be seen as the increased propensity to strike a non-contained LNG ship as opposed to the facility. Thus, whereas containment of such a facility decreases its utility as a target, a near perfect substitute for attack exists in the form of the docked, not-yet-unloaded LNG ship. Thus, containment coupled with remote siting of LNG ship docks accomplishes a more effective security regimen. And, it is also clear that countermeasure costs including aerial defense measures are a major driver of the expected value of a terrorist act.

Exhibit 22

Relative Severities of Potential Terrorist Acts at Selected U.S. LNG Receiving Facilities

Locale	Option	Full Containment Tanks?	Aerial Defenses Implemented?	Millions of Dollars		
				Annualized Costs	Expected Size of Terrorist Event Given an Attack	Factor of L.B. Proposed (b)
Long Beach	Proposed [Pier T]	Yes	No	\$117.60	\$75,178	1.00
Boston	Current - summer	No	No	\$828.90	\$46,049	0.61
Boston	Optimal (a)	Yes	No	\$91.44	\$46,099	0.61
Boston	Optimal (b)	Yes	Yes	\$94.37	\$29,371	0.39
Providence	Current - summer	No	No	\$296.00	\$16,448	0.22
Providence	Optimal (a)	Yes	No	\$64.80	\$16,498	0.22
Providence	Optimal (b)	Yes	Yes	\$77.40	\$10,535	0.14
Long Beach	Optimal (a) [Pier J]	Yes	No	\$74.80	\$27,625	0.37
Long Beach	Optimal (b) [Pier J with jetty]	Yes	Yes	\$205.90	\$3,390	0.05

In **Exhibit 22**, the first iteration for each locale displays its current (i.e., Boston and Providence) or proposed (i.e., Long Beach) status. The current Boston facility indicates about 60 percent the potential severity of the proposed Long Beach facility, and the current Providence facility has about 20 percent of the Long Beach facility's potential (this compares with about 50 percent in the Clarke study). While these estimated average severities are within the same order of magnitude, modest

variations in local siting and mitigation strategies can affect estimated severities significantly (by more than an order of magnitude).

From a policy perspective, this exercise demonstrates a few points. First, since attack frequency cannot be accurately determined, control of potential severity is paramount. Thus, siting of LNG receiving facilities near other critical infrastructure or near population centers should usually be avoided. Next, siting of LNG facilities in areas with low densities at least four miles from population centers and at least two miles from major shipping channels to minimize the exposure of people and property to potential harm is strongly preferred in the regulatory approval process. Moreover, full containment of facility tanks should be mandatory, and the potential for separation of the LNG receiving facility from the LNG ship dock facilities by use of a receiving jetty with mooring and berthing facilities should be considered, especially when siting in higher density areas is preferred for economic or other strategic purposes. Siting, containment, and defense strategies should incorporate multidisciplinary design optimization techniques.

ENDNOTES

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- ¹ This was signed into law on August 8, 2005, by President George W. Bush.
- ² See www.energy.ca.gov/lng/documents/long_beach/2004-02-02_FERC_CP04-58-000.PDF.
- ³ LNG hazards result from three of its properties: cryogenic temperatures, dispersion characteristics, and flammability characteristics.
- ⁴ Usually, these events are assumed to occur randomly and most are not site specific.
- ⁵ Given a terrorist attack that is successful from the attackers' point of view.
- ⁶ For example, in Long Beach, the range of typical air and water temperatures is approximately between 40 degrees and 90 degrees Fahrenheit.
- ⁷ This facility was also the site of the first LNG catastrophe. Shortly after a new storage tank containing a 3% nickel/steel composition was installed, the tank failed due to the extreme cold (9% nickel/steel is required to prevent brittle steel at extremely low temperatures—reportedly, the tank-makers were attempting to “cut corners” during the World War II military drain on commodities), and the resultant LNG spill flowed into local storm drains while regasifying. When the confined gas was exposed to an ignition source, the blast killed 128, injured more than 300 and leveled almost one square mile of the local environs.
- ⁸ Source: www.fe.doe.gov/programs/gasregulation/publications/LNG_Feb05.pdf
- ⁹ Currently, a majority of the world's LNG supply comes from areas with large natural gas reserves. These areas include Alaska, Algeria, Australia, Bolivia, Brunei, Indonesia, Libya, Malaysia, Nigeria, Oman, Qatar, Siberia and Trinidad and Tobago.
- ¹⁰ One kilometer of stainless steel pipe, when cooled by 360 degrees F, will contract by nearly three meters.
- ¹¹ “Liquified Natural Gas in California; History, Risk and Siting.” California Energy Commission Staff White Paper 700-03-005. July 2003.
- ¹² *Areal Locations of Hazardous Atmospheres* (ALOHA) is a program that predicts rates at which chemical vapors escape into the atmosphere from spills and that predicts how the gas cloud will disperse in the atmosphere after a chemical release. ALOHA is a gas dispersion modeling software. Dispersion includes the advection (moving) and diffusion (spreading) of gases. A dispersing vapor cloud will generally move (advent) in a downwind direction and spread (diffuse) in a crosswind and vertical direction (crosswind is the direction perpendicular to the wind). A gas cloud that is denser than air (also known as a heavy gas) can slightly spread upwind. ALOHA models the dispersion of a gas in the atmosphere and displays an overhead view of the area (footprint) in which it predicts gas concentrations typically representative of hazardous levels. Such concentrations are called the Levels of Concern (LOC). The footprint represents the area within which the concentration of a gas is predicted to exceed a LOC at some time during the release. For example, our selected LOC for methane is 50,000 ppm (or 5% of the atmosphere) or its Lower Explosive Limit (LEL). ALOHA uses simplified heavy gas dispersion calculations that are based on the DEGADIS model (Spicer and Havens 1989), one of several well-known heavy gas models. Thus, ALOHA's results are unreliable under very low wind speeds, very stable atmospheric conditions, wind shifts and terrain steering effects, or concentration patchiness, particularly near the spill source, and ALOHA doesn't account for the effects of fires or chemical reactions, particulates, chemical mixtures, and terrain.
- ¹³ If the terrorists use a big jet or multiple jets, their probability of success falls dramatically. A 717 is a relatively small 100 passenger commercial airliner.
- ¹⁴ A number of refereed journal articles are dedicated to simulating the crash of an aircraft into a concrete structure such as the full containment storage tanks to be constructed at the Long Beach SES LNG receiving facility. (e.g., T. Sugano et al. “Full-scale aircraft impact test for evaluation of impact force,” Nuclear Engineering and Design, Vol. 140, 373-385, 1993.) Partially as a result of these studies, provisions for aircraft impact on reinforced concrete structures are incorporated into the Civil Engineering codes used for the design of nuclear containment structures. For example, a full-scale test was conducted by Sugano to measure the impact force exerted by fighter aircraft (F-4D) on a reinforced concrete target slab. This study provided information on the deformation and disintegration of the aircraft. A simplified computational model was also developed in order to capture the overall impact. This study provides experimental evidence that an airframe and the skin of an aircraft alone are not likely to cause the major damage on impacted reinforced concrete targets. The most massive impacting element would be the fuel, as evidenced by the Pentagon impact of September 11, 2001. (e.g., Popescu, V., Hoffmann, C., Kilic, S., and Sozen, M. “Producing high-quality visualizations of large-scale simulations,” Purdue University Computer Science Dept., Tech. Report 03-011, West Lafayette, Indiana, 2003.) The fuselage of the aircraft has little strength at impact, as confirmed by the Pentagon simulation and validated by the actual F-4D experiments. The simulation shows that the structural damage occurs only when the fuel mass hits. For this reason, our original scenario for a terrorist event (i.e., the

use of a small private jet commandeered from Torrance Zamperini airport) should be replaced by a scenario that would more probably assure “success,” the simultaneous hijacking of fully-fueled Boeing 717-class or larger airliners from LAX and LGB with each aircraft targeting none of the LNG tanks. The increased mass coupled with the fuel fires should enable successful breaches of the LNG storage tanks.

¹⁵ For example, for Long Beach, \$83 billion was estimated by valuing each fatality at \$5 million, each injury at \$100,000, the LNG facility at \$400 million, an LNG ship at \$240 million, local property damage at \$4.36 billion, and ongoing economic impacts at \$50 billion (primarily in terms of short- and medium-term reduced port trade).

¹⁶ CAMEO is a suite of software programs for planning and response to chemical emergencies. It was developed by the U.S. Environmental Protection Agency's Office of Emergency Prevention, Preparedness and Response (www.epa.gov/swercepp) and the National Oceanic and Atmospheric Administration's Office of Response and Restoration (response.restoration.noaa.gov). CAMEO includes a set of databases, a toxic gas dispersion model called ALOHA, and an electronic mapping program called MARPLOT.

¹⁷ 200 million pounds is the software maximum.

¹⁸ Note that selecting the frequency of a terrorist event at a specific locale in a given period of time is difficult, if not impossible, because of the paucity of data. As a starting point, one might consider discrete frequency distributions, distributions that often involve counts of occurrences such as terrorist events. Typically, actual distributions of such events may be represented by a table that records the $n \cdot k$ of the observations that pertain to the outcome value k wherein $k = 0; 1, \dots$. For such data, we may wish to estimate the frequencies for all possible outcome values k . This goal can be approached by examining how closely such data are represented by particular discrete probability distributions, for examples, the binomial, the Poisson, the geometric, and the negative binomial distributions. The binomial distribution applies when there are two possible outcomes. In a binomial, the probability p of obtaining either outcome (usually known as a “success” or a “failure”) in a single iteration is known, and the distribution represents the chance of obtaining a certain number of successes in a certain number n of trials. The Poisson distribution applies when there are a number of discrete(, often rare) events occurring in a certain time period. The average number of counts is known, and the distribution represents the chance of actually observing various numbers of objects or events. There is a close connection between the Poisson and binomial distributions. Indeed, the Poisson distribution can be viewed as the limiting case of a binomial distribution as n approaches infinity and p approaches zero, $n \cdot p$ remaining constant. The geometric distribution describes the number of trials including the first success in independent trials with the same probability of success. The geometric distribution depends only on the single parameter p , the probability of success in each trial. The geometric distribution assigns probability $p \cdot (1 - p)^{k-1}$ to the event that it takes k trials to the first success. The expected value of the geometric distribution is $1/p$, and its variance is $(1-p)/p^2$. Thus, the geometric distribution defines the number of failures before the first success. Similarly, the negative binomial distribution describes the number of failures before the n^{th} success. Clearly, of these four common discrete distributions, the most likely candidates to describe a discrete terrorist event's occurrence are the binomial and the Poisson. In order to select the more appropriate distribution between these two, perhaps we should consider that the occurrence of one terrorist event is likely to be related to the occurrence of other terrorist events in the same period such that variance increases with frequency.

Considering that, in the case of a Poisson regression model, the predicted variance equals the predicted mean, if the observed variance of the data is likely to be larger than the predicted variance, then the Poisson may not be an appropriate model due to concerns about overdispersion. Thus, based on theoretical considerations, the binomial distribution may be most appropriate. Given that the selected distribution is binomial, estimates of its parameters are necessary to model the frequency of expected terrorist events at one of these proposed LNG facilities. Using data from the MIPT Terrorism Knowledge Base, we estimated that between three and 26 terror incidents occur annually in the United States at locations of potential similar impact as these. Assuming that these would be among the 100 most probable targets nationwide (with a one percent conditional probability of an incident) and that the LNG receiving facility and its docked LNG tanker would be among the five most probable local targets (with a twenty percent conditional probability), we further estimated that a binomial distribution could serve as a reasonable base frequency. The selected, estimated rate of terrorist attacks on the Port of Los Angeles and Long Beach was 1 in 230 per five years, and, for the LNG facility, 1 in 1150 per five years.

¹⁹ See **Figure A** to note graphically the portions of the decision tree that correspond to these questions.

²⁰ Within each decision to attack, there is a sub-decision to attack either the larger, fixed tanks or the more vulnerable tanker. Such tankers are equipped with up to five LNG cargo tanks housed inside a double walled hull. To unload, it takes an average of 12 to 15 hours. The probability for a successful breach using an airplane directed at the tanker during the tanker's port entry, docking, and unloading process represents a substantial

increase over the probability of a facility full containment tank breach. Since spilled LNG disperses faster on the ocean than on land, water spills provide very limited opportunity for containment. LNG also vaporizes more quickly on water because large bodies of water provide an enormous heat source. For these reasons, the risks associated with shipping, loading and off-loading LNG are generally considered much greater than those associated with land-based storage facilities. Also, due to its practical requirements as a floating mode of transport, an LNG tanker ship cannot be as fully secured as a full containment land-based tank.

²¹ The economic impacts in this paper include the deaths and injuries valued at \$5 million and \$100,000 apiece, respectively.

²² This jetty could be constructed, in part, by moving all or a portion of the existing Long Beach Breakwater. This breakwater is part of the Long Beach-Los Angeles breakwater system that extends from San Pedro's Cabrillo Beach to the Alamitos Bay jetties of eastern Long Beach. It is the longest man-made breakwater in the world. The breakwater system consists of three breakwaters. The Federal Breakwater protects Los Angeles Harbor. The Middle Breakwater was originally built to protect the Long Beach Naval Shipyard and Long Beach Harbor, and it currently provides shelter to Long Beach Harbor. The easternmost segment, the Long Beach Breakwater, was built to provide protected anchorage for the Pacific Fleet (during the time it was based in Long Beach). The 13,350-foot Long Beach Breakwater consists of boulders quarried from Catalina Island and is approximately two miles offshore at an average depth of sixty-five feet.

²³ This represents the lower limit of atmospheric concentration at which an ignition source will combust the methane-air mixture.

²⁴ This compares to Richard Clarke's "implicit" estimate of \$42.3 billion (8000 fatalities at \$5 million apiece, 20,000 injuries at \$100,000 apiece, and \$293 million in economic damages from the report titled LNG Facilities in Urban Areas: A Security Risk Management Analysis for Attorney General Patrick Lynch Rhode Island by Principal Investigator Richard A. Clarke dated May 2005.