BY THE COMPTROLLER GENERAL

Report To The Congress

OF THE UNITED STATES

Liquefied Energy Gases Safety

MASTER

VOLUME 1 OF THREE VOLUMES

Liquefied energy gases--liquefied natural gas, propane, and butane--could become an increasingly important part of U.S. energy supplies, but moving and storing these liquefied gases pose serious dangers. To minimize the public risk involved in meeting the country's needs for these fuels:

--Future facilities for storing large quantities of these gases should be built in remote areas.

--Facilities already in other than remote areas should not be permitted to expand in size or in use, and the safety of each should be evaluated by the Federal Government.

--Large quantities of liquefied energy gases should not be transported through densely populated areas unless delivery is otherwise impossible.

--The Congress should consider consolidating into one agency many Federal responsibilities for evaluating and controlling the adverse consequences on energy operations.

--The Congress should create a Federal Hazardous Materials Compensation Fund to supplement private liability insurance.

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JULY 31, 1978

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COMPTROLLER GENERAL OF THE UNITED STATES
WASHINGTON, D.C. 20548

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To the President of the Senate and the
Speaker of the House of Representatives

This report presents our analysis of the critical safety issues in transporting and storing liquefied energy gases--liquefied natural gas and liquefied petroleum gases (propane and butane). We have identified what we believe to be significant problem areas that warrant the immediate attention of the Congress and the cognizant Federal agencies.

We made the review pursuant to our authority in the Budget and Accounting Act, 1921, 31 U.S.C. 53 (1970); the Legislative Reorganization Act of 1970, 31 U.S.C. 1154 (Supp. V 1975); and the Federal Energy Administration Act of 1974, 15 U.S.C. 771 (Supp. V 1975), made applicable to all of the Department of Energy by Section 207 of the Department of Energy Organization Act (Public Law No. 95-91).

If liquefied energy gases spill from their tanks, they vaporize rapidly and become highly flammable and explosive. A major spill in a densely populated area--whether by accident, natural forces, or sabotage--could result in a catastrophe. Because of the potential danger and the possible increase in the use of these liquefied gases, we believe that it is appropriate now to take any needed actions to protect the public.

We believe that future, large-scale liquefied energy gases facilities should be located away from densely populated areas; that any such existing facilities should not be permitted to expand, in size or in use; and that present urban facilities should be carefully evaluated to ensure that they do not pose undue risk to the public.

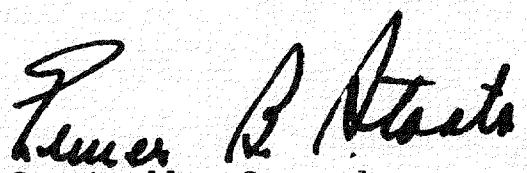
We believe that large quantities of these substances should not be transported through densely populated areas unless they cannot otherwise be delivered. We also see the need for the Congress to consider consolidating in a single Federal Energy Health and Safety Regulatory Agency many such responsibilities currently scattered throughout many departments and agencies.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

The report is presented in three volumes. Volume 1 contains the Executive Summary and the report chapters; Volume 2, the appendixes that support and supplement the chapters; and Volume 3, the full texts of the official comments we received from Federal agencies.

In the Executive Summary, we have attempted to summarize and simplify the most significant points from the chapters.

Copies of this report are being sent to the Secretaries of Commerce, Energy, State, and Transportation; the Chairman of the Interstate Commerce Commission; the National Transportation Safety Board; and the chairmen of energy related congressional committees and subcommittees.



Comptroller General
of the United States

EXECUTIVE SUMMARY

OF

LIQUEFIED ENERGY GASES SAFETY

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ABBREVIATIONS

DOE	Department of Energy
DOT	Department of Transportation
FPC	Federal Power Commission
GAO	General Accounting Office
ICC	Interstate Commerce Commission
LEG	Liquefied Energy Gas (LNG and LPG)
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas (Propane and Butane)
OHMO	Office of Hazardous Materials Operations (DOT)
UBC	Uniform Building Code

SECTION 1

INTRODUCTION

CONTENTS

This Executive Summary contains brief discussions of the critical safety and security issues covered in GAO's full report, Liquefied Energy Gases Safety (EMD-78-28). The report consists of three volumes.

--Volume 1, the Executive Summary and the main text.

--Volume 2, appendixes that support and supplement the main text.

--Volume 3, comments on a draft of this report by the Departments of Commerce, Energy, State, and Transportation, the Interstate Commerce Commission, and the National Transportation Safety Board.

This Executive Summary highlights GAO's findings, conclusions, and recommendations. The body of the report contains the full supporting data and additional, more detailed conclusions and recommendations.

PURPOSE OF THE STUDY

Energy gases are liquefied in order to reduce their volume hundreds of times. This facilitates their transportation and storage, but magnifies the potential hazard.

Liquefied energy gases (LEG) are often transported and stored in densely populated areas. If these liquids spill

from their containers, they rapidly vaporize and become highly flammable and explosive gases. One cubic meter of liquefied natural gas (LNG) makes 424,000 cubic feet of highly flammable natural gas-air mixture. One cubic meter of liquefied petroleum gas (LPG) makes a slightly larger volume of flammable gas-air mixture. A major spill in a densely populated area, whether by accident, natural forces, or sabotage, could be catastrophic.

Because of this potential danger and the possible increase in the use of these liquefied gases, LEG safety issues should now be carefully examined and any needed actions taken to protect the public.

This report analyzes these safety issues, identifies problem areas, and recommends corrective actions to the Congress and the cognizant Federal agencies. We believe that the Nation's LEG needs can be met without posing undue risk to the public if the recommendations developed in this report are adopted by the Congress and the Federal agencies involved.

A BRIEF PRIMER

Although there are many differences in their physical properties and technologies, LNG and LPG are similar substances and have many safety and security problems in common. This has made it convenient to consider them together as LEG. Naphtha,

a less hazardous substance, is included in the report to compare its regulations and handling with those of LEG.

LNG, LPG, and naphtha together make up about 3 percent of the energy used in this country. They are produced domestically and are imported. All three are used to supplement domestic natural gas supplies. As America's energy demand grows, imported LNG and LPG are likely to become increasingly important energy sources. LPG and naphtha also have important industrial applications.

Physical Properties of LEG and Naphtha

Natural gas is an odorless, colorless mixture of hydrocarbons, 65 to 99 percent methane, with smaller amounts of ethane, propane, and butane. Chilled to -260 degrees (F), the gas becomes a liquid about one-600th of its volume at atmospheric pressure. Therefore, a tank of LNG has 600 times as much energy as an equal-sized tank of natural gas.

LPG (propane and/or butane) is processed from natural gas or crude oil. Both propane and butane liquefy under pressure at atmospheric temperature, or when cooled at atmospheric pressure. Propane liquefies at -44 degrees (F); butane at 31 degrees (F).

Naphtha is a group of heavier hydrocarbons separated from crude oil in the refining process. It is transported and stored as a liquid at atmospheric temperature and pressure.

LNG and LPG will only burn at the surface of the liquid. When spilled, however, both substances quickly vaporize.

Because LPG vapor and cold LNG vapor are heavier than air, a spill forms a low spreading cloud, which becomes highly flammable as it mixes with air. An LNG vapor cloud is flammable when the LNG concentration is between 5 and 14 percent (the balance being air). The flammable range of an LPG cloud is between 2 and 9 percent LPG.

Naphtha is between kerosene and gasoline in volatility. All three, being liquids at atmospheric temperatures and pressures, are much less volatile than LNG and LPG; that is, they evaporate much more slowly.

Overview of LNG Storage and Transportation

In the summer, when natural gas demand is low, some excess gas is liquefied and stored in highly insulated tanks. A typical LNG storage tank can hold 95,000 cubic meters--enough to make nearly 2 billion cubic feet of natural gas. When demand peaks in cold weather, the LNG is either regasified and pumped through gas pipelines to customers, or delivered by truck to other gas companies where it is similarly processed.

Such "peakshaving" plants have been operating in the United States for several years. Most large LNG storage facilities are for peakshaving. There are currently 45 of these which hold more than 23,000 cubic meters. There are about 75 LNG trucks, each with about 40 cubic meters capacity.

Recently, LNG has been imported in ships. These imports, which now supply less than one-tenth of one percent of U.S.

natural gas demand, could supply up to 15 percent by 1985.* This would require more than 40 LNG tankers to operate regularly in and out of U.S. harbors. A typical new LNG tanker carries about 125,000 cubic meters.

The 14 major LNG import terminals now operating throughout the world are "base-load" facilities. The LNG is piped from the ship to storage tanks from which it is constantly regasified or re-shipped, instead of being saved for peak demand periods.

There are two LNG import terminals currently operating in this country. The Everett, Massachusetts terminal began operations in 1971. The new Cove Point, Maryland terminal began operations in March 1978, and the Elba Island, Georgia terminal is ready to begin. One other terminal is under construction, and several more have been proposed.

Overview of LPG Storage and Transportation

The much greater use of LPG has drawn less public attention than the relatively new LNG industry. LPG has been used for many years for a variety of purposes, including making synthetic natural gas and providing power on farms.

About 85 percent of the LPG in bulk storage is kept under pressure in underground salt domes or mined caverns. LPG is also stored in aboveground tanks, many of which are small.

*Office of Technology Assessment, Transportation of Liquefied Natural Gas, September 1977, p.5.

There are only 20 LPG aboveground storage facilities that hold more than 23,000 cubic meters.

Domestic transportation of LPG is mostly by pipeline, with the remainder distributed in trucks or railcars. There are 70,000 miles of LPG high-pressure pipeline, 16,000 LPG rail cars, and 25,000 LPG transport and delivery vehicles. A large LPG truck trailer holds about 40 cubic meters.

Ten major LPG import terminals are now operating in the United States, and imports of LPG may rise substantially. LPG ships are smaller than LNG ships; typical new ones hold 75,000 cubic meters.

SECTION 2

LEG STORAGE FACILITIES

VULNERABILITY TO NATURAL FORCES

LEG storage tanks are usually designed to the Uniform Building Code (UBC) standards for their particular geographic areas, the same standards used for most inhabited buildings. They essentially require that LEG tanks be able to withstand the largest earthquake, wind, flood, etc., locally experienced in the last 50, 100, or 200 years.

The probability of these natural forces exceeding UBC standards at a given site in a given year is low. However, the probability that the standards will be exceeded some time at some facility increases with the number of facilities and with the number of years each facility operates.

Because there are already many large LEG facilities, it is virtually certain that during their lifetime many of them will experience natural forces greater than those the UBC standards require them to withstand. This does not necessarily mean that the facilities will fail. The UBC standards are minimum criteria, and most structures have built-in "safety margins"--they are designed to be stronger than the standards require.

By "failure" of a tank, we mean a permanent distortion or rupture that causes significant leakage of the contained fluid. A failure is not necessarily a complete collapse.

We evaluated the LEG tank designs at five sites and found that, while they were adequately designed for the UBC earthquake and 100-year wind criteria, tanks at three of the sites had very small earthquake safety margins--two of these three sites, containing three large tanks, are located next to each other in Boston Harbor.

Nuclear power plants are built to higher standards than any other type of energy installation, much higher than those for LEG installations. Nevertheless, they are never located in densely populated areas. We believe that new large LEG facilities also should not be located in densely populated areas.

Most LNG storage tanks have double metal walls with insulation in between. Some are made of prestressed concrete. LPG and naphtha tanks have single walls.

The outer steel walls of LNG tanks are not normally made to withstand intense cold. Thus, if the inner tank alone fails for any reason, it is almost certain that the outer tank will rupture from the pressure and thermal shock.

The most likely cause of failure of large steel LEG tanks in an earthquake appears to be from breaking the steel straps which anchor the steel tank sides to the concrete foundation. The tank's walls will then separate from its bottom, causing a massive spill.

Large LEG tanks made of prestressed concrete are usually much more resistant to natural forces than those made of steel.

THE ABILITY OF DIKES TO CONTAIN LARGE SPILLS

National Fire Protection Association standards require that each large LEG tank, or group of tanks, be surrounded by a dike which can hold at least the volume of the largest tank. However, most of these dikes are only designed to contain LEG spilled from relatively slow leaks. They cannot contain the surge of LEG from a massive rupture or collapse of a tank wall.

We selected six LEG facilities--with dikes built to National Fire Protection Association criteria--and calculated how much liquid could escape over the dikes. Our calculations were verified by experiments.

Our results indicate that a massive rupture or collapse of a tank wall could spill over 50 percent of the LEG at five of the facilities. The sixth facility would probably spill no more than 13 percent of its LEG, because it has a close, high dike--however, a force that could destroy the tank might also destroy this dike.

The following table shows the maximum calculated spillage from single tanks at each of the six facilities.

Facility	Volume spilled (cubic meters)	Percent of tank capacity spilled
Algonquin LNG, Providence, RI	52,000	55
Columbia LNG, Cove Point, MD	31,200	52
Distrigas, Everett, MA		
Tank 1	37,200	62
Tank 2	60,800	64
Philadelphia Electric, Philadelphia, PA	7,100	13
Southern Energy, Elba Island, GA	36,500	58
Exxon LPG, Everett, MA	36,500	58

Our calculations assumed an immediate, total spill of a full tank, with the fluid moving toward the nearest dike wall. Such an LNG spill occurred in Cleveland in 1944. A similar, much larger LPG spill occurred in the country of Qatar in 1977.

THE ADVANTAGE OF INGROUND LNG STORAGE

Liquid spills from inground tanks are nearly impossible. Many LNG tanks in Japan, the world's largest importer of LNG, are built in the ground for greater safety. Japanese inground tanks are operating satisfactorily and cost about the same there as aboveground tank and dike installations.

VULNERABILITY TO SABOTAGE

Public utilities and petroleum companies in this country have often been the targets of sabotage. Many domestic and foreign groups have the weapons, explosives, and ability to sabotage LEG facilities. Successful sabotage of an LEG facility in an urban area could cause a catastrophe.

We found that security procedures and physical barriers at LEG facilities are generally not adequate to deter even an untrained saboteur.

None of the LEG storage tanks we examined are impervious to sabotage, and most are highly vulnerable. Some designs provide greater protection than others against explosive penetration. Stronger designs complicate sabotage by requiring

specially designed charges, more powerful explosives, and more on-site preparation. Concrete tanks are much more resistant to penetration than single-wall LPG tanks. Double-wall metal LNG tanks fall in between.

In many facilities, by manipulating the equipment, it is possible to spill a large amount of fluid outside the diked area through the draw-off lines.

LEG storage facilities in cities are often adjacent to sites that store very large quantities of other hazardous substances, including other volatile liquids. Thus, a single cause might simultaneously destroy many tanks, or a spill at one facility might cause further failures at adjacent facilities.

MAJOR CONCLUSIONS AND RECOMMENDATIONS

Conclusions

--It is virtually certain that the level of natural forces LEG facilities are required to withstand will be exceeded at many facilities in the next 50 years. This could lead to tank failure, particularly where safety margins are low.

--Little attention has been paid to sabotage at LEG facilities, and most of them are inadequately protected and highly vulnerable to sabotage. Sabotage could also lead to tank failure.

--If an LEG tank fails in a densely-populated urban area, it could cause a catastrophe.

--In the event of a massive rupture or collapse of a tank wall, over 50 percent of the LEG could escape over the dikes at five of the six LEG facilities we examined.

Recommendations to Federal Agencies

1. We recommend that the Secretaries of Transportation and Energy and the Federal Energy Regulatory Commission take steps to ensure that

--all new, large LEG storage facilities are built in remote areas; and

--no existing, large LEG storage facilities in other than remote areas are expanded in size or in use.

2. If, despite our recommendation, new, large LEG storage facilities are built in other than remote areas, or existing ones are expanded in size or use, we recommend that

--all storage tanks be in the ground with the highest level of fluid below ground level; or

--all storage tanks be built and operated to standards similar to those applied to the construction and operation of nuclear plants.

3. We recommend that the Secretary of Energy evaluate each existing, large LEG storage facility and recommend to the President and the Congress the actions necessary to protect the public from the hazards associated with them.

Recommendations to the Congress

We recommend that the Congress:

--Enact legislation requiring that guards at LEG facilities carry weapons and be authorized to use them if necessary to avert sabotage.

--Enact legislation extending Federal authority to cover large LEG storage facilities which are presently not covered by Federal regulation.

SECTION 3

LEG TRANSPORTATION

LEG SHIPS

LNG ships, which hold up to 165,000 cubic meters, are probably the least vulnerable of all the systems involved in LNG transportation and storage. They are double-hulled and have insulated cargo tanks made of welded 9 percent nickel-alloy steel or aluminum alloy, both of which can withstand intense cold. Two basic types of tanks are used--free standing tanks which are anchored in the ship's hull, and "membrane" tanks supported by insulation lining the hull. The double hull helps protect against collisions or sabotage.

On the other hand, most LPG and naphtha ships are single-hulled, and are thus much less resistant to collisions and sabotage than LNG tankers. The largest new LPG ships hold 100,000 cubic meters.

Ships are most susceptible to collision while entering ports through narrow, winding ship channels. They are most vulnerable to sabotage while tied up at terminals.

Since human error is a contributing factor in 85 percent of all marine casualties and operating problems, the best precaution against accidents and sabotage is to have highly-skilled, well-trained personnel operating the ships, ports, and terminals.

We have studied the Coast Guard's port operating procedures, and the training requirements for LEG ships' crews, and believe that they need to be improved.

Most Coast Guard personnel, including some Hazardous Materials Officers, have little training in LEG hazards.

Some training for ships' crews is covered in the Coast Guard's proposed Tankerman Requirements. We do not believe these proposed requirements will be adequate, because

--only one or two crew members responsible for cargo handling are required to receive formal training;

--requirements for practical experience are inadequate; and

--instruction in emergency procedures is not required.

We found similar weaknesses in the training requirements being considered for LNG terminal personnel. These are included in the Coast Guard's contemplated Waterfront Facilities Regulations for LNG in Bulk, and in the LNG terminal regulations being considered by the Office of Pipeline Safety Operations of the Department of Transportation (DOT). Similar regulations for LPG waterfront facilities have not yet been proposed.

The Coast Guard inspects all LNG ships before they enter U.S. harbors. These inspections do not include the operating condition of control equipment such as steering engines, propulsion machinery, and electronic devices.

In February 1976, the Coast Guard issued Liquefied Natural Gas - Views and Practices, Policy and Safety. The publication

offers valuable guidance, but its procedures are not mandatory. Its implementation is left to the discretion of each Captain of the Port. It is the Captain of the Port who decides whether malfunctions in ships' safety systems are serious enough to bar their entry into a U.S. harbor. There are no specific Coast Guard guidelines covering LPG.

Another problem is the proximity of some shipping channels to airports. For example, LEG tankers regularly enter Boston Harbor through a shipping channel adjacent to Logan International Airport. On one occasion, an airplane crashed into the seawall of the shipping channel. The Federal Aviation Administration plans to adopt our suggestion that landings on the adjacent runway be suspended during the few minutes that an LEG ship in the channel is in line with the runway.

LEG TRUCKS

While LEG trucks carry only 40 cubic meters, far less than LEG ships, they move routinely through major metropolitan areas, where a relatively small spill can have very serious consequences.

LNG truck trailers have a higher center of gravity than most tank trucks, which makes them particularly susceptible to rolling over. However, they have inner and outer tanks with insulation in between and thus are quite resistant to puncture and cargo loss. LPG trucks also have a high center of gravity, although lower than LNG trucks; but they are single-walled and

pressurized, and are therefore more vulnerable than LNG trucks to cracks and punctures and more likely to explode in fires.

We confirmed through discussions with LNG transport companies at least 12 LNG trailer accidents. Two of the accidents, which led to LNG spills, pointed out two vulnerable areas on LNG truck tanks--the unprotected portion of the trailer face, and the rear piping.

There have been many LPG truck accidents, some with severe consequences. For example, a 1975 LPG truck accident near Eagle Pass, Texas, caused explosions which killed 16 people and injured 45.

If an LEG truck fell from an urban elevated highway, it would probably split open on the street below. LEG and its vapors could then flow down into sewers, subways, and basements. Because of its low boiling point, LEG would quickly vaporize, generating a pressure which would spread the invisible, odorless, explosive gas. The 40 cubic meters of LNG in one truck, vaporized and mixed with air in flammable proportions, are enough to fill more than 110 miles of 6-foot diameter sewer line, or 15 miles of a 16-foot diameter subway system. Other types of large trucks have fallen off urban elevated highways.

DOT has no special inspection program for LEG trucks. For all U.S. trucking, there are only 128 inspectors to monitor 160,000 licensed carriers and 3 million commercial vehicles.

The Interstate Commerce Commission (ICC) issues special certificates for LNG transport, but LNG can also be hauled

under ICC certificates for the bulk transportation of petroleum products or liquid chemicals. An ICC certified company can hire 'leased operators' to operate under its certificate. This means that LNG may be trucked by companies which have not had to prove their competence to ICC. ICC certificates do not restrict truck routes.

LEG trucks could be easily hijacked or sabotaged. A truck might be hijacked for extortion or for malicious use of the cargo. Trucks that routinely operate over established routes are easy targets for saboteurs. LEG trucks are particularly dangerous, because they allow the easy capture, delivery, and release of a large amount of explosive material any place the terrorist chooses.

LPG RAILCARS

Ten percent of America's 1.7 million railroad freight cars are hazardous materials tank cars. About 16,000 of these, each with approximately 115 cubic meters capacity, carry LPG. LNG is not transported by rail.

LPG cars are involved in many of the 10,000 railroad accidents that occur in this country each year. There are often more than 10 consecutive LPG cars on a train. If vapors from one LPG car ignite, the fire may cause a second, unpunctured car to rupture in a "Boiling Liquid Expanding Vapor Explosion," or BLEVE. Each fire and explosion contributes to

the heating and weakening of neighboring cars and makes additional explosions more likely. A BLEVE can rocket a 45,000 pound steel section of a tank for a quarter of a mile. This is what happened in a derailment near Oneonta, New York, in 1974. LPG vapor from a crushed LPG car quickly ignited and formed a fireball. Fire fighters attempting to cool down several other LPG cars were caught in a subsequent explosion; 54 were injured.

Other types of LPG railroad accidents have also occurred. In a 1974 railyard accident near Decatur, Illinois, an LPG railcar was punctured; the resulting cloud did not ignite immediately, but spread and then exploded over an area one-half by three-quarters of a mile. There were 7 deaths, 349 injuries, and $24 million in damages. Litter and debris from the fire and explosion covered 20 blocks of the city.

The latest LPG railroad catastrophe occurred February 1978, in Waverly, Tennessee. An LPG car exploded two days after a derailment, apparently as a result of internal damage during the accident and a rise in the atmospheric temperature. Fifteen were killed and over 40 injured.

LPG railcars travel through densely populated areas of cities, even cities which prohibit LPG storage. If these LPG railcar accidents (or the LEG truck accidents) had occurred in densely populated areas, far greater damage might have resulted.

The LPG industry and DOT recognize the danger in LPG rail movement, and have collaborated in identifying and correcting deficiencies in tank car design. In September 1977, as a result of a long inquiry, DOT amended its regulations to require that all LPG tank cars have safer couplers, headshields, and thermal protection; old cars were required to have the safer couplers by June 30, 1979, and headshields and thermal protection by December 31, 1981. However, after the Waverly accident, subsequent recommendations from the National Transportation Safety Board, and Congressional inquiries, DOT has proposed regulations to require the couplers by December 31, 1978, and the other features by December 31, 1980.

DOT and the industry oppose restrictions on LPG railcar routing for several reasons. These include:

--it is simpler and cheaper to regulate tank car design than tank car movement;

--trains move more slowly in congested areas, decreasing the chance of an accident; and

--some accidents occur while handling and switching cars, more of which would be necessary in circuitous routing.

DOT believes that the new regulations for tank car construction are sufficient for their safe operation. We believe that restriction of routes is also necessary.

LPG tank cars are as vulnerable to sabotage as LPG trucks. The tanks can be breached with readily available weapons and

explosives, and the cars can be derailed at predetermined times and places. The fact that they must stay on the tracks, however, greatly limits the possibility of hijacking and the places they can be taken.

THE LOCATION OF IMPORT TERMINALS

Locating LEG import terminals in non-urban areas would be an important safety step.

Existing and planned non-urban LPG import terminals will have the capacity to receive all projected LPG imports in 1985. We did not determine the cost of distributing the LPG from those terminals.

With some expansion, existing and planned non-urban LNG terminals could handle all of the LNG imports projected between now and 1990. We did not look at the capacity of the main gas transmission lines to distribute this gas to customers. To our knowledge, the Federal Power Commission (disbanded with the formation of DOE) has not considered the alternative of using only non-urban sites to receive all LNG imports.

MAJOR CONCLUSIONS AND RECOMMENDATIONS

LNG ships are probably the least vulnerable of all the systems involved in LNG storage and transportation. LPG and naphtha ships with single hulls are more vulnerable than LNG

ships in the event of an accident or sabotage. No plans or equipment exist to cope with a major LEG spill. If the Coast Guard is to effectively supervise the increasing number of LEG cargo transfer operations, it will need more money and manpower, revised regulations, and new plans and policies.

LEG trucks and railcars moving through densely populated areas pose a serious threat to public safety. The dangers present in trucking LEG are far greater than those involved in trucking less volatile petroleum products such as fuel oil, naphtha, and gasoline. Both LEG trucks and LPG railcars are vulnerable to accidents and sabotage. An LEG spill in a densely populated area could lead to a catastrophe.

We recommend that the Secretary of Transportation and the ICC:

--Prohibit trucking of LEG through densely populated areas and any areas that have features that increase the vulnerability to a major LEG spill (e.g., sewer systems, tunnel openings, subways) unless delivery is otherwise impossible. DOT should also give particular attention to avoiding routes with highway configurations which make tank rupture accidents likely (e.g., elevated roadways, overpasses, high-speed traffic, roadside abutments).

--Prohibit the travel of LPG railcars through densely populated areas unless it is impossible to deliver the LPG otherwise.

We also recommend that the Secretary of Transportation:

--Develop a computer program able to analyze the capability of the national LPG storage and distribution system. Such a program should be able to determine the rate at which LPG can be delivered (as LPG or as synthetic natural gas) from any point to any other point and the cost to increase this capability by any desired amount.

We recommend that the Secretary of Energy and the Federal Energy Regulatory Commission:

--Require a staff study of the feasibility of using only non-urban sites to receive all LNG imports and developing a gas exchange program using existing pipelines to ensure appropriate distribution of gas supplies.

SECTION 4

THE POTENTIAL CONSEQUENCES

THE EFFECTS OF A LARGE LEG SPILL

While LEG storage and transportation in densely populated areas are very hazardous, it is difficult to estimate the effect of a large LEG spill.

The only significant U.S. LNG spill, in Cleveland in 1944, involved a relatively small amount compared to the quantities stored in urban areas today, about one-fifteenth of one large modern tank.

Some insight can be gained from the spill of naphtha into the sewers of Akron, Ohio, in June 1977. Although naphtha is much less volatile than LEG and less than 15 cubic meters were spilled, the incident caused violent explosions more than 8 miles from the point of the spill.

LEG vapors are highly explosive in confinement, and can explode in the open air--although the conditions which allow this are not completely understood. In Port Hudson, Missouri, in 1970, a relatively small propane leak from a pipeline break led to a large detonation propagating through the open air.

If LEG spreads across a city through sewers, subways, or other underground conduits, or if a massive burning cloud is blown along by a strong wind, a city may be faced with a very large number of ignitions and explosions across a wide area.

No present or foreseeable equipment can put out a very large LEG fire.

THE CLEVELAND ACCIDENT

The only major LNG spill in the United States occurred in Cleveland, on October 20, 1944. It resulted in fires and explosions that killed 130 people, injured 225 more, and resulted in property damage estimated at $7 million.

Casualties could have been much higher if the spill had taken place at a different time of day. At the time of the fire, most children were at school and most men were at work. Furthermore, the National Fire Protection Association Newsletter of November 1944 said:

> "The fact that the wind was blowing away from the congested part of the area is believed to have been a major factor in prevention of an even more devastating conflagration which could have destroyed a very large part of the East Side."

The Cleveland accident virtually halted LNG use in this Nation for 20 years.

This disaster demonstrates the danger of a spill in an urban area, and gives some indication of the potential consequences of a major LNG accident. It was the subject of three independent studies:

--A Technical Consultants Board of Inquiry for the Mayor of Cleveland.

--The Bureau of Mines of the U.S. Department of the Interior.

--The Coroner of Cuyahoga County, Ohio--whose conclusions and recommendations were included in the Mayor's report.

The accident occurred in the liquefaction, storage, and regasification (peakshaving) plant of the East Ohio Gas Company, the first peakshaving plant built in America.

At 2:40 p.m., a 4,200 cubic meter LNG tank collapsed. Although that tank and the three others were surrounded by dikes and had individual drains leading to a pit, some of the liquid escaped the site and spread into streets, storm sewers, and basements. The vapors quickly ignited, setting off explosions and fires.

About 20 minutes later, the legs holding a second tank failed from the heat, releasing another 2,100 cubic meters of LNG. The subsequent explosion shot flames more than half a mile into the air. The temperature in some areas reached 3000 degrees (F).

The following facts are significant.

--Both the tank manufacturer and the gas company assumed that a small leak would precede any more serious spill, and that it would be detected and repaired.

--The gas company took precautions to control small and moderate rates of LNG spillage. They assumed that a sudden, massive spill was extremely unlikely and,

therefore, not a matter for concern. The same assumption is made today in designing dikes around LEG facilities.

--The plant site was selected because it was already company property and was appropriately located on the gas distribution system. The company felt it was building a safe plant that could be located anywhere. Similar assumptions about the safety of LEG plants in urban areas are made today.

--The proximity of other industrial facilities, residences, storm sewers, or other conduits was not considered.

--The Cleveland accident was caused by an amount of LNG which is very small by modern standards. Less than 6,300 cubic meters of LNG spilled and a large portion of that remained on the company property. Typical large LNG storage tanks today can hold up to 95,000 cubic meters, and one site may have several tanks.

The 1945 Bureau of Mines study of the Cleveland accident contained the following recommendations, which have yet to be generally adopted.

1. Plants dealing with large quantities of liquefied flammable gases should be isolated at considerable distance from inhabited areas.
2. Extreme caution should be taken to prevent spilled gas from entering storm sewers or other underground conduits.

SECTION 5

LIABILITY, RESEARCH, AND REGULATION

LIABILITY AND COMPENSATION

A major LEG accident could cause damage of such severity that injured parties could not be fully compensated under existing arrangements. Present corporate structures and legal limits on liability offer great protection to the parent corporations. This may diminish their incentives for safety. At present, no Federal agency addresses the question of offsite liability for LEG accidents.

Each LNG ship is usually owned or leased by a separately incorporated subsidiary of a parent firm, and the LNG is stored in terminals owned by other subsidiaries. In many cases, the parent firms are wholly-owned subsidiaries of still larger firms.

Most of the assets in the system are protected by these corporate chains, and the top corporations, which derive all of the profits, would generally not be liable for the consequences of an accident. The front-line companies, which are most vulnerable to liability claims, are usually the most thinly capitalized in the chain. Most of their assets may be the ship or terminal itself, which is unlikely to survive an accident that does extensive offsite damage.

The liability of shipowners and bareboat ship charterers is limited by U.S. statute to the post-accident value of the vessel, plus any amounts owing for freight, if they can prove that they did not know about the causes of the accident.

Claimants after a major LNG accident would face long, complex, and expensive litigation involving potential complications at every step in the legal process. If the defendant corporation is foreign-owned, it and its assets may be out of reach--in fact, it may be impossible to serve legal papers on the corporation unless it maintains an agent in the United States.

It is not always possible to prove the primary cause of a major accident, since critical evidence may be destroyed by the accident itself. If the accident resulted from sabotage or natural forces, the company may not be liable at all.

Present and planned liability coverage for LNG import terminals ranges from $50 million to $190 million per incident. Ten states require proof of liability insurance for LPG facilities, but the maximum required is only $100,000 per incident.

LEG SAFETY RESEARCH

All LEG safety research has involved quantities which are very small compared to those in large commercial facilities. The Coast Guard has done some good quality hazard analyses, primarily on the effects of small LEG spills on the water.

Isolated pieces of research of varying quality have been done by other government and private laboratories around the world.

We believe that much more research needs to be done, on an expedited basis, in many areas of LEG safety. In particular, the following areas need much more attention:

--The interaction of spilled LEG with man-made structures, such as buildings, subways, sewers, and ships.

--The conditions under which a large LEG cloud ignited on its downwind side will burn back to its source.

--The conditions under which LEG clouds can detonate.

--The distances that large LEG clouds can travel, under varying atmospheric conditions, before they are safely dispersed.

The present plan to channel the bulk of LNG safety research through the Department of Energy (DOE) is faulty and will not produce timely or useful safety results. DOE plans to support LNG research in a manner analogous to its support of basic research in other areas. This is entirely inappropriate because of the number of facilities now under development, under construction, or in use. LNG facilities may only be importing for the next 20 or 30 years. The research needed for current, temporary technology is different from that which is needed for long-term and not yet perfected technologies. At the same time, the organizations responsible for safety regulations and enforcement have inadequate budgets and personnel to make informed technical judgments on safety.

LEG risk assessment studies have not reached a stage where they give confidence in their conclusions. Therefore, safety decisions cannot logically be based on them. Regulatory agencies will have to attempt to make timely, prudent decisions with the realization that many important questions cannot currently be answered with confidence.

FEDERAL, STATE, AND LOCAL REGULATIONS

LNG and LPG are very hazardous substances. Federal regulation and inspection of their importation, transportation, and storage have not been adequate to ensure the public safety.

Federal safety responsibilities are shared by many departments and agencies.

The Department of Transportation has overall authority for the movement of hazardous materials. Specific authority has been delegated to several agencies within the Department. Among them:

--The Materials Transportation Bureau promulgates regulations for all hazardous materials transportation. It includes the Office of Pipeline Safety Operations which regulates and inspects pipelines and connected storage facilities; and the Office of Hazardous Materials Operations (OHMO) which prescribes regulations for other modes of transportation.

--The Coast Guard promulgates regulations for ships and waterfront facilities. It also has broad enforcement authority for its own regulations, and for OHMO's.

--The Federal Railroad Administration and the Federal Highway Administration prescribe and enforce regulations, including OHMO's, in their respective jurisdictions.

The Department of Energy has the authority to certificate some LNG facilities. This authority is vested in the Economic Regulatory Administration and the Federal Energy Regulatory Commission, which can impose requirements beyond the DOT minimum standards on facilities under their jurisdiction.

The Interstate Commerce Commission has economic authority over interstate trucks and railroads, and can consider safety matters in its certification process.

These agencies have generally failed to give adequate attention to the unique dangers presented by LEG. Rulemaking has been too slow. Regulations for LEG facilities have been partly based on outdated National Fire Protection Association standards, some of which we have shown to be inadeguate. Many LEG facilities have not been subjected to Federal regulation at all, partly because of a failure of the cognizant agencies to fully assert their authority.

The regulation of LEG and naphtha by state and local governments varies widely. Some jurisdictions have no specific regulations other than normal fire hazard restrictions.

Others, such as the New York State Public Service Commission and New York City Fire Department, have more stringent regulations than the Federal Government.

The problem is further aggravated by a shortage of trained inspectors at all levels of government.

MAJOR CONCLUSIONS AND RECOMMENDATIONS

Liability and Compensation

The present liability and compensation system is not equitable and does not provide sufficient incentives for safety. We believe that the corporate owners who profit from LEG operations should bear liability for a major accident.

The banks and insurance companies which finance LEG ships and terminals insist that all companies in the corporate chain co-sign notes. This insures that, in the event of a catastrophic accident, the lending institutions will be protected by the assets of the whole corporate chain. Public safety deserves no less protection.

Recommendations to the Congress

We recommend that the Congress enact legislation which would:

--Require corporations transporting, storing, or using significant amounts of flammable materials to (1) carry the maximum liability insurance available from the private sector, and (2) contribute money to a Federal Hazardous Materials Compensation Fund.

--Provide that the United States be subrogated to the rights of injured persons compensated by the fund so that the Attorney General of the United States can sue the companies or persons responsible for an LEG incident to recover whatever monies the fund has paid out.

--Allow injured parties to sue all companies in the corporate chain for all damages beyond those covered by insurance and the fund.

We also recommend that the Congress:

--Enact legislation which requires that strict liability be applied in all accidents involving LNG and LPG, and consider requiring that strict liability be applied to other highly hazardous materials.

--Amend the 1851 Act (46 U.S.C. 183) which limits the liability of owners and bareboat charterers of ships and barges by substantially raising the statutory limit for vessels carrying hazardous materials.

Recommendations to the Secretary of Energy and the Federal Energy Regulatory Commission

We recommend that the Secretary of Energy and the Federal Energy Regulatory Commission:

--Ensure that adequate compensation for offsite damage will be available to injured parties before permitting LNG projects to proceed.

--Use their authority to require that importers and LNG tanker companies maintain agents for the receipt of legal documents in all states in which they operate.

LEG Safety Research

The limited research that has been carried out on LEG spills and LEG vapor cloud behavior does not provide a sound basis for assessing LEG hazards.

LEG risk assessment studies have not reached a stage where their conclusions can be relied on. Until they do, regulators will have to attempt to make timely, prudent, siting and other critical judgments with the realization that many important safety questions cannot yet be answered with confidence.

DOE's currently planned LNG safety research program will not provide answers soon enough. We believe that an effective safety research program, focusing on those issues most important to decision makers, can be carried out within two years for less than one-fifth of the $50 million DOE is planning to spend on long-term LNG research. We have made detailed suggestions for such a program in the body of the report.

Federal Regulation of LEG and Naphtha

Present Federal efforts to regulate LEG and naphtha do not adequately protect the public. We believe that many Federal regulatory responsibilities for energy health and safety should be consolidated into a single, independent agency. This was one of the options for Congressional consideration provided in GAO's 1977 report, "Energy Policy Decisionmaking, Organization, and National Energy Goals".

With a mandate to adequately protect the public health and safety, such an agency could assemble a technical staff capable of developing appropriate regulations and inspecting and enforcing the implementation of those regulations.

We recommend that the Congress:

--Consider creating an Energy Health and Safety Regulatory Agency. The new agency could include the Nuclear Regulatory Commission; the pipeline safety aspects of fuel transportation on land, now handled by DOT; and safety aspects of importing energy, now handled by DOE, plus all safety responsibilities formerly carried out by the Federal Power Commission.

--Consider including within the Energy Health and Safety Regulatory Agency the safety regulation of LEG carried by truck and train. DOT would continue to be responsible for all safety regulation of motor carriers and railroads, except those transporting nuclear materials and LEG. The Environmental Protection Agency should retain the responsibility for setting air and water quality standards impacting on energy development, use, and waste disposal.

--Consider making the Energy Health and Safety Regulatory Agency completely independent of DOE, or including it within DOE with strong statutory provisions to insure its independence.

SECTION 6

THE BASIS AND SCOPE OF GAO'S STUDY

For GAO, this study was unique in several ways. It covered highly complex subject matter, required the use of many technical consultants and contractors, and involved laboratory and field experiments to verify certain calculations.

The purpose of the study was to determine whether, under current practices and regulations, the public is adequately protected from the dangers of LNG and LPG. Naphtha, a much less volatile mixture of hydrocarbons, was included to permit comparisons of its handling with that of LNG and LPG.

We conducted an extensive review of LEG safety literature, including previous studies, company literature, government reports, and technical journals.

We visited 37 import, storage, shipyard, transportation, and design facilities in the United States and Japan, and made a detailed study of the blueprints of many of them. We spoke with concerned Federal, state, and local officials, and industry and citizen organizations. Each group we visited was offered a briefing on the problems we were examining, and we suggested that they look into the same areas so they would be in a position to comment on our findings. On the whole, we received excellent cooperation from companies, organizations, and Federal agencies.

COMMENTS FROM THE INDUSTRY AND FEDERAL AGENCIES

In keeping with GAO policy, we provided a draft of the full report to all cognizant Federal agencies for their review and comment. In addition, we provided over 50 LEG companies with copies of those chapters of the draft in which they were discussed.

We received official comments from six Federal agencies, and 34 private LEG organizations. We considered all of these comments before preparing the final report.

While we can only briefly summarize the comments here, many of them are addressed on a chapter-by-chapter basis in the full report. The final chapter discusses general concerns of agencies and companies that are not covered in specific chapters. In addition, the full texts of the Federal agencies' comments have been printed as Volume 3 of this report. Many of the LEG companies' comments also are addressed in the report chapters; the full texts of those comments are available for review at the U.S. General Accounting Office, 441 G Street, N.W., Washington, D.C.

We greatly appreciate the time and effort that many of these organizations spent on the report. Their comments contributed significantly toward assuring the quality and accuracy of the report, and in lending balance to the positions we have taken.

The comments generally fell into the following four categories:

1. Concern that GAO had singled out LEG, to the exclusion of other hazardous substances.

   Yes, we did single out LEG for this study, because it is an important energy source, its use may increase substantially, and it is potentially very hazardous. We do not, however, mean to suggest that LEG is the only commodity for public concern. There are other hazardous substances that may pose considerable threat to the public, and many of the issues discussed in this report are applicable to them.

2. Concern that GAO had overlooked the safety record of the LEG industry.

   There is a long history of accidents in all aspects of LPG use. There have been fewer accidents in the relatively new LNG industry. Nonetheless, there have been many documented incidents in LNG production, storage, and transportation.

   The only catastrophic LNG accident occurred in Cleveland, in 1944. We discuss that accident for two reasons. While the amount spilled is small compared to the quantities stored in urban areas today, it gives some indication of what the effects of a major accident in a metropolitan area might be; and it still offers lessons to be learned.

The Cleveland facility was the first U.S. LNG plant. After the plant was destroyed, LNG was not used in this country for 20 years.

3. Concern about the discussion of sabotage.

We believe that the possibility of sabotage must be considered and carefully treated in any complete evaluation of LEG safety.

In preparing the report, we tried to ensure that the sabotage discussions were free of inflammatory statements or expressions, and that they contained no detailed information that could be used by saboteurs or terrorists.

4. Disagreement with specific statements in the draft.

Where comments pointed out errors in the draft, we have made the appropriate corrections. Some of the comments with which we disagreed are evaluated in the chapters of the report.

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DEPARTMENT OF COMMERCE

DEPARTMENT OF ENERGY

DEPARTMENT OF STATE

DEPARTMENT OF TRANSPORTATION

INTERSTATE COMMERCE COMMISSION

NATIONAL TRANSPORTATION SAFETY BOARD

ACRONYMS

AAR	Association of American Railroads
ACI	American Concrete Institute
ALJ	Administrative Law Judge
ANSI	American National Standards Institute
API	American Petroleum Institute
ASLAB	Atomic Safety and Licensing Appeals Board
ASLB	Atomic Safety and Licensing Board
ASME	American Society of Mechanical Engineers
BLEVE	Boiling Liquid Expanding Vapor Explosion
BMCS	Bureau of Motor Carrier Safety, DOT
BNG	Bureau of Natural Gas, FPC
CBI	Chicago Bridge and Iron Company
CFR	Code of Federal Regulations
COTP	Captain of the Port, U.S. Coast Guard
CPUC	California Public Utilities Commission
CTIAC	Chemical Transportation Industry Advisory Committee
DEIS	Draft Environmental Impact Statement
DH	decision height
DOD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
EHSRA	Energy Health and Safety Regulatory Agency (proposed)
EIS	Environmental Impact Statement
EOG	East Ohio Gas Company
EPA	Environmental Protection Agency
ERDA	Energy Research and Development Administration
FBI	Federal Bureau of Investigation
FERC	Federal Energy Regulatory Commission
FHWA	Federal Highway Administration, DOT
FPC	Federal Power Commission
FRA	Federal Railroad Administration, DOT
HMD	Hazardous Materials Division, FRA
HMCF	Hazardous Materials Compensation Fund (proposed)
HMO	hazardous materials officer, Coast Guard
ICC	Interstate Commerce Commission

IHI	Ishikawajima-Harima Heavy Industries Company
IMCO	Intergovernmental Maritime Consultative Organization
LEG	liquefied energy gases
LNG	liquefied natural gas
LOC	Letter of Compliance
LPG	liquefied petroleum gases
MHI	Mitsubishi Heavy Industries
MSA	Maritime Safety Agency, Japan
MTB	Materials Transportation Bureau, DOT
NASA	National Aeronautics and Space Administration
NBS	National Bureau of Standards, DOC
NFPA	National Fire Protection Association
NFPCA	National Fire Prevention and Control Administration, DOC
NHTSA	National Highway Traffic Safety Administration, DOT
NRC	Nuclear Regulatory Commission
NNG	Northern National Gas Company
NTIS	National Technical Information Services
NTSB	National Transportation Safety Board
NYCFD	New York City Fire Department
OCA	Office of Crash Avoidance, NHTSA
OHMO	Office of Hazardous Materials Operations, MTB
OPSO	Office of Pipeline Safety Operations, MTB
PAD	Petroleum Administration for Defense
PDM	Pittsburgh-Des Moines Steel Company
PWSA	Ports and Waterways Safety Act of 1972
SAI	Science Applications, Inc.
SNG	synthetic natural gas
SSE	safe shutdown earthquake
TET	Texas Eastern Transmission Corporation
TID	Technology Information Division, Atomic Energy Commission
UBC	Uniform Building Code
USC	United States Code
VTS	Vessel Traffic Service

ABBREVIATIONS OF UNITS

BBL	=	barrels
BTU	=	British thermal units
cal	=	caliber
cm	=	centimeters
cps	=	cycles per second
CV	=	horsepower (metric)
d	=	days
ft	=	feet
^{o}F	=	degrees Fahrenheit
g	=	acceleration of gravity (32 ft/sec^2)
gm	=	grams
gpm	=	gallons per minute
hp	=	horsepower
hr	=	hour
Hz	=	hertz
in	=	inches
kcal	=	1000 calories
k-ft	=	1000 foot-pounds
kg	=	kilograms
kip	=	1000 pounds
km	=	kilometers
ksi	=	kips per square inch
kt	=	1000 metric tons
kts	=	knots
lbs	=	pounds
LT	=	long tons (2240 lbs)
m_3	=	meters
m^3	=	cubic meters
MBBL	=	1,000 barrels
MCF	=	1,000 cubic feet
MCM	=	1,000 cubic meters
min	=	minutes
mm	=	millimeters
MM	=	1,000,000
MMCF	=	1,000,000 cubic feet
$MMCF_3D$	=	1,000,000 cubic feet per day
MMm^3	=	1,000,000 cubic meters
mph	=	miles per hour

MMSCF	=	1,000,000 standard cubic feet
MMSCFD	=	1,000,000 standard cubic feet per day
MT	=	metric tons (1,000 kilograms)
MW	=	1,000,000 watts
NM	=	nautical miles
psf	=	pounds per square foot
psi	=	pounds per square inch
psia	=	pounds per square inch (absolute)
psig	=	pounds per square inch (gauge)
SCFM	=	standard cubic feet per minute
sec	=	seconds
T	=	tons
yr	=	years

CHAPTER 1

INTRODUCTION

Liquefied natural gas (LNG), liquefied petroleum gas (LPG), and naphtha together make up about 3 percent of the energy we use. All three are used to supplement natural gas. LPG and naphtha also have other important uses. This study is about the safety of these fuels.

Outside their containers, LNG and LPG rapidly vaporize and become highly flammable and explosive gases. A major spill in a densely populated area could be catastrophic. The report examines whether these fuels are being stored and moved without undue risk to the public.

Although there are many differences in their physical properties and technologies, LNG and LPG are similar substances and have many safety and security problems in common. This often makes it convenient to speak of them together as liquefied energy gases (LEG).

Naphtha, a mixture of hydrocarbons between kerosene and gasoline in volatility, was included to allow us to compare this much less dangerous material with LNG and LPG.

LNG and LPG are not the only highly dangerous materials which are transported and stored in large quantities, and some of our work is applicable to a broader class of hazardous materials. We have made more general conclusions and recommendations where they were warranted.

The report is intended to serve two purposes: to discuss issues, and to serve as a source of basic, relevant information. It is divided into three volumes. The executive summary and the main text appear in Volume 1. The appendixes, containing basic information which supplements the text or technical material which supports it, appear in Volume 2. The comments we received on our draft from Federal agencies make up Volume 3.

The second chapter is a brief primer to introduce the basic concepts on which the rest of the chapters are based. We strongly urge any reader not already familiar with this area to read it before reading the later chapters.

The next three chapters deal with the potential for large spills from LEG storage tanks. Chapter 3 examines the vulnerability of storage tanks to earthquakes and other natural forces. Chapter 4 estimates the "critical crack length" of metal LNG tanks. Cracks larger than this may cause a tank wall to suddenly unzip, immediately releasing all the enclosed fluid. Chapter 5 calculates the amount of fluid that could vault over the dike if there is a sudden, massive spill from an LEG tank, even though the dike meets current safety standards.

Chapters 6,7, and 8 explore safety problems of LEG ships, trucks, and railcars. Chapter 9 analyzes the vulnerabilities of LEG storage and transportation systems to sabotage, and the level of current safeguards.

Chapter 10 covers the only catastrophic LNG accident, which occurred in Cleveland, Ohio in 1944. While the amount of LNG involved is much smaller than that stored in current facilities, it indicates the type of effects that

can occur in a major LEG spill in an urban area. Chapter 11 examines the adequacy of present LNG liability and compensation arrangements.

LEG research (including LEG cloud dispersion models and detonation and flame propagation in LEG clouds) is evaluated in Chapters 12 and 13.

Chapters 14 and 15 discuss the ability of non-urban terminals to handle all needed LEG imports.

Chapters 16 and 17 deal with LEG regulations: Federal, state, and local regulations in Chapter 16, and Federal regulation of LEG trucks and railcars in Chapter 17. The Federal Power Commission's performance is evaluated in Chapter 18.

LEG systems used in Japan, the world's largest importer of LNG, are covered in Chapter 19, including a discussion of Japanese LNG inground storage tanks.

Many chapters include specific recommendations to improve the safety and security of LEG operations. Each chapter, however, focuses on a narrow aspect. Chapter 20 draws general overall conclusions and recommendations, based on the findings and recommendations in the previous chapters.

Chapter 21 discusses the general comments on the report that were submitted to GAO by Federal agencies and by companies. Comments on specific chapters are handled at the end of those chapters.

Methodology

We started by isolating what we believed to be the critical questions about LEG and naphtha safety. We then determined what answers were available to these questions and on what the answers were based. On this basis we decided how deeply to explore each question. Because this exploration often needed skills beyond those available at GAO, a great deal of the work was done by contractors and consultants. We demanded that such companies and consultants meet two criteria: that they be eminently qualified in the area they were investigating and that they be independent, having no financial or intellectual stake in the answer. The major exception was that companies with previous activity in the area were allowed to bid competitively on a contract to compare Federal, state, and local regulations. The contractors and consultants who made major contributions to the study are listed in Appendix I-1.

The reports received from companies and consultants were broken up, edited, added to, corrected, and incorporated into various places in the final document. The GAO staff planned the study, hired the participants, and wrote the text, findings, conclusions, and recommendations. No chapter is the responsibility of any particular consultant, company, or staff member.

We visited 37 import, storage, shipyard, design, and transportation facilities in the United States and Japan (listed in Appendix I-2), and made a detailed study of the plans and blueprints of many of them. We spoke with Federal, state, and local agencies, industry and citizen organizations, and members of Congress. We offered each group we visited a full (more than one hour) briefing on

the problems we were examining. We suggested to each of them that they look into the same problems, so that they would have substantive comments to make. On the whole, we received excellent cooperation from companies, organizations, and Federal agencies, and we are most grateful. We could not have done the study without it.

Because of the innovative nature of this report, a number of eminently qualified consultants were asked to review the accuracy of the material and provide us with their criticisms, comments, or recommendations. They include present or former leaders of industry, labor, government, consumer groups, science, law, and security. (See Appendix I-1.) None had any other interaction with the study. Further, they were not asked to evaluate findings, conclusions, or recommendations.

Eight Federal agencies have reviewed the entire report, and 52 companies and industry organizations were sent the parts of it in which they were mentioned. We received extensive comments from both groups. Formal comments, received from six agencies, are reproduced in full in Volume 3. Company, industry, and organization comments will be available at GAO to interested readers.

We have carefully considered all the comments and made revisions where appropriate.

Although this report has looked deeply into highly technical areas, we have tried to make the text understandable to non-technical readers. A few chapters required highly technical discussions. We have put these sections in italics, to indicate that non-technical readers may wish to omit them.

CHAPTER 2
PRIMER

This primer is meant to give an overall view of a very complex subject in a few pages. As such, it has less precision than the rest of the report and should be read only as a general introduction to the field. It does not summarize the rest of the report.

Energy gases are liquefied in order to reduce their volume. This facilitates transportation and storage, but increases the potential hazard. Liquefied natural gas (LNG) and liquefied petroleum gas (LPG)-- together called liquefied energy gases (LEG)--are produced domestically and imported. As the nation's natural gas supplies dwindle, imported LEG could become an increasingly important source of energy.

Natural gas is a mixture of hydrocarbons, 65 to 99 percent methane, with smaller amounts of ethane, propane, and butane. Chilled to -260 degrees Fahrenheit (^{o}F), natural gas becomes an odorless, colorless liquid one-600th of its volume at atmospheric pressure. Thus, a 150,000 cubic meter LNG tanker can carry the equivalent of 3.2 billion cubic feet of natural gas. (Table 2-1 provides a volumetric conversion table.) When LNG is warmed, it turns into natural gas again.

LPG--propane and butane--is processed from natural gas or crude oil. LPG liquefies and contracts in volume when stored under pressure at ambient temperatures, or when cooled at atmospheric pressure. Propane, for example, is reduced to one-270th of its volume at normal temperature

Table 2-1 LNG VOLUME, MASS, AND ENERGY EQUIVALENTS

		Volume Natural Gas	Volume LNG				Mass	Energy Content
		MCF	cubic meters	barrels	cubic feet	gallons	Metric tons	Therms
volume natural gas	1 MCF (1000 cubic feet)	--	0.04569	0.28735	1.6134	12.070	0.02123	10.860
volume LNG	1 cubic meter	21.886	--	6.2888	35.314	264.16	0.46463	237.68
	1 barrel	3.48008	0.15901	--	5.6148	42.005	0.07388	37.794
	1 cubic foot	0.61980	0.02832	0.17810	--	7.4811	0.01316	6.7311
	1 gallon	0.08285	0.00378	0.02380	0.13367	--	0.00176	0.89975
mass	1 metric ton (2204 lbs.)	47.103	2.1522	13.535	75.996	568.53	--	511.54
energy content	1 Therm (100,000 Btu's)	0.09208	0.00421	0.02646	0.14856	1.1114	0.00195	--

Source: Office of Technology Assessment, "Transportation of Liquefied Natural Gas" September 1977, p. 2.

and atmospheric pressure so it can be transported easily. Propane liquefies at -44°F; butane, at 31°F. Methane cannot be liquefied by pressure at temperatures above -116°F.

LPG vapor is heavier than air. Any spill or leak will collect on the ground or water and form a dense, spreading cloud which is explosive. The flammable range in an LPG vapor cloud is between 2 and 9 percent. Very cold natural gas is also heavier than air and forms a low, spreading cloud. When the natural gas content of the cloud is between 5 and 14 percent, the mixture is flammable. Eventually both types of clouds will dissipate. Both LPG and LNG clouds can explode in confined spaces. Table 2-2 gives the physical properties of LEG.

Naphtha is a generic term for various mixtures of hydrocarbons extracted from crude oil in the refining process. Its physical properties are not defined precisely. Naphtha is denser than LNG and LPG, and its vapor is heavier than air. The boiling point of naphtha ranges from 100° to 500°F. This means that, when exposed to the atmosphere, it evaporates slowly—at about the rate of water on a dry day. Naphtha is between kerosene and gasoline in volatility.

LNG has been used for several years in this country to supplement natural gas supplies. During the summer, when demand is low, utilities liquefy and store gas in specially designed tanks. When the weather is cold and demand is high, the LNG is regasified and pumped through gas mains to consumers. More than 100 of these "peakshaving" plants are operating throughout the United States, including 45 that hold at least 23,000 cubic meters.

TABLE 2-2 PHYSICAL PROPERTIES OF LEG

Property	Methane	Ethane	Propane	Butane
Boiling Point	-263°	-127°	- 44°	31°
Specific Gravity	0.466 at -263°	0.546 at -127°	0.585 at -49°	0.601 at 31°
Vapor Density at 32° (Air = 1.0)	0.555	1.04	1.56	2.04
Flash Point	-306°	-211°	-156°	-76°
Auto-Ignition Temperature	1004°	950°	871°	806°
Flammable Limits (concentration)	5.3-15.0%	3.0-12.5%	2.2-9.5%	1.8-8.4%
Laminar Burning Velocity	0.87 mph	0.92 mph	0.98 mph	1.03 mph
Gas-to-liquid Volume ratio (Gas at 32°, Liquid at boiling point)	650	410	290	230

All temperatures in degrees Fahrenheit.

Sources: Chemical Rubber Company Handbook of Chemistry and Physics, 57th ed., 1977; U.S. Coast Guard CHRIS Handbooks, 1974.

Propane is also used to supplement natural gas supplies. Since propane gas is heavier in molecular weight and has up to three times the energy density of natural gas, it is diluted with air or converted into synthetic natural gas (SNG) before being added to the gas stream. There are more than 450 domestic propane/air plants for standby and full-time use,[2] and five SNG plants use propane as a feedstock component. A new method injects liquid LPG directly into a passing gas stream.

Some 13 million customers used LPG in 1976. Most of these customers are in rural areas, including approximately 1.4 million farms. Many factories also rely on propane as a back-up fuel in case their natural gas supplies are reduced.

LPG and naphtha are used as feedstocks for petrochemicals. Naphtha is also used as jet fuel. Butane is a feedstock for aviation fuel, high octane gasoline, and synthetic rubber.

About 2 percent of the nation's energy is supplied by LPG, primarily propane. (LEG and naphtha consumption data are contained in Appendix II.) Over the years, a widespread LPG storage and distribution network has developed in the United States: 16 import terminals, 70,000 miles of cross-country pipelines, 16,300 LPG rail tank cars in service, and 25,000 LPG transport and delivery trucks.[3] In addition, more than 8,000 LPG storage and distribution facilities are scattered throughout the country.

About 86 percent of the LPG in bulk storage is kept under pressure in underground salt domes or mined caverns.[4] LPG is also stored at $-44^{\circ}F$ in large, steel, single-walled,

aboveground tanks ranging in capacity up to 80,000 cubic meters. There are 20 LPG aboveground storage facilities that hold more than 23,000 cubic meters. Insulating big tanks is less expensive than building them strong enough to resist high pressure. Smaller amounts of LPG are stored in pressurized containers called "bullet tanks", which run from 8 up to 450 cubic meters in capacity.

In 1976, 95.2 percent of the LPG shipped in the United States was pumped under pressure in LPG pipelines to distribution points, where it was loaded into pressurized tank trucks or railroad tank cars and carried to rural and industrial customers. Only 3.4 percent of the LPG was transported the entire way by trucks (which carry as much as 45 cubic meters), and 0.9 percent was transported in pressurized railcars (which hold up to 125 cubic meters).[5]

Around 18.2 million cubic meters of LPG moved in international trade in 1976, transported primarily by 83 tankers, each with a capacity of at least 10,000 cubic meters. With the increasing demand for LPG, larger ships—of 50,000, 75,000, and 100,000 cubic meters capacity—are coming into use. These ships are refrigerated to keep propane and butane liquefied. Some LNG ships can and do carry LPG instead.

Large LPG tankers have about half the capacity of those carrying LNG because LPG has a greater density. A 75,000 cubic meter LPG tanker has a draft of 38 feet, while a 125,000 cubic meter LNG tanker has a draft of 36 feet. Smaller 50,000 cubic meter LPG tankers have a draft of 35 feet and can be received by all of the major LPG marine terminals in the U.S.

LNG is harder to handle than LPG because it is intensely cold. The -260°F temperature of LNG makes complex shipping, storage, and handling techniques necessary. LNG exporters, such as Algeria, Brunei, and the United States, liquefy natural gas and pump it into unique tankers which are like floating thermos bottles. The five separate tanks on a typical carrier are heavily insulated to prevent the LNG from vaporizing or "boiling off" during a voyage. The small amount that does vaporize provides most of the fuel to power the ship.

The insulated tanks holding the LNG are made of welded 9 percent nickel alloy steel or aluminum alloy that can withstand the intense cold and great temperature changes. Two types are used: free-standing tanks which are anchored in the ship's hull, and "membrane" tanks supported by insulation lining the inner hull.

LNG carriers have to meet far more exacting specifications than oil tankers. LNG ships are double-hulled. They are equipped with methane detection devices and fire-fighting systems that deliver high pressure foam, dry powder, or water sprays. Other systems cool and warm the storage tanks and fill them with inert, non-combustible gas when the ship is empty. The newer LNG carriers have bow thruster propellers and other features which give them greater maneuverability.

The 38 currently operating LNG tankers carry an average of 46,000 cubic meters of LNG.[6] By 1980, about 80 LNG ships will be in service.[7] At least one will have a capacity of 165,000 cubic meters—enough liquid to cover a football field to a depth of 130 feet. But the industry seems to be settling on 125,000-130,000 cubic meter

capacity vessels as a standard. Such tankers will be 1,000 feet long, 150 feet wide, and able to cruise at 20 knots.

When an LNG carrier reaches an import terminal, it unloads in 10-15 hours at a rate of up to 190 cubic meters a minute. Jointed marine loading arms on the dock are attached to the ship and the LNG is pumped into huge storage tanks. The insulated piping is made of cold-resistant (cryogenic) steel or aluminum alloy. Emergency shutdown systems automatically cut off the LNG flow in case of a mishap.

Major LNG terminals generally have more than one storage tank. A typical tank has a capacity of 95,000 cubic meters of LNG. Such a tank is 140 feet high and 190 feet in diameter. Its inner walls are made of cryogenic 9 percent nickel alloy steel, aluminum alloy, or pre-stressed concrete. Surrounding this inner tank is about 3 feet of perlite, a non-flammable insulating material. The tank's outer wall is usually built of non-cryogenic carbon steel. Inside the tank's dome is an insulated, suspended ceiling.

LNG storage tanks in this country are built aboveground, and most are enclosed by earthen dikes. The volume of the diked area is usually equal to the volume of the fluid in the largest tank enclosed by the dike. The Japanese, however, are constructing many new LNG storage tanks in the ground. The cryogenic inner liner is surrounded by thick insulation and a concrete outer shell. Many Japanese engineers say that such below-ground tanks are intrinsically safer.

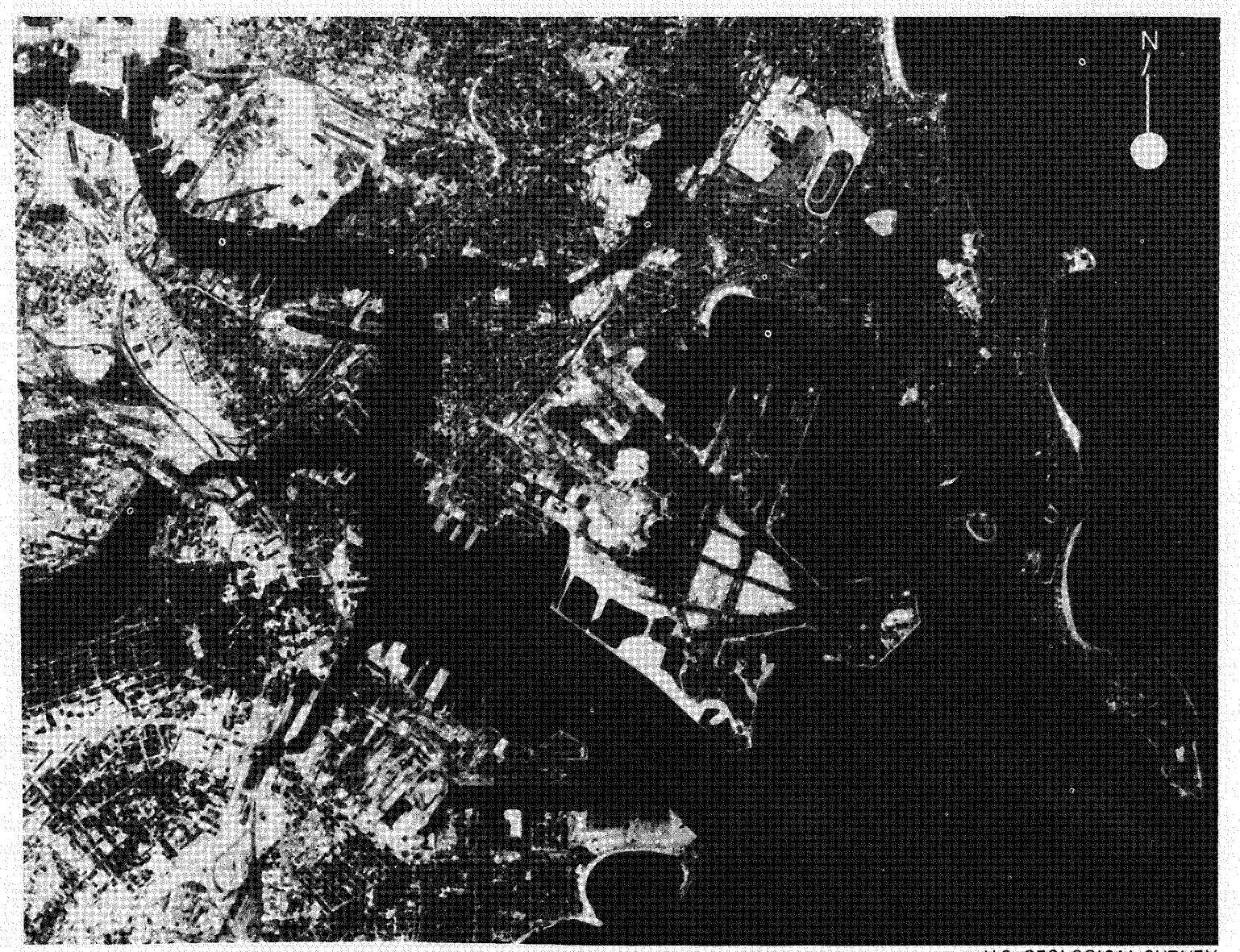
The 14 major LNG import terminals now operating throughout the world are "base load" facilities in which

incoming LNG is constantly regasified and pumped into utility distribution lines. European nations have been bringing in LNG through such facilities since 1964. Imported LNG now accounts for 80 percent of Japan's natural gas consumption.[8]

LNG imports now supply less than one-tenth of one percent of U.S. natural gas demand, and there are only two import terminals in this country. Another new base load facility will go into operation in the near future, and several more have been proposed. LNG could supply up to 15 percent of the nation's natural gas needs by 1985,[9] with more than 40 LNG tankers operating regularly in and out of U.S. harbors. Imports of LPG are also expected to rise sharply, from 1.9 million cubic meters in 1976 to 26.9 million cubic meters by 1985.[10] The photographs show the sites of two existing LEG terminals and a proposed LNG terminal site.

In the short history of LNG use in this country there has been only one major accident at an LNG facility. On October 20, 1944, a 4,200 cubic meter LNG storage tank at a peakshaving facility in Cleveland suddenly gave way. Vapor from the spilled liquid ignited as it spread into streets, storm sewers, and basements. Later, another tank containing 2,100 cubic meters failed, shooting flames nearly 3,000 feet into the air. The fires and explosions killed 130 persons and injured 225 more.[11] Property damage was estimated at $7 million.

The Cleveland disaster halted the use of LNG for twenty years. It was not until the mid-1960's that natural gas utilities again began using LNG.



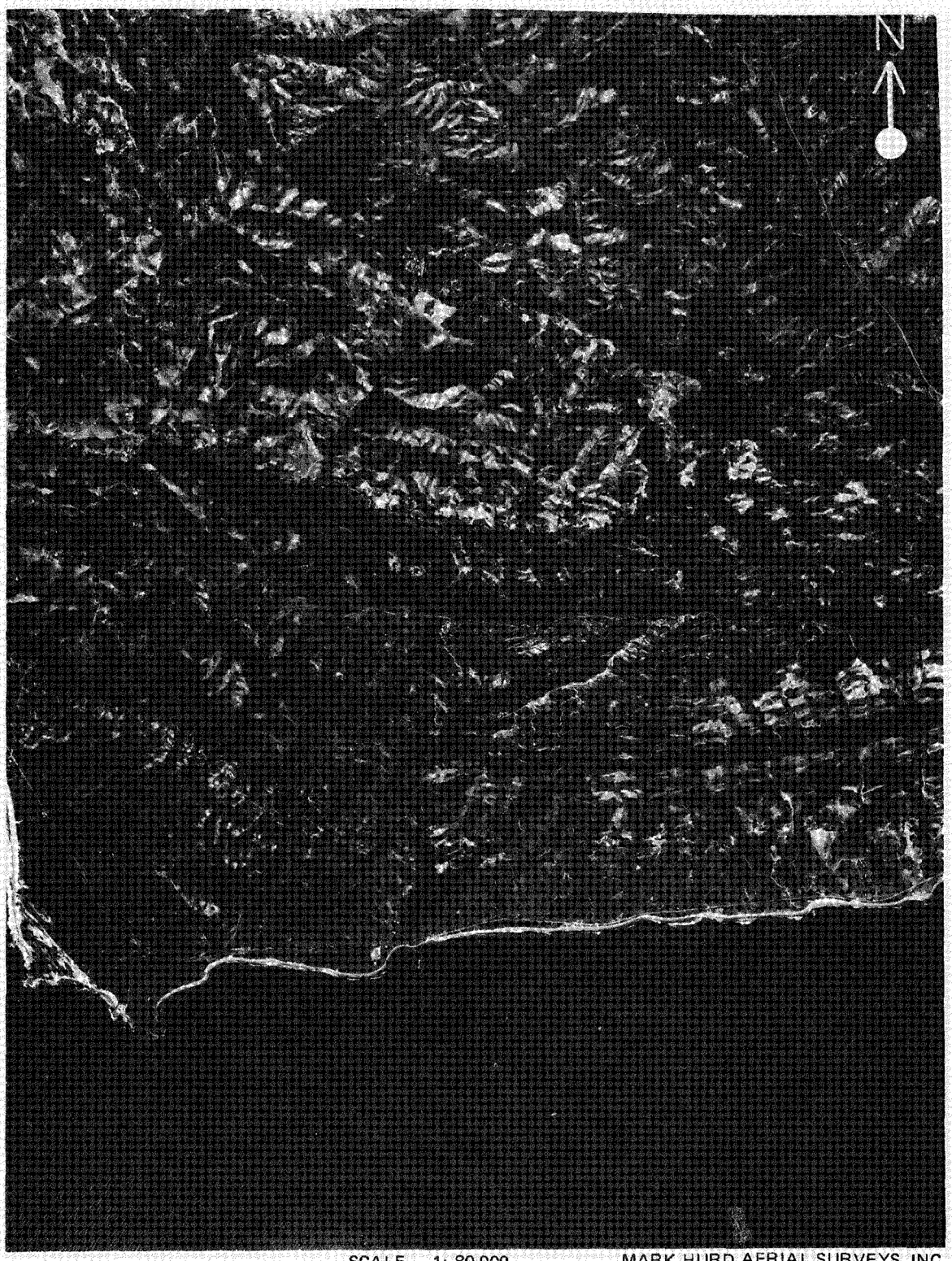
U.S. GEOLOGICAL SURVEY

THE PHOTOGRAPH ABOVE IS AN EXAMPLE OF AN LNG IMPORT TERMINAL LOCATED IN AN URBAN AREA. THE ARROW POINTS TO THE DISTRIGAS TERMINAL IN EVERETT,MASSACHUSETTS, IN OPERATION SINCE 1971. LNG SHIPS REACH IT THROUGH BOSTON HARBOR, PASSING LOGAN INTERNATIONAL AIRPORT AND BOSTON AS THEY GO UP THE SHIP CHANNEL. NEXT TO THE TERMINAL ARE EXXON'S LPG RECEIVING TERMINAL, OTHER INDUSTRIAL FACILITIES, AND POPULATED NEIGHBORHOODS.



SCALE 1:12,000 AMERICAN AERIAL SURVEYS, INC.

THIS PHOTOGRAPH SHOWS THE URBAN LOCATION OF PETROLANE, INC'S LPG RECEIVING TERMINAL NEAR LOS ANGELES HARBOR IN CALIFORIA. THE ARROW INDICATES THE COMPANY'S TWO LARGE PROPANE STORAGE TANKS NEAR THE TERMINAL ARE THE PALOS VERDES FAULT, (DOTTED LINE) A U.S. NAVY FUEL DEPOT, A COMPLEX OF STORAGE TANKS, AND A RESIDENTIAL AREA THAT GOES FOR MANY MILES.



SCALE 1: 80,000 MARK HURD AERIAL SURVEYS, INC.

POINT CONCEPTION, CALIFORNIA, SHOWN IN THE PHOTOGRAPH ABOVE, IS AN EXAMPLE OF A PROPOSED LNG IMPORT TERMINAL SITE WHICH HAS A VERY LOW POPULATION DENSITY FOR MANY MILES AROUND IT. THE PROJECT IS A PROPOSAL OF WESTERN LNG TERMINAL ASSOCIATES, INC.

The first U.S. LNG import terminal began operations at Everett, Mass., in 1971. In 1973 the Federal Power Commission asserted jurisdiction over the Everett facility and any new LNG import terminals. Although FPC has been disbanded, its functions have been assumed by the Federal Energy Regulatory Commission (FERC) and other parts of the Department of Energy (DOE). The U.S. Coast Guard and the Office of Pipeline Safety Operations (OPSO), both in the Department of Transportation (DOT), also have regulatory responsibilities for LNG import terminals.

LNG peakshaving plants involved in interstate commerce come under the jurisdiction of both DOE and OPSO. OPSO also regulates LPG and naphtha pipeline facilities in interstate commerce.

LEG trucks and railcars under Federal jurisdiction are regulated by a number of agencies within DOT. The Interstate Commerce Commission (ICC) is also involved, since only it can revoke or suspend the certificates of interstate motor carriers found to be unsafe.

The U.S. Coast Guard has been given broad authority to regulate all aspects of LEG shipping, including the design and construction of vessels, the training of crew members, the movement of vessels in U.S. ports and waterways, and harbor security.

Throughout the report liquid volumes are given in cubic meters, in order to make it easier to compare the volumes held or carried in various storage and transportation systems. All temperatures are given in degrees Fahrenheit (F).

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3. See Chapter 14.

4. American Petroleum Institute, "API Monthly Report Covering Inventories of LP-Gas and LR-Gas as of September 30, 1977," October 25, 1977.

5. National LP-Gas Association, "1976 LP-Gas Market Facts," p. 7.

6. E. Drake and R. Reid, "The Importation of Liquefied Natural Gas", Scientific American, April, 1977, p.24.

7. Office of Technology Assessment, "Transportation of Liquefied Natural Gas," September 1977, p. 12.

8. Drake and Reid, p. 22.

9. Office of Technology Assessment, p. 5.

10. See Chapter 14.

11. Coroner's Report on East Ohio Gas Company Disaster, Cuyahoga County, Cleveland, Ohio, July 1945.

CHAPTER 3

VULNERABILITY OF STORAGE TANKS AND CONTAINMENT DIKES TO NATURAL FORCES

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INTRODUCTION

The first part of this chapter evaluates the ability of selected LEG storage facilities to withstand earthquakes and tornadoes. The conclusions reached should be generally applicable to U.S. LEG storage facilities, since most designers use the same codes and standards and employ similar analytical methods and design assumptions.

The second part of the chapter evaluates the effects of flooding and the potential for foundation failure from ground liquefaction in earthquakes. These phenomena tend to be highly site dependent and site specific.

SITE LOCATION AND DESCRIPTION

The specific storage facilities evaluated are described in Table 3-1. We consider them representative of the types of storage facilities currently in use or planned in the United States:

- Insulated Storage Tanks and Containment

  Double-Wall Steel LNG Tank - Figure 3-1.

  Prestressed Concrete LNG Tank - Figure 3-2.

  Prestressed Concrete High Dike - Figure 3-3.

  Single-Wall Steel Propane Tank - Figure 3-4.

- Pressure Storage Tanks

  Vertical Steel Propane Tank - Figure 3-5.

TABLE 3-1 DESCRIPTION OF LNG AND PROPANE STORAGE TANK FACILITIES EVALUATED FOR SEISMIC AND WIND LOADS

	Facility Location	Tank Capacity Cubic Meters	Tank Dimensions*	Tank Designer	Remarks
1.	LNG Storage Tank Distrigas Corp. Everett, Mass. (designed 1970)	55,000	150' I.D. x 123' Ht. to S.L.	Chicago Bridge & Iron	Tank consists of a primary and secondary steel vessel as shown in Fig. 3-1
2.	LNG Storage Tank Public Service Electric & Gas Rossville, Staten Island, N.Y. (designed 1970)	143,000	240' I.D. x 117' Ht. of Cyl. Wall	Preload Technology	Tanks consist of an inner and outer circular prestressed concrete wall and reinforced concrete berm as shown in Fig. 3-2.
3.	High Dike for LNG Storage Tanks Western LNG Terminal Associates Oxnard, Calif. (planned)	87,000	259' I.D. x 81' Ht. to top of Containment wall	Chicago Bridge & Iron (The facility, including the dike, was designed by Fluor Engineers and Constructors)	The dike containment acts to contain the LNG in the event of a rupture of the primary double-wall metal storage tanks as shown in Fig. 3-3.
4.	LPG Storage Tank Exxon Co., U.S.A. Everett, Mass., (designed 1972)	64,000	190' I.D. x 80' Ht. to S.L.	Pittsburgh-Des Moines Steel Co.	The storage tank is a single wall storage vessel as shown in Fig. 3-4.

TABLE 3-1 DESCRIPTION OF LNG AND PROPANE STORAGE TANK FACILITIES EVALUATED FOR SEISMIC AND WIND LOADS (continued)

	Facility Location	Tank Capacity Cubic Meters	Tank Dimensions*	Tank Designer	Remarks
5.	LPG "Bullet" Tank Boston Gas SNG Plant Everett, Mass. (vertical pressurized cylinder installed 1947)	114	8.6' I.D. x 66' Cyl. Ht. with 2:1 Ellipse Head	J.F. Pritchard & Co.	This vertical cylindrical pressurized storage tank is shown in Fig. 3-5.
6.	LPG "Bullet" Tank (horizontal pressurized cylinder designed 1977)	342	9.75' I.D. x 133' Cyl. with Spherical Head	Trinity Industries, Inc.	This horizontal cylindrical pressurized storage tank is shown in Fig. 3-6.

*I.D. = Internal Diameter
Ht. to S.L. = Height to Springline (the Springline is the top of the cylinder wall).

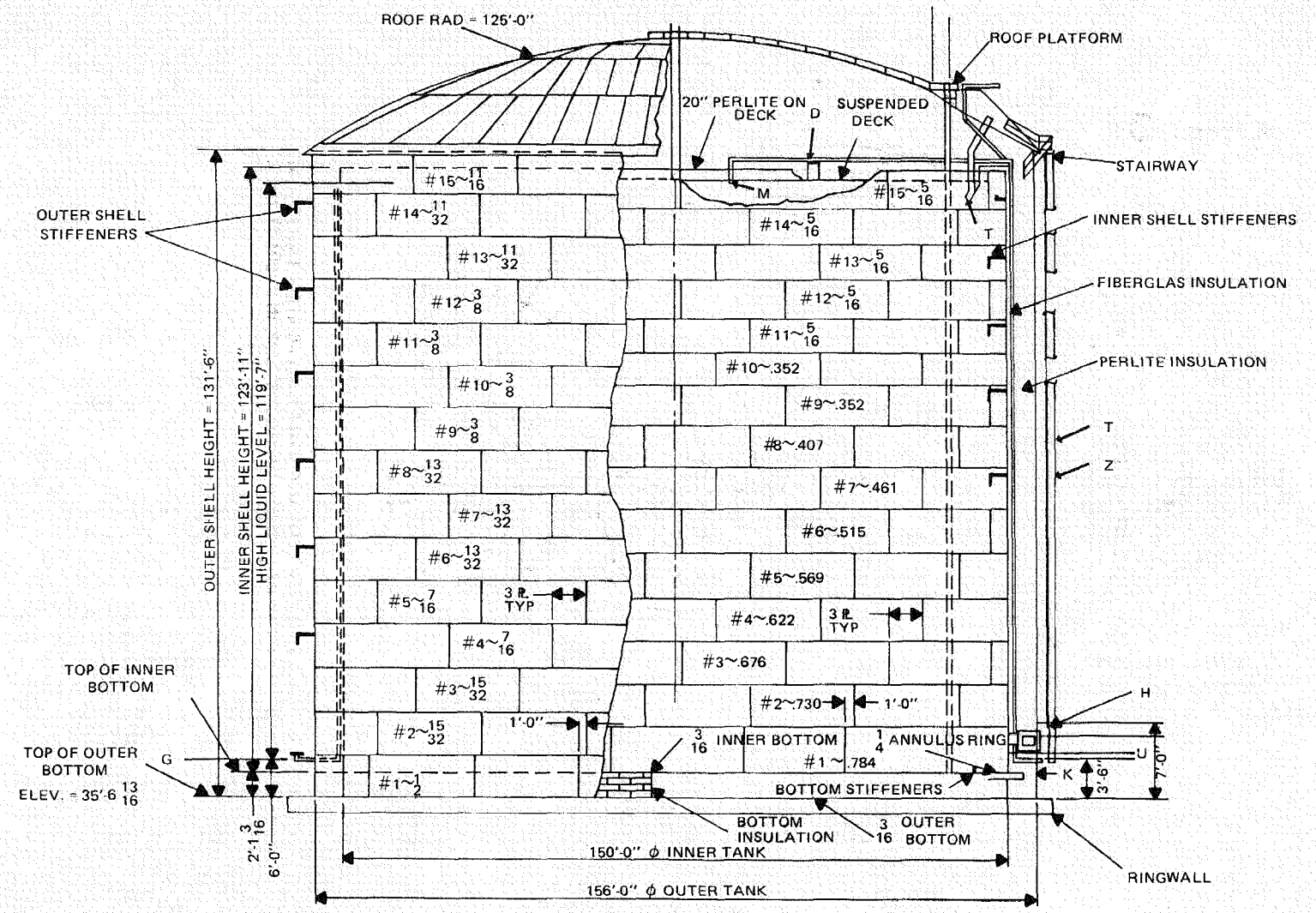


FIGURE 3-1a – ELEVATION VIEW OF A TYPICAL DOUBLE WALLED LNG STORAGE TANK OF THE TYPE BUILT BY CB&I FOR DISTRIGAS IN EVERETT, MASS.

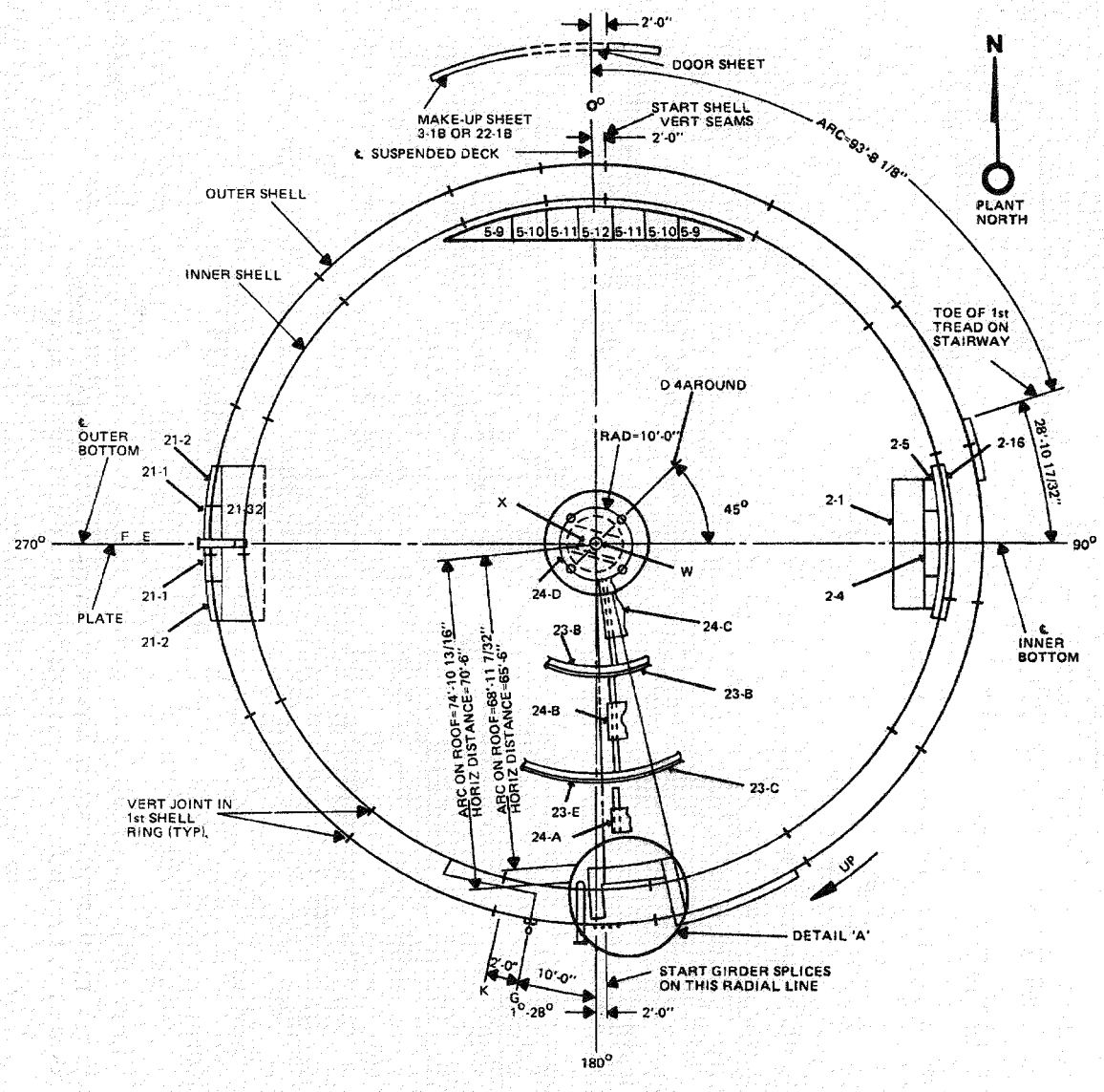


FIGURE 3-1b – PLAN VIEW OF A TYPICAL DOUBLE WALLED STEEL LNG STORAGE TANK OF THE TYPE BUILT BY CB&I FOR DISTRIGAS CORP. IN EVERETT, MASS.

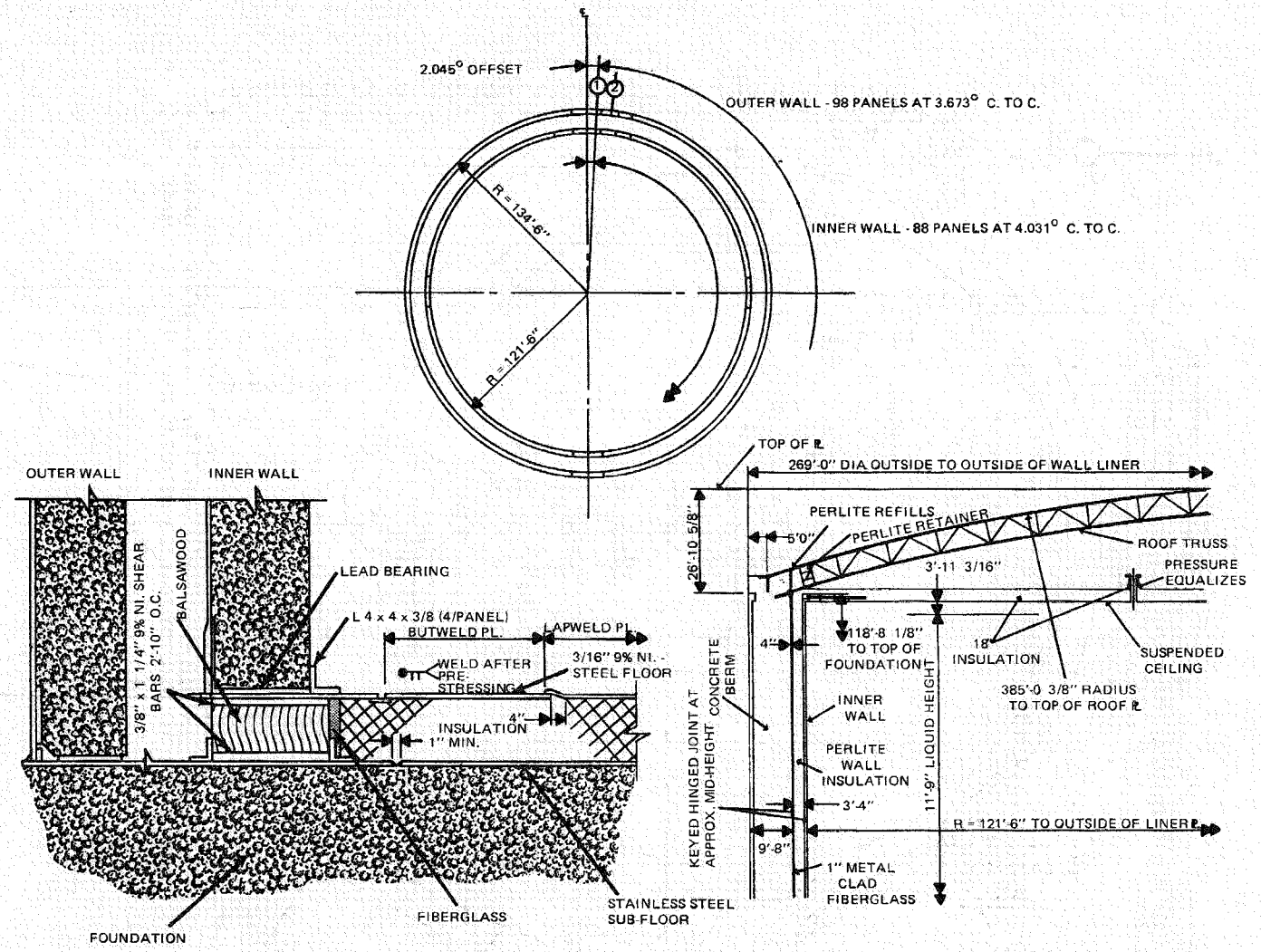


FIGURE 3-2 – PLAN AND ELEVATION SECTIONS OF THE PUBLIC SERVICE ELECTRIC AND GAS DOUBLE-WALLED PRESTRESSED CONCRETE LNG STORAGE TANK BUILT BY PRELOAD AT ROSSVILLE, STATEN ISLAND, NEW YORK.

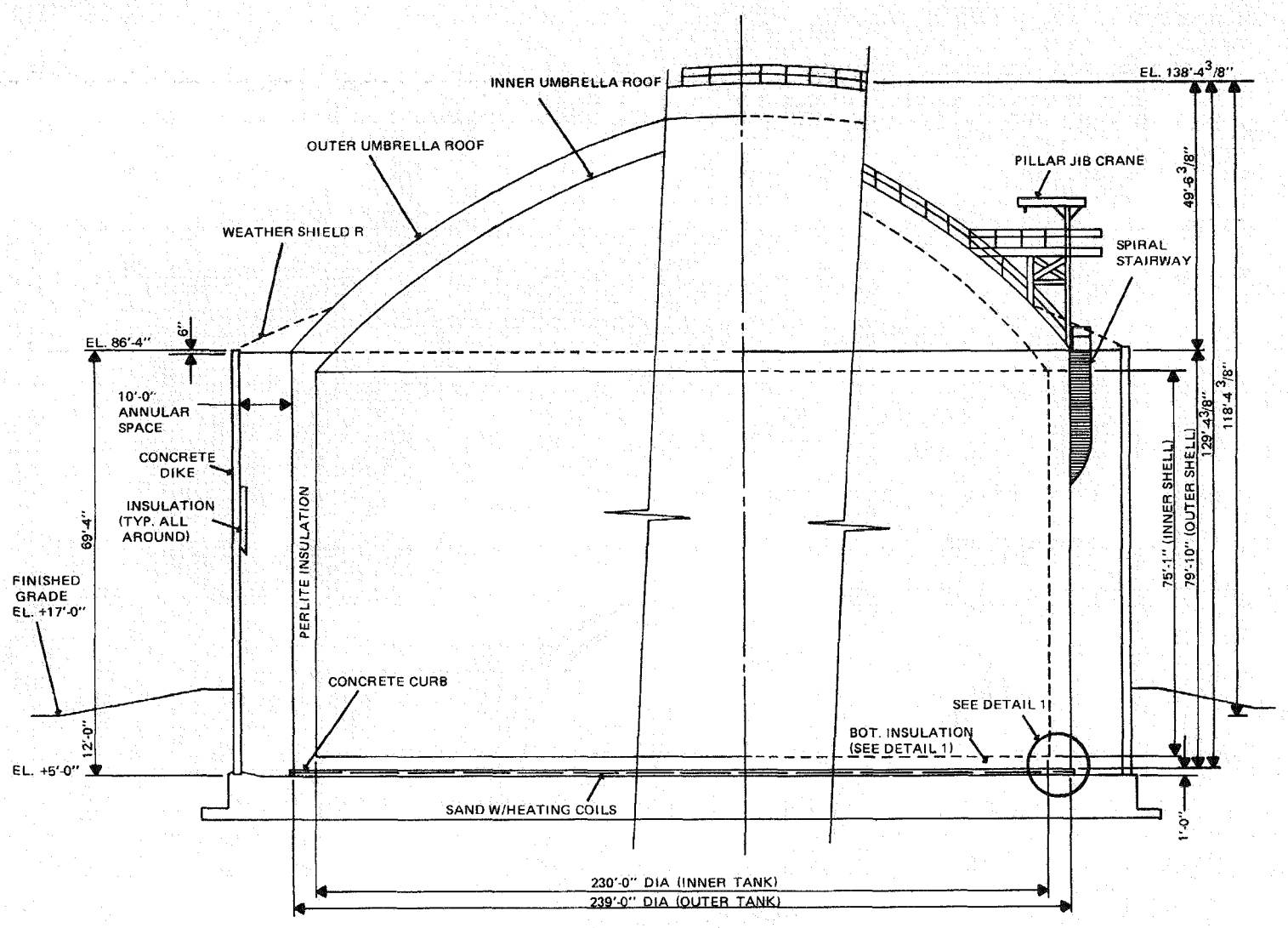


FIGURE 3-3 – ELEVATION VIEW OF PROPOSED OXNARD LNG STORAGE FACILITY FOR WESTERN LNG TERMINAL ASSOCIATES, SHOWING A PRESTRESSED CONCRETE HIGH DIKE.

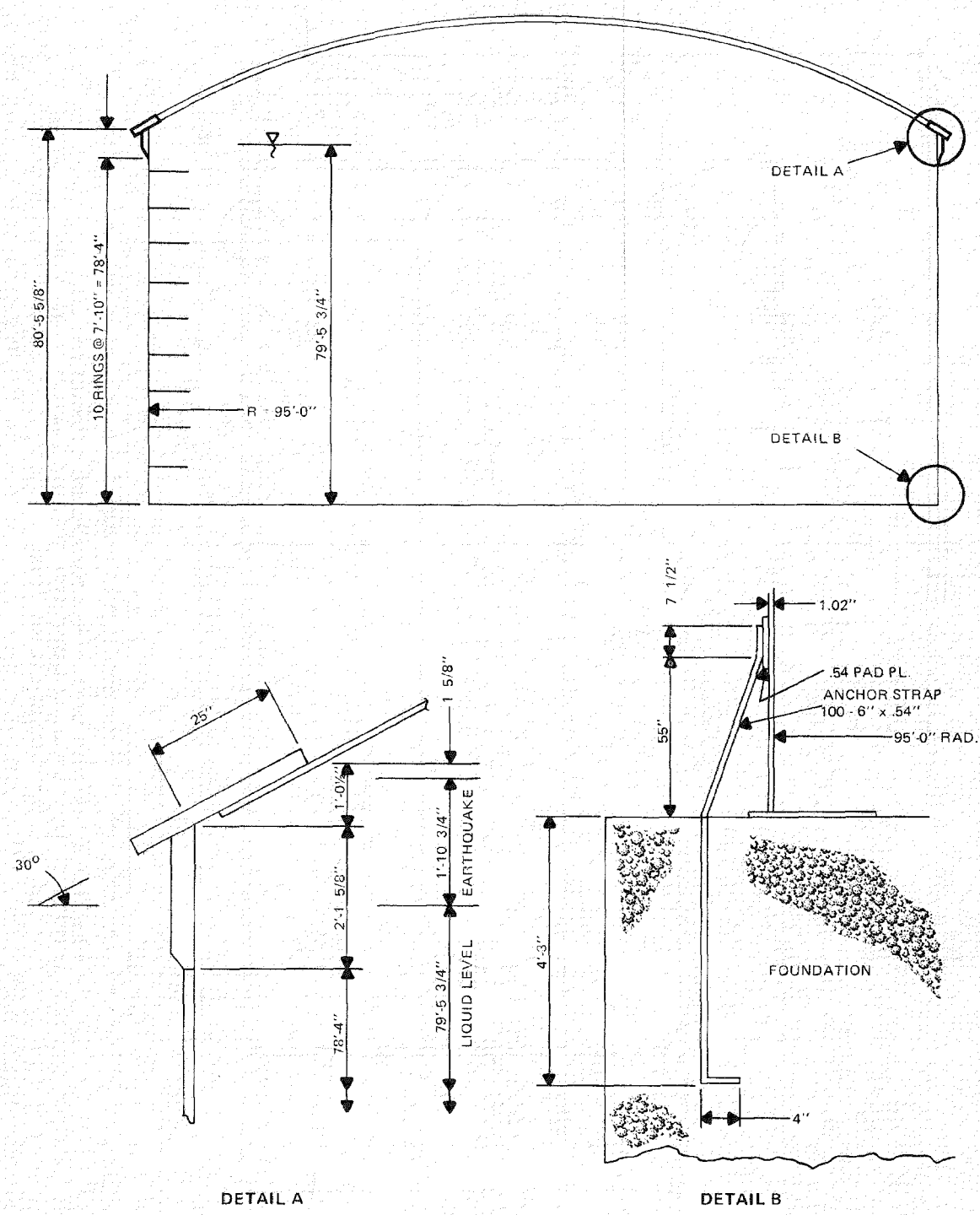


FIGURE 3-4 – ELEVATION VIEW AND DETAILS OF EXXON STEEL PROPANE STORAGE TANK DESIGNED BY PDM AT EVERETT, MASS.

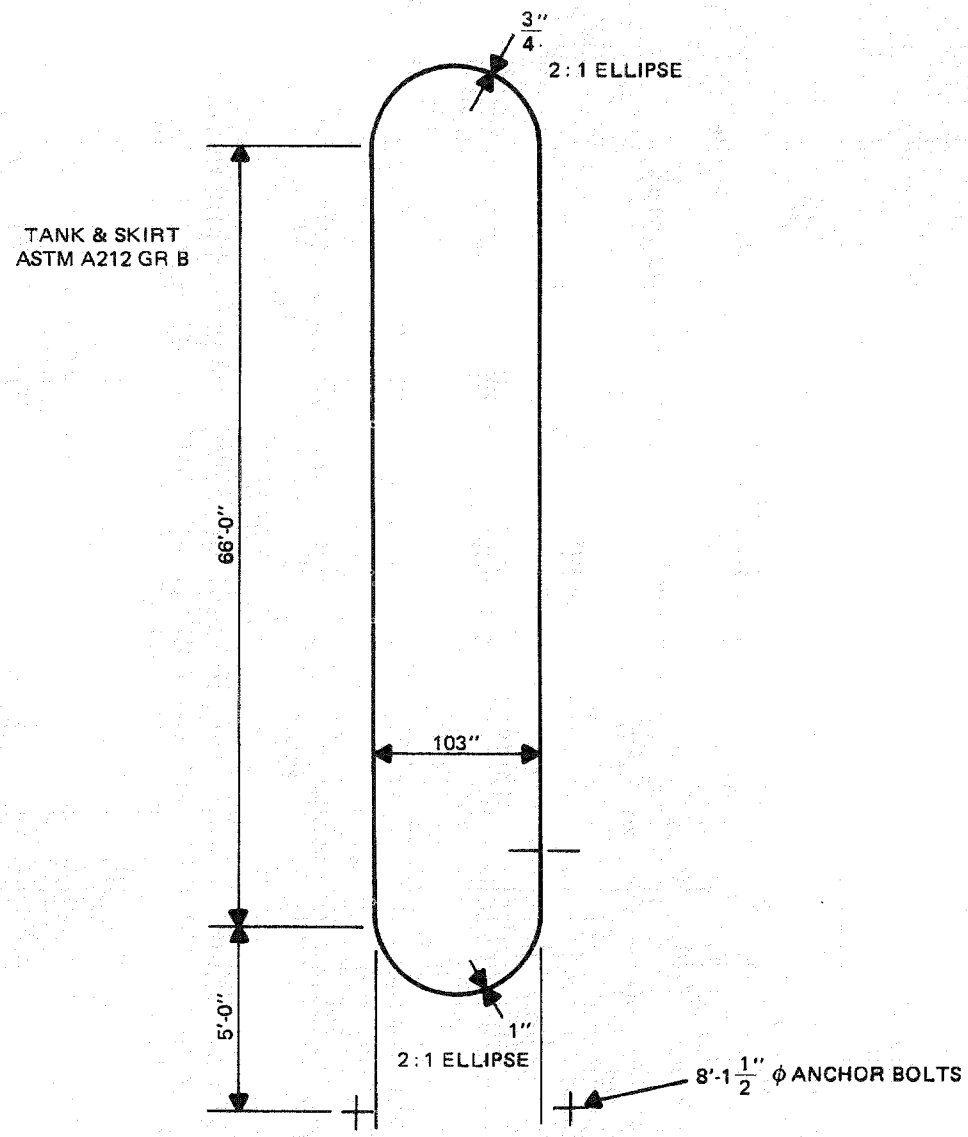


FIGURE 3-5 – ELEVATION VIEW OF BOSTON GAS COMPANY STEEL VERTICAL PRESSURIZED PROPANE "BULLET" TANK AT EVERETT, MASS. MANUFACTURED BY J. F. PRITCHARD & CO.

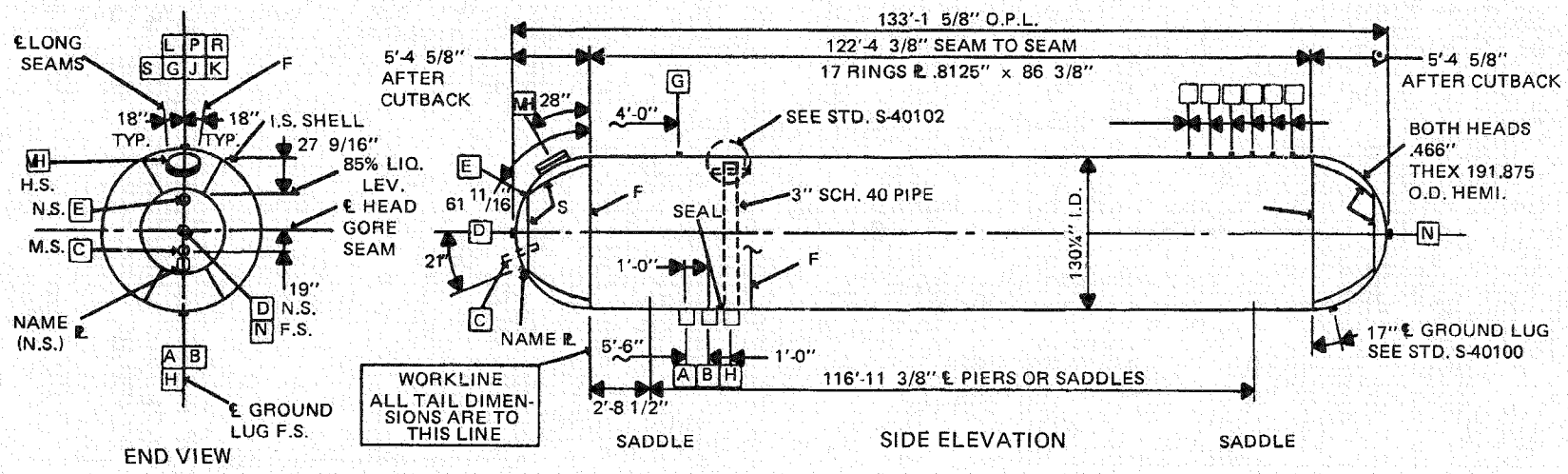


FIGURE 3-6 – ELEVATION VIEWS OF TYPICAL STEEL HORIZONTAL PRESSURIZED PROPANE "BULLET" TANK MANUFACTURED BY TRINITY INDUSTRIES.

Horizontal Steel Propane Tank - Figure 3-6.

EARTHQUAKES AND TORNADOES

Two specific levels of earthquake and wind loadings are considered. The lower level for earthquake evaluation corresponds to the Uniform Building Code (UBC) requirement.[1] This is the minimum level that is required for any commercial building. Seismic standards in NFPA 59A (1975)[2] are based on the UBC requirement, except that site-specific geotechnical analyses are required in Seismic Zones 2 and 3. The higher level for earthquake evaluation is approximately that currently used on commercial nuclear power plant facilities at the locations evaluated. This is the most stringent standard applied to commercial facilities.

For extreme wind loading, the lower wind load is the maximum wind associated with a 100 year return cycle for a level C exposure as defined in ANSI A 58.1-1972, and is used for the design of ordinary buildings and other structures.[3] The chance that a 100-year wind, earthquake, or flood will be exceeded at least once at any given site, if the three phenomena are independent, is 3 percent per year and 78 percent during a nominal 50-year lifetime of a facility. There is better than a 99 percent chance that the design basis will be exceeded more than 75 times during the nominal lifetime of the present 100 large storage facilities. (This assumes that the average facility uses a 100 year repeat interval for natural phenomena design. Some use a shorter interval, and some a longer one.) In general, structures can survive stresses greater than design stresses (those generated by design events). For a more complete analysis, see Fig. 16-1 and the discussion in

Chapter 16 of requirements for resistance to natural phenomena (special issue 5).

The higher wind loading, that associated with nuclear power plant design, is a tornado so large that there is only one chance in 10 million that one at least that large would hit the site in a given year.[4]

Earthquakes

While earthquakes can be caused by volcanic action, water inclusion (such as pumping water into deep wells), and major changes in loading (such as filling a dam with water), the cause of most damaging earthquakes is believed to be tectonic in origin (e.g., as the result of fault movement). Modern seismology views earth's crust as a series of large plates which are in motion relative to each other and the semi-liquid magma underneath. There are seismically active zones along the U.S. West Coast.

Although most damaging earthquakes originate at plate boundaries, about 5 percent of all earthquakes have occurred in regions located within plates where there had been little known seismic activity or active faulting. Within the past 250 years, at least five major earthquakes in the United States have followed this pattern—Boston (Cape Ann), Massachusetts in 1755; New Madrid, Missouri, 3 earthquakes within a six month period in 1811 and 1812; and Charleston, South Carolina in 1876. The New Madrid and Charleston earthquakes were of major magnitude, causing either significant epicentral* damage or changes in

*The epicenter is the part of the earth's surface directly above the origin of the earthquake.

topography. Each was felt over an area of 2,000,000 square miles. West Coast earthquakes caused by fault movement, even those which do considerable local damage, are seldom felt over an area of more than a few thousand square miles.

Seismologists and geologists have generally not been able to identify tectonic structures which cause the earthquakes east of the Rocky Mountains. It is the existence of this unexpected and usually unexplained 5 percent which has prompted regulating authorities, industrial standards, and prudent owners to insist upon earthquake or seismic design requirements being incorporated into hazardous facilities design regardless of the recorded seismic history of the site.

The earthquake design criteria we used in evaluating storage facilities were in accordance with the UBC requirements and the U.S. Nuclear Regulatory Guide 1.60, Horizontal Response Spectrum[5] as shown in Fig. 3-7 for 5.0 percent critical damping for steel and 7.0 percent for concrete. The zero period surface accelerations (the acceleration of a particle rigidly attached to the ground) assumed in the evaluation as a function of geographic location, are shown in Fig. 3-8, which is a modification of the current zone map which appears in the UBC.[1]

The maximum seismic acceleration which nuclear power plants are designed to withstand is known as the Safe Shutdown Earthquake (SSE). At the 6 sites examined in this chapter, the chance that there will be an earthquake at least as large as an SSE in a given year varies from one in 10,000 to one in 10 million.[6]

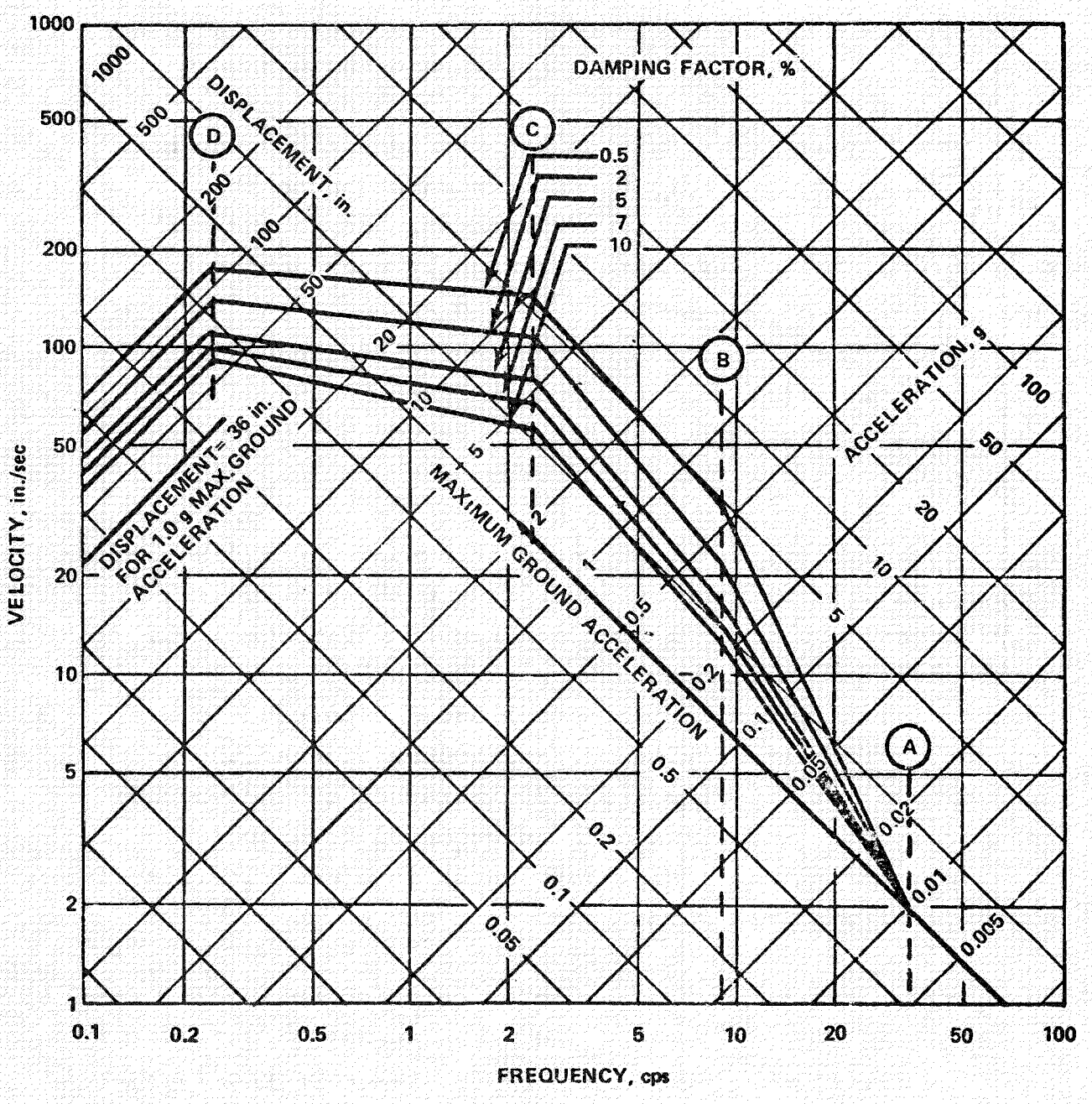


FIG. 3-7 HORIZONTAL DESIGN RESPONSE SPECTRA – SCALED TO 1g HORIZONTAL GROUND ACCELERATION

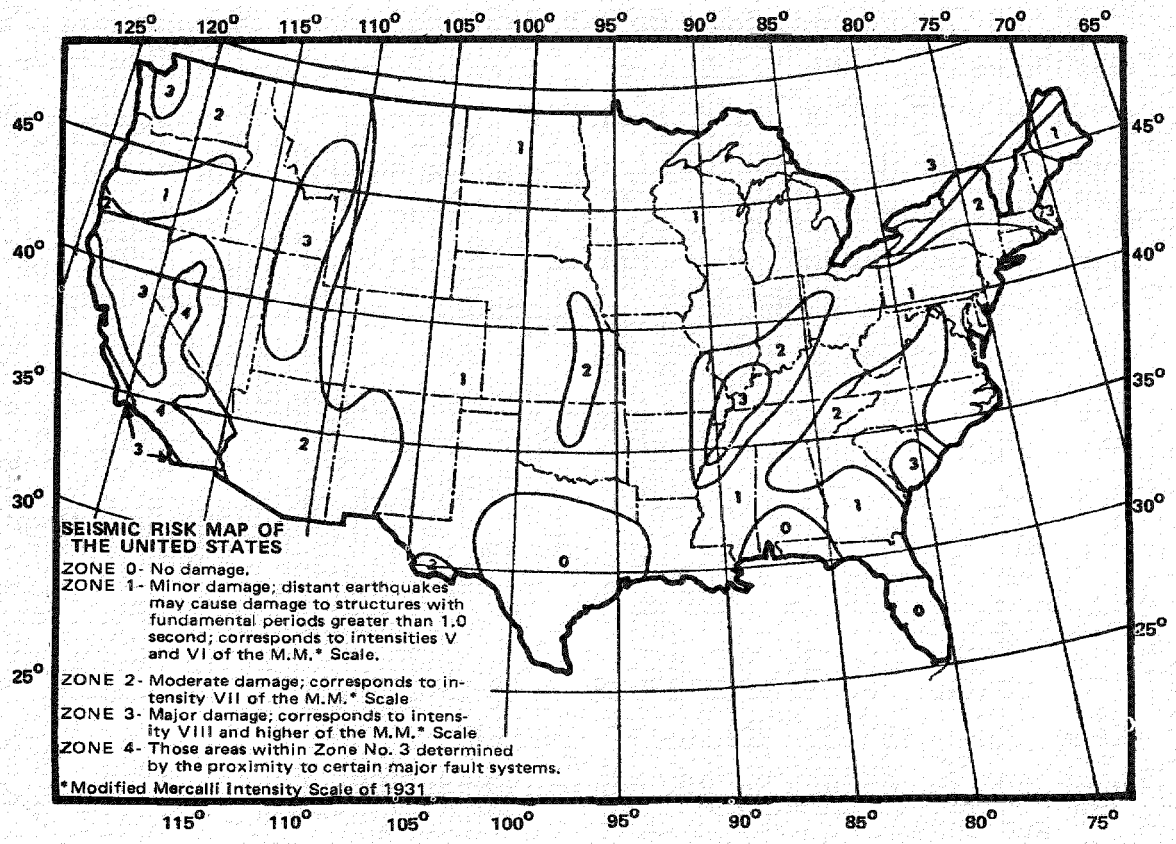


FIGURE 3-8 – TYPICAL ZERO PERIOD FREE FIELD SURFACE GROUND ACCELERATION USE IN SAFE SHUTDOWN DESIGN OF NUCLEAR POWER STATIONS

ZONE 0 - 0.1g

ZONE 1 - 0.15g ± 0.05g as a function of foundation condition.

ZONE 2 - 0.20g ± 0.05g as a function of foundation condition.

ZONE 3 - 0.3g ± 0.1g as a function of foundation conditions and proximity to areas of historical major seismic disturbances.

ZONE 4 - 0.55g ± 0.15g as a function of foundation conditions and proximity to known active faults.

Tornadoes

Nuclear power plants are designed to withstand the wind pressure and differential pressure drop from a "design tornado." The design tornado is chosen so that a nuclear power plant at a particular site will have only one chance in 10 million of being hit by a tornado at least that large in any given year.[4] To simplify design, the United States is divided into three regions as shown in Fig. 3-9[8]. In Region 1 the design wind speed is 360 MPH. In Regions 2 and 3 the design wind speed is 300 and 240 MPH, respectively. Differential negative pressure design varies from 3.0 psi at 360 MPH to 1.5 psi at 240 MPH.

Design Evaluation of Tanks

Design calculations, specifications, and drawings associated with the facilities described in Table 3-1 were obtained directly from owners or designers. We did not evaluate their numerical accuracy, but only the applicability of the calculations to current methods of analysis and to the design assumptions used for nuclear power plants.

The results in Tables 3-2, 3-3, and 3-4 are based upon stress levels. The "design load stress" in a structure is the stress produced by the force (i.e., normal load, earthquake, wind) which a building code requires a structure to withstand. The code also specifies the "allowable stress." The ratio of the allowable stress to the corresponding design load stress is called the "safety factor". A safety factor greater than one indicates that a structure is stronger than required by a particular code. If the safety factor is less than one, then the structure

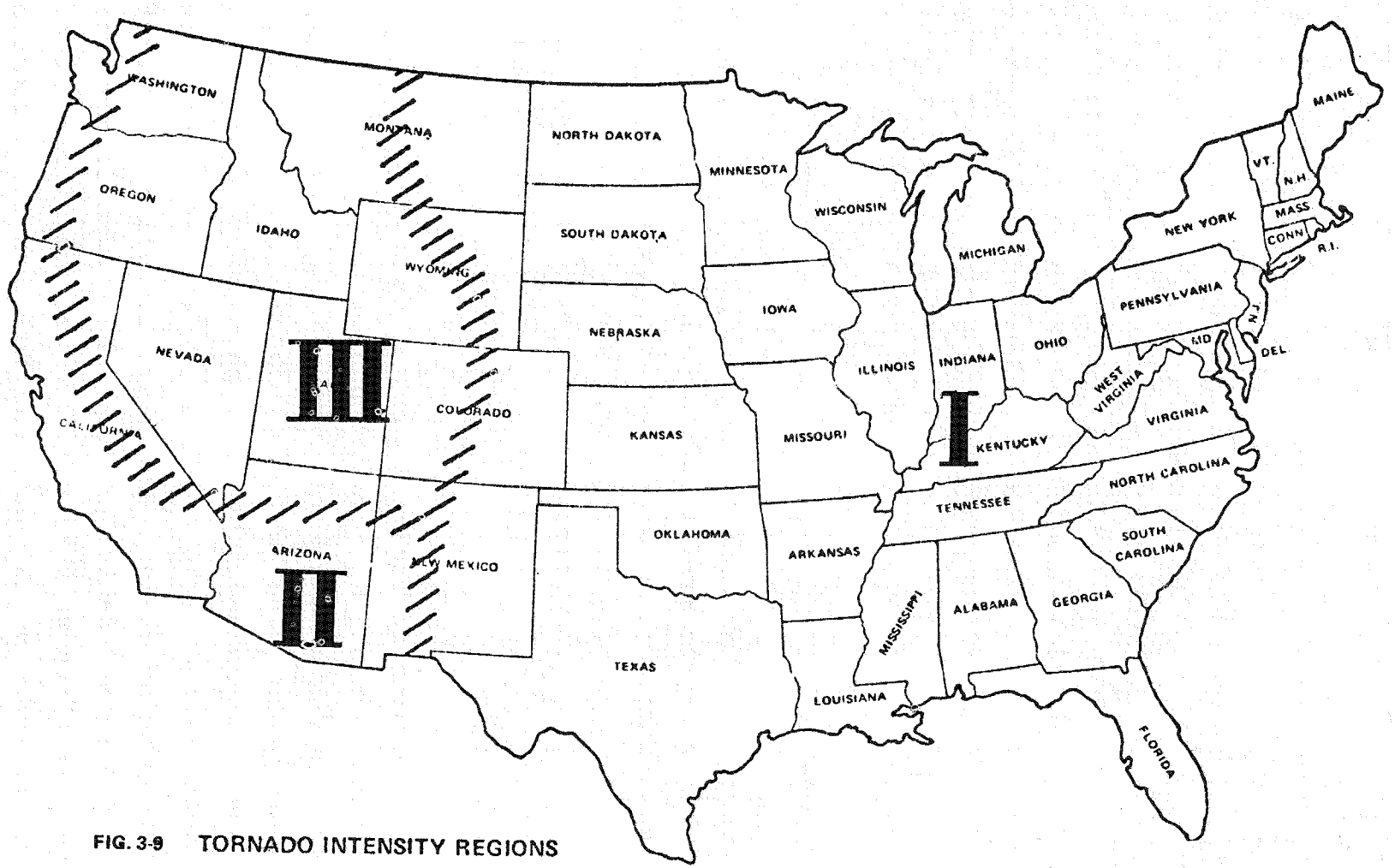


FIG. 3-9 TORNADO INTENSITY REGIONS

TABLE 3-2 STEEL TANK SEISMIC DESIGN PARAMETERS, FAILURE MODES, AND SAFETY FACTORS

	FACILITY	DESCRIPTION	ORIGINAL SEISMIC CRITERIA	NUCLEAR PLANT SEISMIC CRITERIA	MOMENT OF LIMITING FAILURE MODE[5] (10^3 K-ft.)		FACTOR OF SAFETY			
							All. Stress in Tie Down Straps or Bolts		Design Load Stress in Tie Down Straps or Bolts	
					UBC	Nuclear Criteria	UBC Kip/Sq. in. (Ksi)	Nuclear Criteria Kip/Sq. in. (Ksi)	UBC Kip/Sq. in. (Ksi)	Nuclear Criteria Kip/Sq. in. (Ksi)
1	LNG Marine Terminal for Distrigas Corporation Everett, Massachusetts Designed - 1970	55,000 m^3 150 ft. dia. x 123 ft. ht. to Springline (Inner Tank)	UBC Zone 2 0.05g static load in accordance with TID 7024 Chapter 6 (Rigid Tank) method of analysis.	0.20g Safe Shutdown Earthquake Zero Period Ground Acceleration 5.0% Damping for Reg. Guide 1.60 Response Spectrum.	258	1241	Material: ASTM TP 304 f_a = 22.5 Ksi [9] f^a = 30.0 Ksi f^y = 75.0 Ksi [1] f^u 1.33 x 22.5 = 29.9 Ksi	1.2 f_y [2] =36.0 Ksi	25.8 Ksi F.S. = 1.16 [8]	153.9 Ksi [3] F.S. = 0.24
2	LPG Marine Terminal for Exxon Co., U.S.A. Everett, Mass. Designed - 1972	64,000 m^3 190 ft. dia. x 80 ft. ht. to Springline	Same as 1. above	Same as 1. above	293	875	Material: ASTM A 537 B f_a = 23.3 Ksi f^a = 50.0 Ksi f^y = 70.0 Ksi f^u 1.33 x 23.3 = 31.0 Ksi	.7 f_u [2] =49.0 Ksi	25.1 Ksi [4] F.S. = 1.23	64.3 Ksi [3][4] F.S. = 0.76
3.	Vertical Pressurized LPG "Bullet" tanks for Boston Gas SNG Plant Everett, Mass. Designed - 1947	114 m^3 cylinder 66 ft. long with 2:1 elliptical heat closure supported on a 5 ft. high, 3/4 in. thick skirt anchored by 8 - 1-1/2" A 193 bolts.	None specified but assumed for evaluation purposes the same as 1. above, except sloshing neglected.	Same as 1. above.	0.463	5.14	Material: (AISC) ASTM A 193 Bolts f_a = 63.0 Ksi f^a = 105.0 Ksi f^y = 125.0 Ksi f^u 1.33 x 63.0 = 83.8 Ksi	.7 f_u [2] = 87.5 Ksi	Act. M = 463 K-ft. Lim. M = 3150 K-ft. F.S. = 6.8 [7]	154.1 Ksi F.S. = 0.57
4.	Typical Horizontal Pressurized LPG "Bullet" Tanks Supported by Two Piers Designed by Trinity Industries, 1977	342 m^3 horizontal cylinder with hemispherical ends, 116 ft. between support saddles. Total length is 133 ft. I.D. of cylinder is 130 in.	None specified but assumed for evaluation purposes the same as 1. above, except sloshing is neglected.	Same as 1. above.	0.381[5]	5.55[5]	Material: (ASMC Sec. ASTM SA 612 PL (VIII) f_a = 20.2 Ksi f^a = 50.0 Ksi f^y = 81.0 Ksi E.Q. All.=20.2Ksi Div. 1 E.Q. All.=27.0Ksi Div. 2	.7 f_u [2] = 56.7 Ksi	18.6 Ksi F.S. = 1.08 [6] F.S. = 1.42	22.0 Ksi F.S. = 2.58

(1) Allowable stress for both Earthquake and Wind based on 1.33 times normal allowable in accordance with 3.06.5 of API 620 Sup. No. 3.
(2) Based on Faulted Condition of Appendix F, ASME Section III Criteria for Component Supports.
(3) Note that this comparison is based on simple tensile stress calculation, neglecting shear carried by tie down straps or bolts. If two horizontal components of motion are considered such that significant shear and tension occur simultaneously and the friction capacity between the tank bottom and foundation are exceeded, tie down straps or bolts required to carry seismic shear, all safety margins shown for nuclear criteria would be reduced by at least a factor of 2.
(4) Tie down straps assumed to carry both internal pressure uplift and seismic with thermal stress neglected.
(5) Limiting Failure mode for Tank 1, 2, and 3 base overturning moment to be carried by anchor straps or bolts. For tank 4 limiting failure mode is bending moment plus pressure tensile stresses at center of span of tank. No saddle designs were evaluated.
(6) This Safety factor is based on ASME Section VIII Div. 1 allowables; if Div. 2 allowables are used, F.S. is increased as shown.
(7) With UBC E.Q. Base Moment = 5.56 K-ft, there is no up-lift on bolts. F.S. is ratio of the base moment to moment required to overstress anchor bolts.
(8) F.S. = Safety Factor = Allowable Stress/Design Load Stress.
(9) f_a = normal load allowable stress

f_y = yield stress

f_u = ultimate stress

1.33 x f_a = earthquake/wind load allowable stress

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TABLE 3-3 PRESTRESSED CONCRETE TANK AND DIKE SEISMIC DESIGN PARAMETERS FAILURE MODES AND SAFETY FACTORS

FACILITY	DESCRIPTION	ORIGINAL SEISMIC CRITERIA	NUCLEAR PLANT SEISMIC CRITERIA	MOMENT OF LIMITING FAILURE MODE — Design Load Moment, M (10^3 k-ft.) Design Load Shear, V (10^3 Kips)		Moment or Shear to cause lift off or sliding		FACTOR OF SAFETY — Ratio of Lift Off Moment or sliding shear to design load moment or shear	
				UBC	Nuclear Criteria	UBC	Nuclear Criteria	UBC	Nuclear Criteria
1. LNG Marine Terminal[1] for Public Service Electric & Gas Rossville, Staten Is. N.Y. designed - 1970.	143,000 m^3 Capacity Pre-stressed concrete tank. 240 ft. dia. with ht. to spring line of 117 ft.	UBC Zone 1 static load in accordance with TID 7024 Chapter 6 (Rigid Tank) method of analysis .	0.20g Safe Shutdown Earthquake Zero Period Ground Acc. 7% damping of Reg. Guide 1.60 Spectrum.	M = 270 V = 5.7	M = 1933 V = 45.4	M = 1843 V = 11.1	M = 1474 V = 12.5	6.83 6.15	0.76 0.19
2. High Dike for LNG Marine Terminal for Western LNG Terminal Associates, Oxnard, Cal. (planned)	87,000 m^3 Capacity Pre-stressed concrete high dike. 259 ft. I.D. x 80 ft. to Spring-line.	Equivalent to Nuclear Plant Design Criteria for a 0.3g zero period ground acc. and 5% damping expect allowable stress limited to 1.33 x allowable .	0.6g[3] zero period ground acc. for 7% damping in accordance with R.G. 1.60 spectra with stress limited to 1.6 x allowable.	M = 1756 V = 53.9	M = 23.3 V = 107.2	M = 2745 (2)	M = 1568 (2)	1.56 (2)	0.67 (2)

(1) In this analysis, it is assumed radial shear bars carry shear in excess of 0.3 x Dead weight of concrete in tank walls (4608 Kips). The bearing bars have an assumed capacity of 1.6 Ksi for UBC and 1.92 for Nuclear Criteria. Factor of Safety shown is the ratio of the allowable stress in the bearing bars to the design load stress, assuming that the bars must carry shear load in excess of the shear load carried by friction.

(2) Shear capacity not evaluated since design of base detail not complete. However, because of the magnitude of forces, some positive membrane shear resistance system might be required.

(3) Value of 0.6g selected as representative of current design conservatism imposed on Nuclear Stations in Coastal Zone of Southern California.

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TABLE 3-4 SUMMARY OF ANALYTICAL RESULTS AND COMPARISON OF 100-YEAR WIND TO TORNADO DESIGN MARGINS FOR CONCRETE AND STEEL LNG AND LPG STORAGE TANKS

	FACILITY	ORIGINAL WIND DESIGN CRITERIA	NUCLEAR PLANT TORNADO CRITERIA	MOMENT OF LIMITING FAILURE MODE (10^3 K-ft)		FACTORS OF SAFETY			
						Allowed Stress, Moment on Shears		Design Load Moment, Shear, and Stresses and Factors of Safety	
				100-Year Wind	Tornado	100-Year Wind	Tornado	100-Year Wind	Tornado
1.	LNG-Distrigas Everett, Mass.	25 psf 0-30 ft. 35 psf 30-50 ft. 45 psf 50-100 ft. 55 psf > 100 ft. App. = 100 MPH EXP.C	360 MPH Wind 3.0 psi pressure drop	36.4	296.2	Material: ASTMA-36 f_{all} = 20.0 Ksi f^{y} = 58.0 Ksi f^{u} 1.33 x 20.0 = 26.6 Ksi	.7 f_u 40.6 Ksi	16.9 Ksi F.S. = 1.58	78.1 Ksi F.S. = .52
2.	Propane - Exxon Everett, Mass.	30 psf Const. Approx. = 90 MPH EXP. C ANSI A 58.1	360 MPH Wind 3.0 psi pressure drop	16.6	151.3	Material: ASTM A 527B f_a = 23.3 Ksi f^{y} = 70.0 Ksi f^{u} 1.33 = 23.3 = 31.0 Ksi	.7 f_u = 49.0 Ksi	9.53 Ksi F.S. = 3.25	55.0 Ksi F.S. = .89
3.	Propane - Boston Gas Everett, Mass.	Unknown	360 MPH Wind 3.0 psi pressure drop	.455	3.7	Material: (AISC) ASTM A 193 f_a = 63.0 Ksi f^{y} = 125.0 Ksi f^{u} 1.33 x 63.0 = 83.8	.7 f_u = 87.5 Ksi	Act M = 955 K-ft Lim M = 3150 K-ft F.S. = 6.9	83.17 Ksi F.S. = 1.05
4.	Trinity Industries Typical 90,000 gallon LPG "bullet" tank.	None specified	360 MPH Wind 3.0 psi pressure drop	.284	3.63	Material: (ASME Sec. VIII) ASTM SA 612 PL f_a = 20.2 Ksi f^{y} = 50.0 Ksi f^{u} = 81.0 Ksi E.Q. All. = 20.2 Ksi Div. 1 E.Q. All. = 27.0 Ksi Div. 2	.7 f_u = 56.7 Ksi	18.6 Ksi F.S. = 1.08 F.S. = 1.42	19.5 Ksi F.S. = 2.90
5.	Public Service Electric & Gas Staten Is., N.Y.	Unknown	360 MPH Wind 3.0 psi pressure drop	46.5	321.3	M = 1161	M = 1542	F.S. = 25.0	F.S. = 4.8
6.	LNG Dike, Western LNG, Oxnard, California	Unknown	240 MPH Wind 1.5 psi pressure drop	16.0	53.9	M = 3920	M = 3920	243.7	72..7

(1) For notes applicable to material properties and allowable stresses, see Table 3-2.

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does not fulfill the code's requirements.

Typical values for various allowable stresses are shown in the chart below. All values are expressed as fractions of the ultimate (breaking) stress (f_u) of the construction material.

Normal load allowable stress	$0.3f_u$
Earthquake/wind load allowable stress	$0.4f_u$
Yield stress	$0.4\text{-}0.6f_u$
Nuclear design earthquake/wind load allowable stress	$0.7f_u$

In this chapter we use "facility failure" to mean significant uncontrolled leakage of LEG from the primary (insulated) container. Generally, such failure will occur as a result of plastic (inelastic) deformation of the structure. Plastic deformation begins when a material's yield stress is exceeded.

The calculations of failure and safety factor depend upon conventional engineering techniques, which involve simplifications. The exact stress needed to produce failure is almost never determined because it is so difficult to do so. It is possible, however, to find the weakest or most vulnerable component in a structure. The "limiting failure mode" is the process most likely to cause this component to fail. Appendix III-3 is a more detailed discussion of these factors.

Seismic Design

Prior to the mid-1960's, there appears to have been no general requirement for seismic design evaluation. The

seismic designs of those tanks designed after the mid-1960's meet or exceed the UBC requirements for the area in which they are built and use a seismic static horizontal coefficient.[2] The proposed Oxnard LNG facility has design criteria which generally follow and are equivalent to those required for nuclear power plants. It is not, however, designed to withstand as large an earthquake as would a nuclear plant at the same site.

Steel Tanks Containing Stored Liquid

In general, our evaluations of tanks and dikes for seismic loads follow the same procedures used in the original design and are described in TID 7024,[9] which has been used as a standard method for several years, except that we considered tanks to be flexible rather than rigid* (as discussed by Veletsos and Yang).[10] As can be seen from Fig. 3-7, the dynamic response of flexible tanks can increase response inertia shear and moment by a factor of two or three times over that used in the rigid assumption.

The most likely cause of failure due to seismic loads on steel tanks containing LNG or liquefied propane appears to be shear and overturning moment induced forces in the steel straps that anchor the steel cylinder sides of the tanks to the concrete flat bottom foundation. In other words, if a tank fails because of an earthquake, it is likely to be by tensile rupture of the hold-down straps, which would permit the tank walls to lift off and separate from the tank bottom. The next most likely cause of

*The impulse mass of the fluid in a rigid tank is assumed to have the same acceleration as the ground. In a flexible tank the fluid mass acceleration is a function of the tank frequencies, including the effective mass of both tank and fluid. Typical flexible tank fundamental frequencies occur between 1 and 4 cycles per second.

failure would probably be buckling of the walls due to overturning moment compression. However, since failure of the anchor straps would occur at much lower acceleration and would result in a significant spill of the contained fluid, the effect of less likely failure causes has not been evaluated in detail.

The base shear, overturning moments, and safety factors determined for the UBC seismic criteria and those determined for nuclear plant seismic criteria are summarized in Table 3-2. The full SSE earthquake has been assumed in the "Nuclear Criteria" column. The results show that the tanks, while adequate using the UBC criteria, come nowhere near meeting nuclear seismic criteria.

Steel Outer Tanks

Many LNG storage vessels consist of two steel tanks with the outer tank protecting the insulation and the inner tank from the weather and wind. In general, if the inner tank fails due to seismic effects, the outer tank will fail also. The outer Distrigas tank, for example, was evaluated for seismic load assuming the inner tank had failed and the LNG was bearing on the outer tank. In such an instance, the factor of safety against outer tank lift-off failure for the SSE event is 0.28, compared to 0.24 for the inner tank; and for the UBC earthquake, the factor of safety is 0.70 for the outer tank compared to 1.16 for the inner tank. Furthermore, the outer tanks are not normally made of cryogenic material. If the inner tank fails, the outer tank is almost certain to rupture from the resulting pressure and thermal shock.

Concrete Tanks Containing Stored Liquid

Under the UBC criteria, concrete tanks for containing stored liquid use their own dead weight to resist seismic overturning moment; hence, no tensile or uplift ties are provided to anchor the concrete cylinder to the base mat. These two-way prestressed tanks are generally fabricated from precast, vertically prestressed panels. After erection, the panels are spirally wound to provide horizontal prestress. Radial shear lugs are used to provide seismic shear resistance. As in the case of steel tanks, seismic-induced lift-off of the tank walls and shear appear to be the most likely failure modes. The seismic base shear and overturning moment safety factors determined for the actual UBC design criteria and those determined for nuclear plant seismic criteria are summarized in Table 3-3.

Concrete High Dikes

The design details of concrete high dikes are similar to those used for concrete tanks, except that the insulation details between the wall and base mat can be much simpler, and radial shear lugs may not be required since overall height to width ratios have been significantly reduced. It was assumed, in performing the earthquake analysis shown in Table 3-3, that the diked area was filled with LNG.

Earthen Dikes

Earthen dikes are normally made of selected engineered backfill designed for optimum density and slope stability, which precludes their failure during earthquakes. Usually they are significantly more

earthquake resistant than the surrounding foundation media, unless that is also engineered fill.

Tornado Design

The tanks analyzed were designed as detailed in ANSI A 58.1-1972, to withstand a wind which has only one chance in 100 per year of occurring at the site, except that velocity is considered constant with height and the gust factor is taken as a constant 1.0. Tornado design wind speeds typically range, as a function of location, from 240 to 360 MPH, while normal design wind velocity ranges from 100 to 130 MPH. Since wind loads vary as the square of velocity, tornado wind loads are typically 5 to 10 times greater in magnitude than normal 100-year wind design load. Tornado design also considers differential pressures.

Tornado winds have been known to generate significant missiles. A 360 MPH tornado wind can propel missiles at velocities between 200 and 300 MPH. We have not done a detailed evaluation of tornado-borne missiles, but, in general, to stop missiles at these velocities, cylindrical shells require a thickness between 1.0 and 1.5 inches of steel, or between 18 and 24 inches of concrete. LNG and LPG steel outer tanks would be penetrated by some tornado-borne missiles.

Table 3-4 summarizes and compares overturning moments, shear, forces in tie-downs, and factors of safety for the ANSI A 58.1-1972 design for the 100-year wind with nuclear plant tornado design requirements. For double-wall tanks, this analysis is applicable to the outer tank. Two of the six facilities evaluated fail to meet the tornado resistance requirements demanded of nuclear plants.

UBC Earthquake and 100-Year Wind Evaluation

All the LNG and LPG tanks and dikes we evaluated, as summarized in Tables 3-2, 3-3, and 3-4, were adequately designed for the UBC earthquake and the 100-year maximum wind design criteria. The smallest factor of safety was 1.08. This is not to say that, if this 8 percent margin were exceeded, failure would result. Given the stress levels which were allowed for this load case, gross failure would probably not occur until loads exceeded by 30 to 75 percent those loads which would be determined with a safety factor of 1.0. However, when overturning moment or gross stability values are the limiting behavior or failure mode, there is little excess capacity and the 30 to 75 percent margin should not be assumed available.

In addition to meeting the minimum UBC earthquake and 100-year wind criteria, all the tanks and dikes were adequately designed for their own facility specific criteria, which were in some instances more stringent than the UBC requirement; the Oxnard concrete dike is an example.

Nuclear Standards: Safe Shutdown Earthquake and Tornado

These input loads are significantly larger than the UBC earthquake and 100-year wind, in many cases more than 10 times greater. In general, the tanks evaluated fail to meet these standards. Also, since the allowable stresses permitted for this load case are significantly greater than those used for the UBC earthquake and 100-year wind, the additional margin above a 1.0 safety factor on stresses to actual failure has probably been reduced to the 20 to 40 percent range. The results of this evaluation indicate

that most LNG and LPG storage facilities would fail if they were subject to the same seismic load phenomena that nuclear power plants are designed to resist. The limiting seismic and wind loads used in the design of nuclear plant facilities have a probability of occurrence between 1/100,000 to 1/10,000 per year.

LIQUEFACTION

The specific earthquake phenomenon called liquefaction has been generally considered in seismic design only in the past ten to fifteen years. The term liquefaction refers to the development (due to cyclic loads) of pore water pressure equal to the confining pressure in sands and silts. When this happens, particularly in relatively loose soils, very large deformations can occur, and the foundation acts like water, with little or no shear strength. This can result in catastrophic failure of the building foundation. Liquefaction normally occurs in poorly graded, saturated sands and silts, with a relative density from 35 to 70 percent. Since most engineered or selected backfill is made up of relatively well-graded materials and is compacted to a relative density between 70 and 90 percent, it is unlikely such materials will liquefy.

FLOODING AND TSUNAMI

Flooding and tsunami at a site could cause a tank to shift or lift off from its foundation, causing a massive spill. This could be caused by the buoyancy of the tank or by the drag resistance of the tank to the flow of the flood water. The procedure normally followed to prevent this is to locate the tank above the flood plain, or to use high

enough dikes or levees to keep potential flood water from reaching the storage tanks.

Evaluation

From the responses we received to the questionnaire in Appendix III-1, we determined the site conditions and the design procedures that were followed at a number of LEG storage facilities. A summary of the responses is given in Table 3-5 for liquefaction and Table 3-6 for flooding and tsunami.

When liquefaction analysis was done for a site, it was generally done in accordance with the simplified procedures of Seed and Idriss,[11] which have been used as more or less standard practice in the industry for evaluating liquefaction potential since their publication in 1971.

Sites on rock or on cohesive clay type foundations are generally not susceptible to liquefaction, and no such evaluation is made in these cases.

For one of the two facilities built on piles, no evaluation was made of the potential loss of lateral pile support due to liquefaction. This could lead to significant lateral deformation of the tank.

Some evaluations of the forces associated with liquefaction, flood, and tsunami on LEG storage facilities have been much better than others. The facilities whose design work began after the period 1972 to 1974 have had much more attention devoted to extreme natural loads and hazards than have the tanks designed earlier. In many

TABLE 3-5 SUMMARY OF LIQUEFACTION EVALUATION PERFORMED AT TYPICAL LNG AND LPG STORAGE TANK SITES

	FACILITY AND LOCATION	FOUNDATION POTENTIALLY SUSCEPTIBLE TO LIQUEFACTION	ANALYSIS PERFORMED	MINIMUM FACTOR OF SAFETY	REMARKS
1.	Port O'Connor, Tex., Proposed LNG Marine Terminal, El Paso LNG Terminal Co.	Yes	Seed & Idriss (11)	2.0	Based on 0.07g Zero Period Ground Acceleration. Final foundation system - Flexible mat or piles.
2.	Cove Point, Md., LNG Marine Terminal, Columbia LNG Corp. (Designed - 1972)	Yes	Liquefaction Analysis made in accordance with Seed & Idriss (11) with conclusion reached that there was little potential for liquefaction. However, no analysis available for review.	N/A	No analysis available for review.
3.	Oxnard, Cal. Proposed LNG Marine Terminal, Western LNG Terminal Associates	Yes, Top 20 ft. of foundation material was determined to liquefy and is to be removed and replaced with selected backfill.	Seed & Idriss (11) Donovan (12)	1.44 1.21	Based on free field ground acceleration of 0.37g and acceleration at tank foundation level of 0.21g.
4.	Staten Island, N.Y. LNG Peakshaving Facility Texas Eastern Transmission Co. (Designed - 1972)	Yes	Apparently no specific liquefaction evaluation was made. Site employs selected backfill for 25 feet below tank. This backfill should not be susceptible to liquefaction.	N/A	The selected backfill is underlaid with approximately 17 feet of well-graded sand. Potential for liquefaction in this layer is unknown based on data supplied.
5.	Lake Charles, La. Proposed LNG Marine Terminal Trunkline LNG Co.	A friction pile foundation was used.	Seed & Idriss (11) Opinion of design engineer was that foundation could take 4 Kip/pile lateral transient load.	N/A	Analysis not available for review. Not clear how the capacity stated compares with potential lateral earthquake load.
6.	Elba Island, Ga. LNG Marine Terminal Southern Energy Co. (Designed - 1972)	A friction pile foundation was used	Lateral capacity of pile not stated.	N/A	Not enough data furnished to evaluate either liquefaction potential or lateral load capacity of the pile system. UBC Zone III used in design of facility although it is in Zone II.
7.	Plymouth, Wash. LNG Peakshaving Facility Northwest Pipeline Corp. (Designed - 1975)	Probably not. Foundation media is gravel 50 ft. deep over basalt rock.	No	N/A	
8.	Everett, Mass. LNG Marine Terminal Distrigas Corp. (Designed - 1970)	Probably not since foundation below fill either stiff clay or dense coarse sand.	Not apparent from data furnished.	N/A	Site design for UBC Zone 2.
9.	Houston (Galena Park), Tex., LPG Marine Terminal Warren Petroleum Co.	Yes	Not performed.	N/A	Potential for tank foundation liquefaction not considered as a design parameter.
10.	West Deptford, N.J. Proposed LNG Marine Terminal Tenneco LNG Corp.	Yes, Founded on sand.	Not performed.	N/A	UBC Seismic Zone I.

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TABLE 3-6 SUMMARY OF FLOODING AND TSUNAMI EVALUATION PERFORMED AT TYPICAL LNG AND LPG STORAGE TANK SITES

	FACILITY AND LOCATION	POTENTIAL FORMALLY EVALUATED		CRITERIA OR ANALYTICAL METHOD USED IN EVALUATING DESIGN BASIS		FACTOR OF SAFETY		REMARKS
		FLOODING	TSUNAMI	FLOODING	TSUNAMI	FLOODING	TSUNAMI	
1.	Port O'Connor, Tex. Proposed LNG Marine Terminal, El Paso LNG Terminal Co.	Yes	No	100 yr. Storm	N/A	30/27.1= 1.1 (1)	N/A	Tank also designed to withstand flood load as buoyancy force assuming tank full.
2.	Cove Point, Md. LNG Marine Terminal Columbia LNG Corp. (Designed - 1972)	Yes	No	10 yr. Local Run Off	N/A	N/A	N/A	Tank foundation located 110 ft. above mean sea level. This height differential considered sufficient to preclude possibility of coastal flooding.
3.	Oxnard, Cal. Proposed LNG Marine Terminal, Western LNG Terminal Associates	Yes	Yes	Probable Maximum Flood	500 yr. Return Period	15/12=1.25 (2)	15/14.7= 1.02	Since tank located approx. 1200 ft. inland and surrounded by 80 ft. dike, tsunami and storm damage not considered credible.
4.	Staten Island, N.Y. LNG Peakshaving Facility, Texas Eastern Transmission Co., (Designed - 1972)	Yes	No	Based on Historical Records	N/A	None Stated. Max. historical flood has not reached height of base	N/A	Since reported height of tank bottom is only 10 ft. above mean sea level, potential for flooding probably not adequately covered by historical data.
5.	Lake Charles, La. Proposed LNG Marine Terminal, Trunkline LNG Co.	Yes	No	100 yr. Flood	N/A	12/7=1.7 (3)	N/A	Tsunami not considered credible since site is 20 miles from coast.
6.	Elba Island, Ga. LNG Marine Terminal Southern Energy Co. (Designed - 1972)	Yes	No	100 yr. Flood & Storm	N/A	15.69/13.0= 1.2 (4)	N/A	
7.	Plymouth, Wash. LNG Peakshaving Facility Northwest Pipeline Corp. (Designed - 1975)	No	No	N/A	N/A	N/A	N/A	Tank base located ½ mile from Columbia River +30 ft. above controlled height of river.
8.	Everett, Mass. LNG Marine Terminal Distrigas Corp. (Designed - 1970)	Yes	No	Based on Historical Record	N/A	34.4/16= 2.15 (5)	N/A	Bottom of tank located 1000 ft. from shore and 18 ft. above highest recorded flood level.
9.	Houston (Galena Park), Tex., LPG Marine Terminal, Warren Petroleum Co.	Yes	No	N/A	N/A	N/A	N/A	Maximum recorded flood height 10 ft. below bottom of tank.
10.	West Deptford, N.J. Proposed LNG Marine Terminal, Tenneco LNG Corp.	Yes	No	50 yr. Storm	N/A	25/8.8= 2.84 (6)	N/A	Design still in preliminary stage.

(1) Height of sea wall protecting site = 30.0 ft.; combined 100-year tide and wave surcharge 27.1.
(2) 15 ft. height of protective sand dunes and perimeter road; 12 ft. height of storm wave run up; 14.7 ft. height of tsunami run up.
(3) 100-year flood stage 7.0 ft. above mean sea level; base of tank equal to or greater than 12.0 ft.
(4) Bottom of tank = 15.69 ft.; 100-year flood height 13.0 ft.
(5) Bottom of tank = 34.4 ft.; historical flood height equal 16.0 ft.
(6) Plant elevation = 25 ft.; highest recorded flood level 8.8 ft. in 1933.

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cases these higher levels of concern may be associated with increased State and Federal regulatory interest. However, in some cases (e.g., the proposed Port O'Connor Terminal, El Paso LNG Terminal Company), the level of engineering effort appears to significantly exceed the efforts expended on similar facilities anywhere in the United States, except California. This great variation in engineering effort appears to result partly from the lack of consistent State or Federal regulatory requirements in these areas.

Most LEG storage facilities are being designed for at least the 100-year flood and associated storm. The potential for seismic-induced flooding, separate from storm flooding, is currently being evaluated only in the recognized high seismic zones, such as the California coast. The evaluation of the potential for liquefaction due to seismic excitation also seems to be restricted in general to high seismic sites, although it is interesting to note that a low seismic site, Magnitude 4.8 in Texas, was also formally evaluated for liquefaction.

FINDINGS

- About 5 percent of all earthquakes in the United States have occurred in regions located within tectonic plates where there had been little known seismic activity or active faulting. Within the past 250 years, at least five major earthquakes have followed this pattern. The ones at New Madrid, Missouri, and Charleston, South Carolina, were each felt over an area of two million square miles. On the other hand, West Coast earthquakes which do considerable local damage are seldom felt over an

area of more than a few thousand square miles.

- It is very likely that many large LEG facilities will be impacted by winds, floods, or earthquakes greater than those they are required to withstand. However, structures can generally withstand stresses somewhat greater than those required by regulations.

- If a tank fails because of an earthquake, high wind, or flood, it is likely to be by tensile rupture of the hold-down straps, which would permit the tank walls to lift off and separate from the tank bottom. This would result in a massive spill of the contained fluid.

- The seismic designs of those tanks designed after the mid-1960's meet or exceed the requirements of the Uniform Building Code used in the area in which they are built. Prior to this period, there appears to have been no general requirement for seismic design evaluation.

- All the LEG tanks we evaluated at five sites were adequately designed for the Uniform Building Code earthquake and the 100-year maximum wind design criteria, but tanks at three of the five sites had earthquake safety margins less than 25 percent. Two of these sites (a total of three tanks), the Distrigas LNG import terminal and the Exxon propane import terminal, are next to one another in Boston Harbor.

- Most LEG storage facilities come nowhere near meeting nuclear criteria and would fail if they were subject

to the same load phenomena that nuclear power plants are designed to resist.

- Large LEG tanks made of steel are usually much less resistant to natural forces than those made of prestressed concrete.

- Steel outer tanks could be penetrated by some tornado-borne missiles.

- The outer steel walls in double-wall tanks are not normally made of material designed to withstand intense cold. Thus, if the inner tank fails, the outer tank is almost certain to rupture from the pressure and thermal shock.

- There is a very large difference in the level of engineering effort that has been expended by owners in evaluating the extreme natural forces associated with liquefaction, flood, and tsunami on LEG storage facilities. This difference appears to result partly from the lack of consistent State or Federal regulatory requirements in these areas.

CONCLUSION

There is no reason why storage tanks in densely populated areas, holding large amounts of highly hazardous materials, should have to satisfy very much weaker standards for resistance to natural phenomena or sabotage (see Chapter 9) than do nuclear plants in remote areas.

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CHAPTER 4

CRACK-INDUCED FAILURE OF METAL LNG TANKS

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DISCUSSION

Our assessments of the vulnerability of LNG systems in Chapters 3, 6, 7, 8 and 9 are partly based on our calculations of crack behavior in the spherical and cylindrical metal tanks used for transporting and storing LNG.* It is generally accepted that the two materials currently used for LNG tanks, 5083 aluminum alloy and 9% nickel alloy steel, are very resistant to crack growth under cryogenic conditions. Most small-scale tests (with some significant exceptions) have produced very stable tearing of cracks, rather than rapid crack propagation. Nevertheless, under the dead weight of LNG, a large, fully-loaded tank can suffer catastrophic failure (immediate, total collapse) if a sufficiently long crack is suddenly created by sabotage or natural forces. Cracks long enough to cause catastrophic failure are called "critical".

Federal agencies responsible for LEG safety have not made calculations of critical crack lengths of LEG tanks.

The critical crack lengths we calculated range between 4-1/2 and 8-1/2 feet. These calculations are far from exact, but we have done them in a way that we believe is conservative. We have neglected plasticity, and inertial thermal and slosh loading stresses in our calculations. The inclusion of these would make the calculated critical crack lengths shorter.

The catastrophic failure we observed in our sabotage experiments further strengthens our belief that our

*The technical discussion that goes with this chapter is given in Appendix IV.

estimates are conservative. They imply that a perfect crack is not needed for catastrophic failure; a hole with jagged edges may be sufficient.

Moreover, the numbers we have calculated for critical crack length should not be interpreted as saying that shorter cracks will be "safe", i.e., non-propagating. Present technical knowledge is insufficient to support such a claim in the crack-size range we are discussing.

Columbia LNG Corporation, in reviewing a draft of this chapter, commented that the critical crack lengths for cylindrical tanks are between 1 and 1-1/2 feet for 9% nickel alloy steel tanks and between 3 and 4 feet for aluminum alloy tanks.

CONCLUSION

We estimate that crack lengths between 4-1/2 and 8-1/2 feet are long enough to cause catastrophic failure in cylindrical and spherical LNG tanks. We believe these estimates to be conservative. (Lengths calculated by Columbia LNG Corporation are much shorter).

RECOMMENDATION

We recommend that the Secretary of Energy institute a testing program to accurately determine the critical crack lengths for the various types of tanks used to store and transport LNG and LPG. The critical crack lengths should be determined for real types of tanks under real types of static and dynamic stresses, including those that might be caused by sabotage.

AGENCY COMMENTS AND OUR EVALUATION

The Coast Guard comments on this chapter make three points:

(1) Although the Coast Guard has not determined critical crack lengths of ship cargo tanks, it does require such calculations from ship designers.

(2) Testing and inspection during tank construction insure that flaws are limited to a very small size.

(3) If a crack were to grow, a leak would be detected before the critical length was reached.

The Coast Guard approach may be adequate for cracks that develop in ordinary use, but it ignores the possibility that grounding, collision, or sabotage may produce a sudden, large crack. The danger of catastrophic failure from these causes cannot be adequately assessed until critical crack lenths are adequately determined.

CHAPTER 5

FLOW OVER CONTAINMENT DIKES

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INTRODUCTION

National Fire Protection Association safety standards require that every group of LNG storage tanks be surrounded by a dike which can contain at least the volume of the largest tank. Dikes have not been designed to prevent the overflow of a rushing liquid, and, in fact, little is known about such problems. We examined the consequences of a massive rupture or collapse of the tank wall which releases a large amount of liquid in a short period of time. We found that a substantial part of the stored fluid can surge over the dike and escape the containment area. Design criteria will have to be modified if such surges are to be contained.

It is not improbable that the same natural or man-made cause could rupture more than one tank. If more than one tank ruptures within the same dike, the overflow would be even greater. In our analysis, however, we assumed that only one tank is enclosed by the dike. A dike may be constructed with either vertical or sloping sides. A schematic configuration is shown in Fig. 5-1.

We also examined the possibility of fluid spurting over the dike from a sizable puncture of the tank at some distance above ground level. Figure 5-2 demonstrates such "spigot" flow where all "dike" dimensions meet or exceed safety requirements. The volume of the demonstration "tank" pictured is two quarts. This is slightly less than the containment capacity of the surrounding "dike". A puncture results in a fluid jet whose parabolic arc easily clears the safety barrier. We calculated the amount of spillage from a puncture in the wall of actual facilities and its dependence on geometrical parameters.

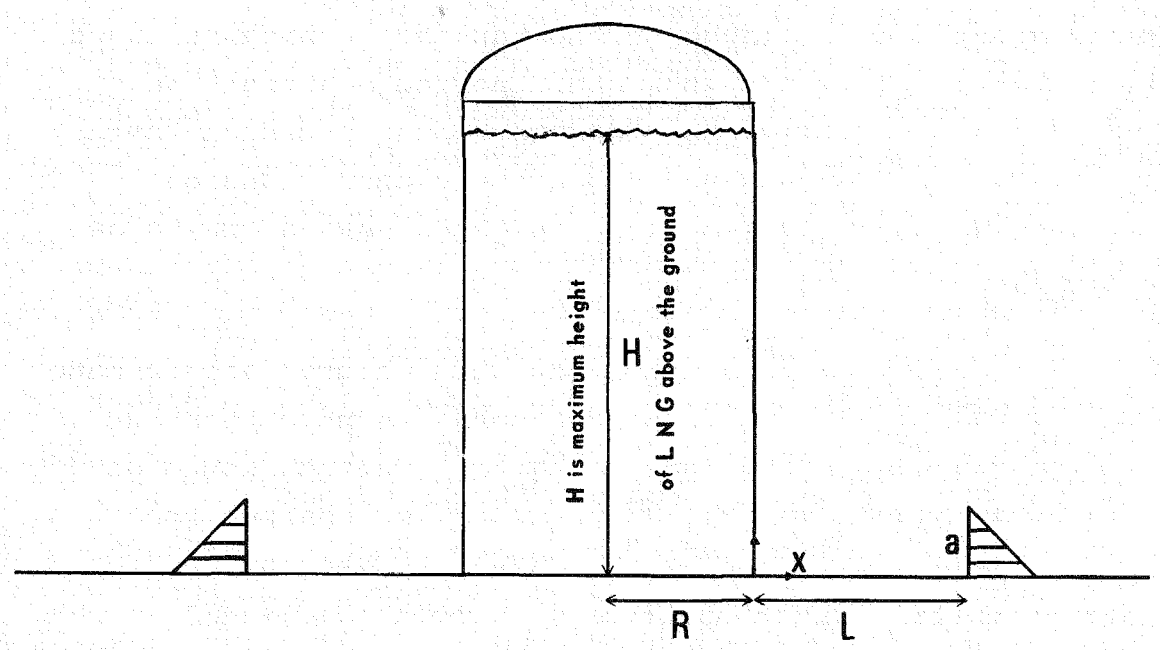


FIG. 5-1

SIMPLIFIED CROSS SECTION OF A STORAGE FACILITY SHOWING THE TANK AND DIKE. THE LABELLED CONFIGURATION TO THE RIGHT OF THE SYMMETRY AXIS CORRESPONDS TO THE TWO DIMENSIONAL PROBLEM STUDIED.

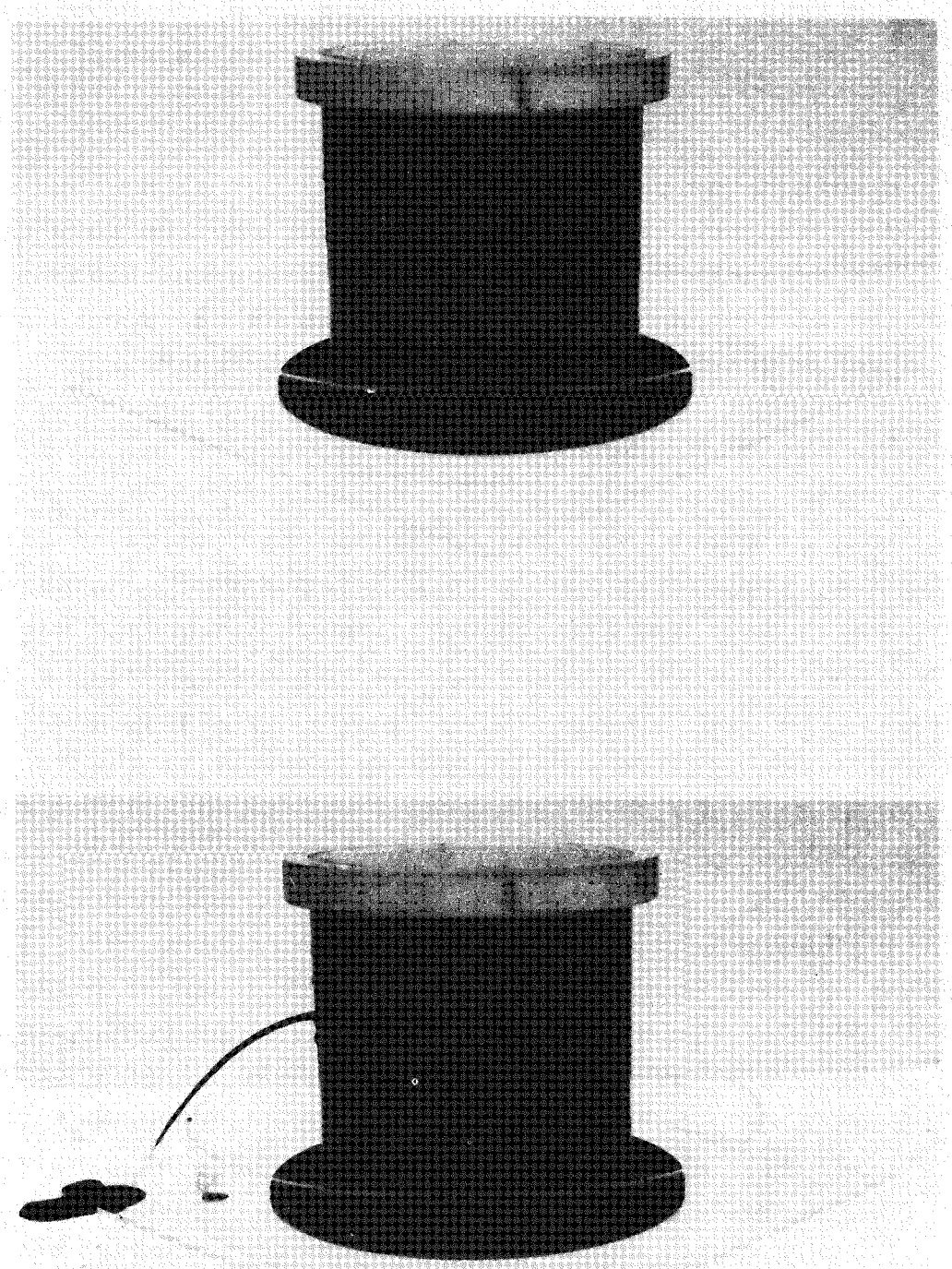


FIG. 5-2
A MODEL OF A STORAGE TANK AND A SURROUNDING DIKE. THE VOLUME CAPACITY OF THE DIKE IS SLIGHTLY LARGER THAN THAT OF THE TANK. A PUNCTURE PRODUCES A SPIGOT FLOW WHICH ARCS OVER THE BARRIER.

The theoretical work and computer model we developed for the analysis in this chapter were validated by experiment.

Although the relevant mathematical formalism, the details of the analysis, and the computer program results appear in Appendix V, much of the discussion in this chapter is still quite technical. The highly technical sections are italicized. Non-technical readers may omit them.

FLOWS OVER DIKES

If a tank wall ruptures or collapses because of an earthquake, flood, high wind, or sabotage, a mound of liquid will move rapidly and hit the containment dike. The way in which the fluid surmounts the barrier depends in part on the design of the dike. The rushing liquid may simply vault an inclined side, or it may pile up very rapidly at the face of a vertical wall and then flow over the top. In either case, a strong shock wave forms at the dike and returns towards the storage tank. The process is a very complicated, highly non-linear, dynamical interaction. However, the essential features of surge and overflow can be explained by examining the fluid motion in simpler and closer to ideal conditions. To do this, we built a two-dimensional model whose cross section is shown in Fig. 5-1. Liquid is released when the wall of the tank at $x = 0$ collapses (vanishes) at time zero. In the experimental arrangement the tank is a cube 9 inches on a side. The inner wall is a movable slide which is pulled out quickly to simulate a massive rupture. The fluid released flows along a 48 inch long channel that is open at the other end. A vertical dike of height a is placed at $x = L$. The specific dike height that satisfies the two safety criteria—equal storage and containment volume, and

$L=.6\,(H-a)$—will be referred to as the "prescribed height" and written a_p. Flow against inclined dikes is examined below.

Since no exotic properties of the liquid were considered in this analysis of dynamical effects (e.g., evaporation of LNG), water was used as the fluid in the experiments.

Fig. 5-3 is a typical sequence of photographs showing the fluid motion after the wall of the tank is pulled out. (The total time period involved is about one second.) Water rushing towards the dike at high speed catapults high into the air upon impact. The fluid piles up and pours over the dike as a shock returns to the region of collapse. The overflow, designated by Q_0, and defined as the fraction of the original fluid volume that escapes upon impact, is the primary quantity that is measured in these experiments. Shock reverberations between dike and wall may involve additional spillage. However, the total overflow, denoted by Q_1, is found to differ little from Q_0. *For $L/R = 2$, the maximum difference is 5% of the fluid in the tank.*

Overflow is also calculated on the basis of a theoretical model. The comparison of theory and experiment for the same simple geometry establishes the accuracy of the model and the specific approximations used.

The description of impact provided by the theoretical and numerical analysis is reasonably accurate as indicated by the comparison of Figs. 5-3 and 5-4. An account of the quantitative agreement achieved is given after the following general discussion of the theoretical model.

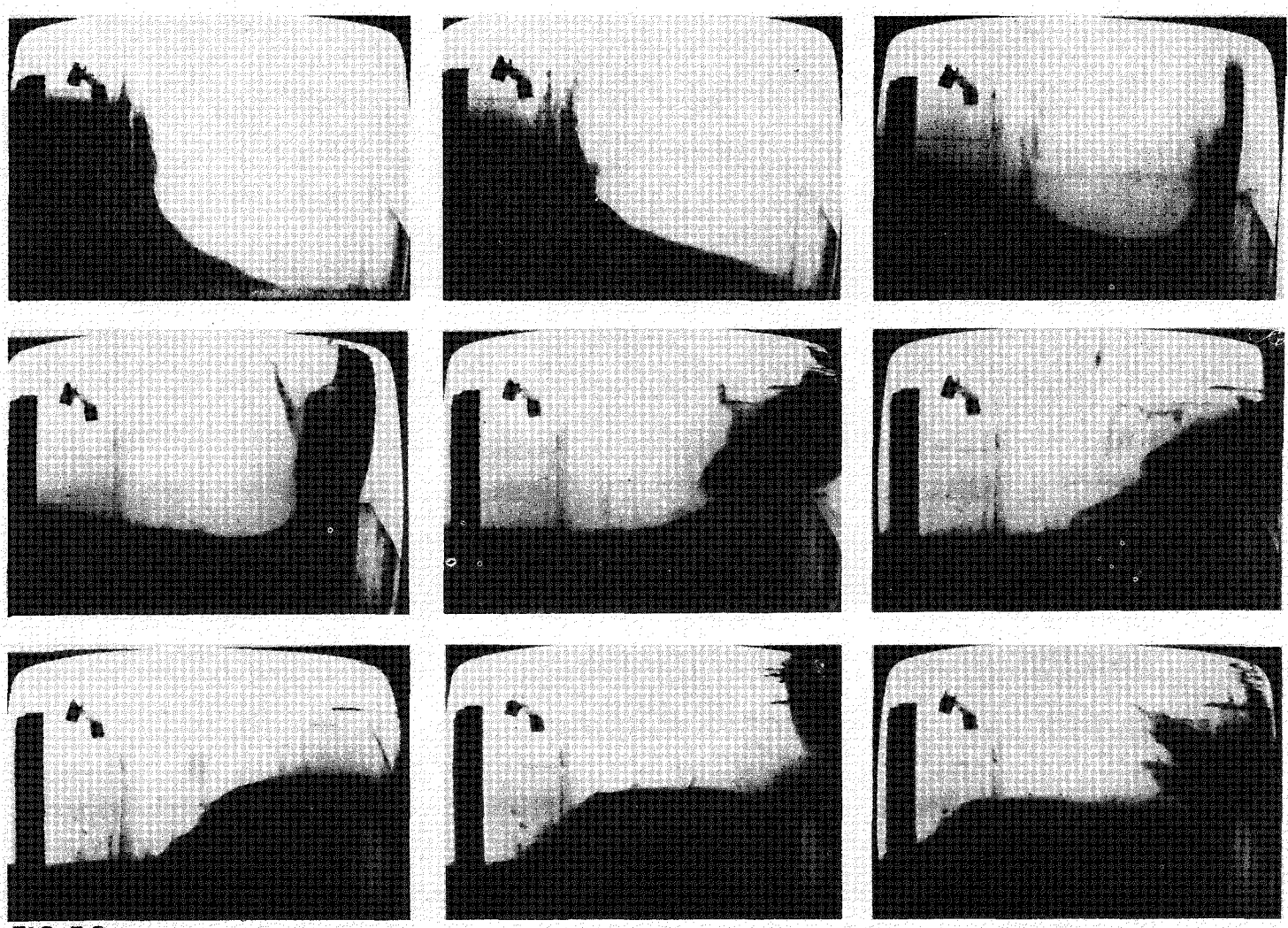


FIG. 5-3

COLLAPSE AND SURGE AGAINST A DIKE SHOWING OVERFLOW AND THE FORMATION OF A SHOCK. PHOTO SEQUENCE CORRESPONDS APPROXIMATELY TO .1 SECOND INTERVALS, IN NOTATION OF FIG. 5-1, H=8", R=9", L=9", A=4".

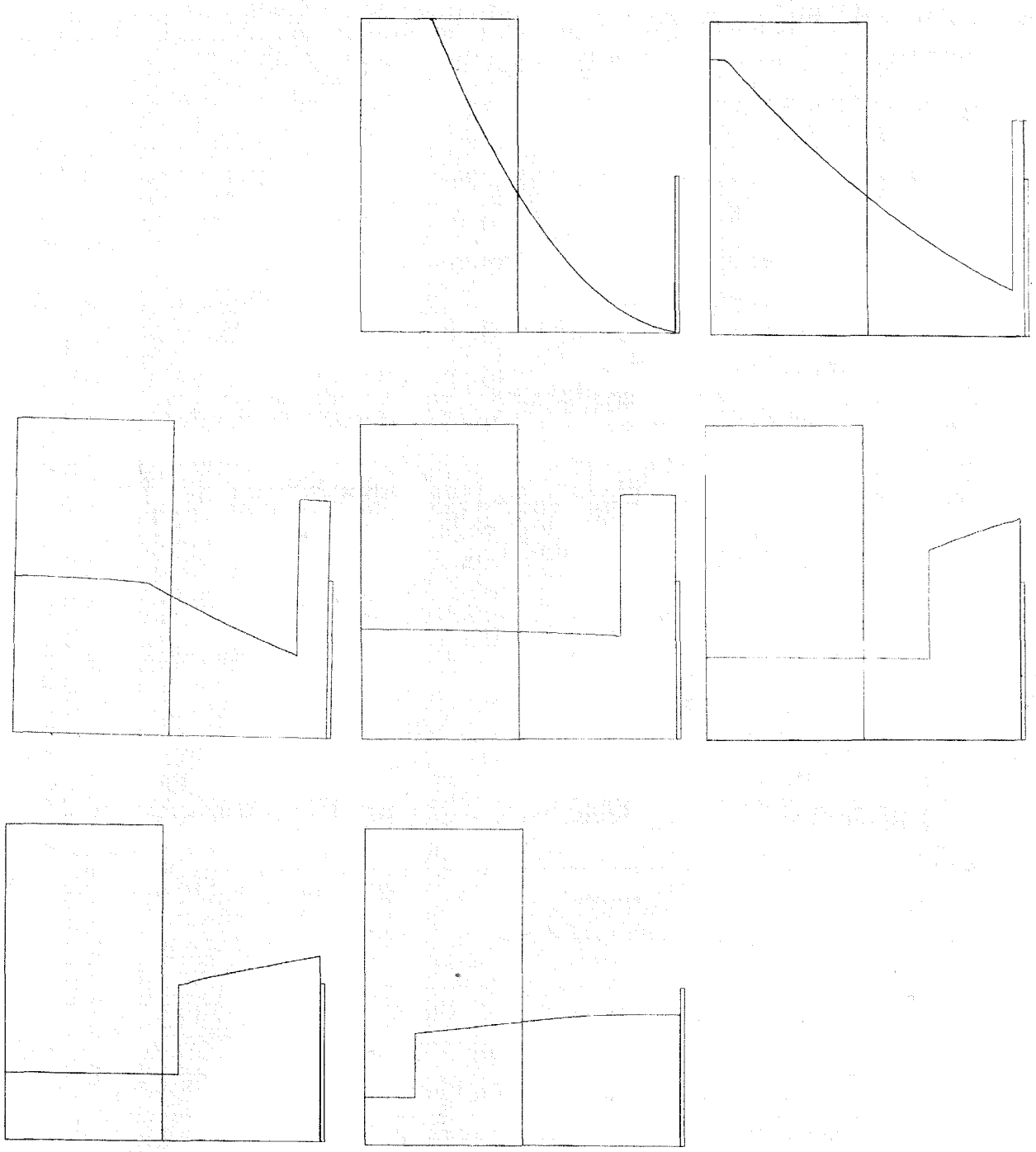


FIG. 5-4

COMPUTER SIMULATION OF THE COLLAPSE AND SURGE SHOWN IN FIG. 5-3. GRAPHS ARE ARRANGED IN CORRESPONDENCE WITH THE PHOTO SEQUENCE

The fluid velocity in the idealized geometry has only x and y components and all physical quantities are independent of the third coordinate that measures horizontal distance along the wall (i.e., perpendicular to the plane of the page). However, the exact theory is still intractable and we employ instead the non-linear shallow water equations which are essentially depth-averaged versions of the conservation laws of mass and momentum. The vertical coordinate is thereby eliminated from the formulation and a much simplified problem is obtained for the mean horizontal velocity and free surface height as functions of distance x and time t. A dimensionless notation is adopted to render results independent of scale and directly applicable to other geometries.

Non-linear shallow water theory has had a long and fruitful history in hydraulics[1], and it has been applied with remarkable success in "dam-break" problems of the type under investigation.

The fluid is assumed to be inviscid; turbulence and ground resistance are also neglected. The errors introduced by these approximations are small, although the theory can be modified to account for such effects.[2,3]

An exact theoretical solution exists for the initial phase of collapse which lasts until the surging water meets the dike. This allows a detailed check of the numerical program that is used to determine the motion in later and more difficult stages. Analysis of the initial impact and shock formation provides the information and conditions that are required to start the computer routine. The theory yields an accurate approximate solution for large times as well, as long as no spillage occurs. Only then does the

computer become invaluable. The boundary condition to describe overflow states that the wave speed and local fluid velocity are equal atop the dike. This means that fluid which passes over the wall ceases to influence the main body of water still within the containment area.

Experiments were performed to motivate, verify, and assess theoretical hypotheses, approximations, and conclusions and also to explore quickly a number of modifications of the basic configuration. Among these variants are inclined dikes, multiple barriers, partial wall collapse, and lateral spread of the surge.

RESULTS

The principal finding concerning flow over a vertical dike is that, within the parameter range studied, the volume fraction of fluid that escapes depends mainly on a/H, the ratio of the dike height to that of the fluid level in the tank. Fig. 5-5 shows the volume fraction that escapes, Q_0, versus a_p/H in the situation where containment and storage capacities are equal. Theory is in good agreement with observations; the larger values of Q_0 predicted are due in part to having neglected ground resistance and turbulence. The amount of fluid that escapes increases as the dike is placed further from the wall and its height decreased accordingly. Ground friction ultimately negates this finding when extremely large distances are involved, but this is not the case in existing facilities. *Fig. 5-6 indicates that the overflow Q_0 is mainly a function of a/H for all combinations of barrier and maximum liquid heights, $\frac{1}{3} \leq \frac{L}{R} \leq 4$. In fact the calculations show very little dependence on L/R. Fig. 5-6a compares the curve fit to the experimental data where the dike holds the same volume as*

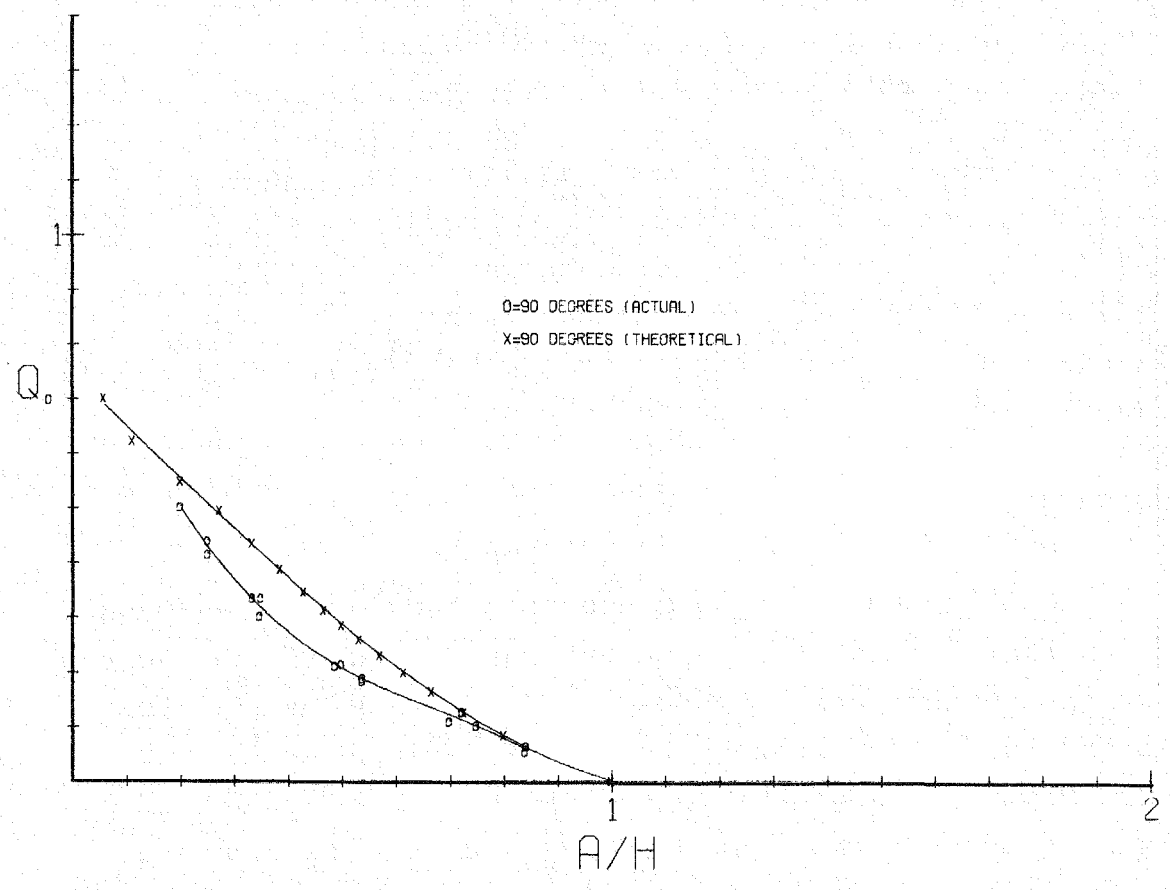


FIG. 5-5

COMPARISON OF EXPERIMENTAL DATA AND THEORETICAL CALCULATIONS FOR VERTICAL DIKES, WHERE CONTAINMENT AND STORAGE CAPACITIES ARE EQUAL.*

*** THE POINTS IN FIGS. 5-5 AND FIGS. 5-10 THROUGH 5-13 WERE FITTED WITH AN EQUATION OF THE FOLLOWING FORM:**

$$Q_0 = A(X^3 - 1) + B(X^2 - 1) + C(X - 1), \text{ Where } X = a/H.$$

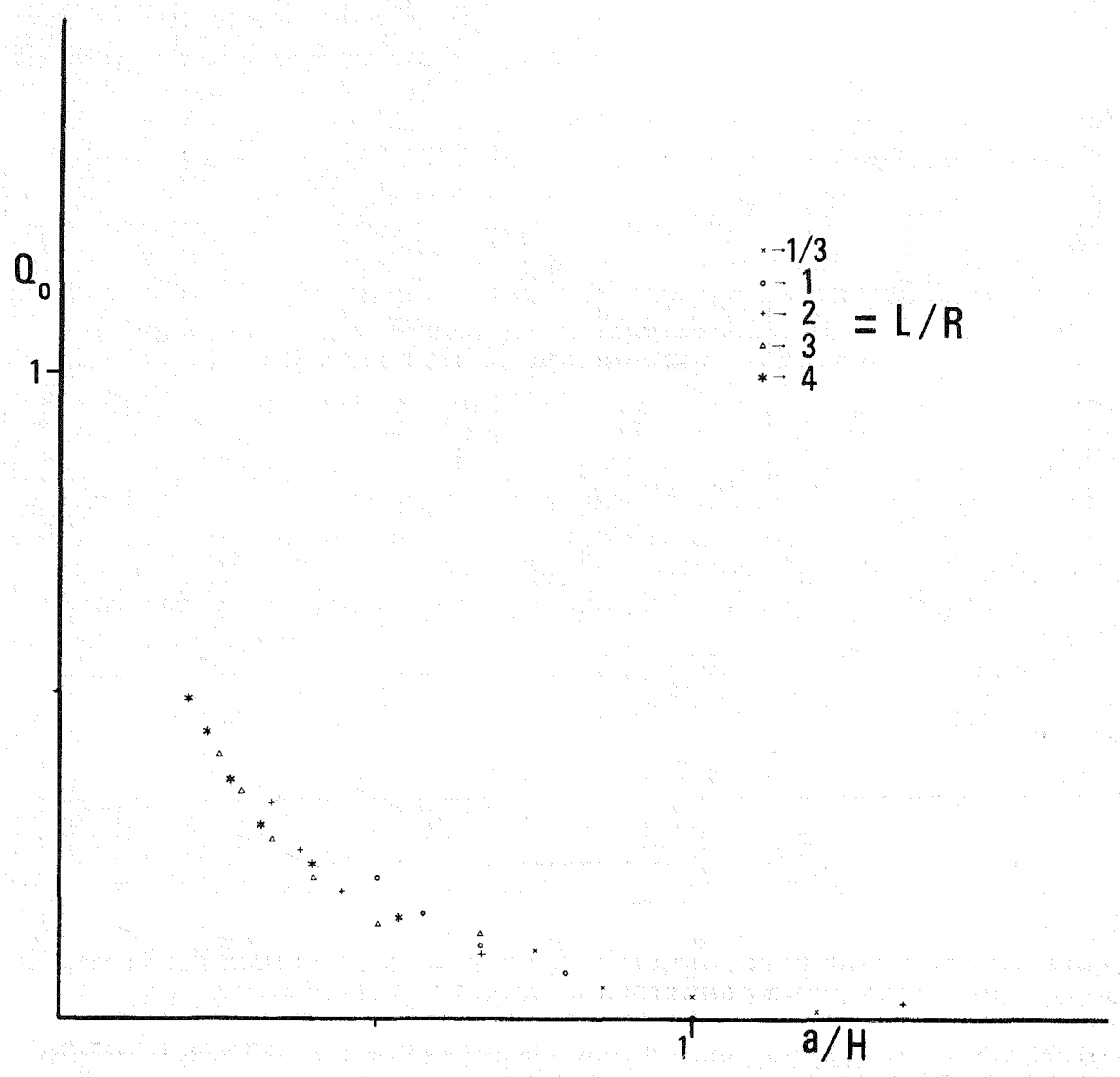


FIG. 5-6

SPILLAGE FRACTION VERSUS THE RATIO OF HEIGHT OF THE DIKE TO THAT OF THE TANK.

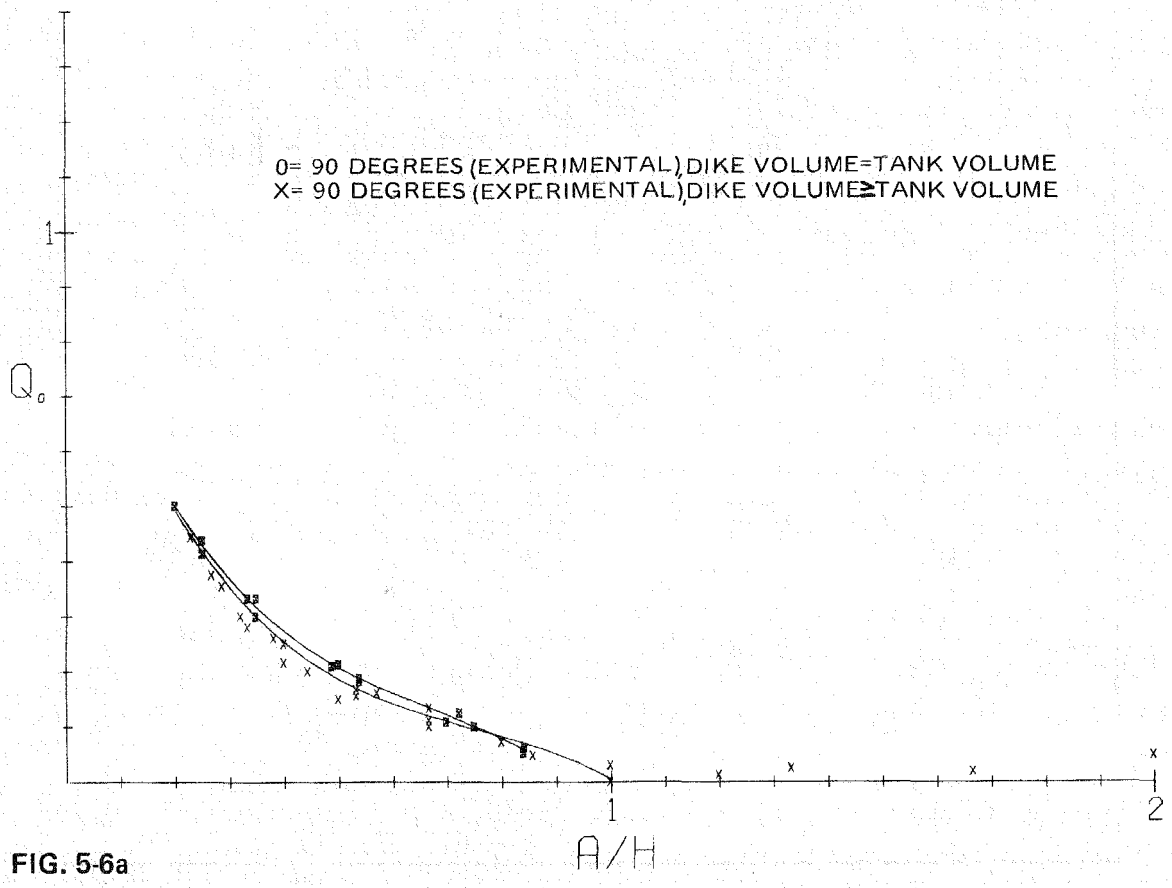


FIG. 5-6a

COMPARISON OF EXPERIMENTAL RESULTS FOR OVERFLOW OF VERTICAL DIKES WHEN DIKE VOLUME EQUALS TANK VOLUME AND WHEN DIKE VOLUME IS GREATER THAN OR EQUAL TO TANK VOLUME

the tank with the curve fit to all the experimental data, including points where the dike holds more than the tank.

Flows over a 90^{o} (vertical) dike and over dikes with 60^{o} and 30^{o} slopes are shown in Figs. 5-7, 5-8, and 5-9 respectively. *Comparisons of observed versus theoretically calculated spill fractions, Q_0, for dike inclinations of 30^{o}, 60^{o}, and 90^{o}, are presented in Figs. 5-10, 5-11, and 5-12. The theoretically calculated values of Q_0 versus a/H for dikes with inclinations of 30^{o}, 60^{o}, and 90^{o}, are compared in Fig. 5-13. The supporting analyses are presented in Appendix V.* Obviously, a decrease of inclination allows more liquid to escape because the surging fluid retains much of its forward horizontal momentum during and after impact. As a result, for less steeply angled slopes the water vaults over the barrier and lands a considerable distance away, as shown in Fig. 5-9.

Some of the fluid that hits the face of a vertical dike is catapulted straight up, about three times the original height of the fluid in the storage tank, i.e., 3H. The main body of fluid piles up quickly, its top rising slightly higher than H, which is more than needed to cause flow over the smaller dike.

Raising the movable slide only 30% of the full distance, in order to simulate a partial rupture of tank wall, decreases the overflow by about 6%, a very small change. Indeed, none of the slight modifications of design attempted significantly reduced the overflow.

Spillage from a puncture is easily calculated using Bernoulli's theorem and simple geometry (see Appendix V-3). If $L+a > H$ or $H < (R+L)^2/(2R+L)$, no spigot flow from a

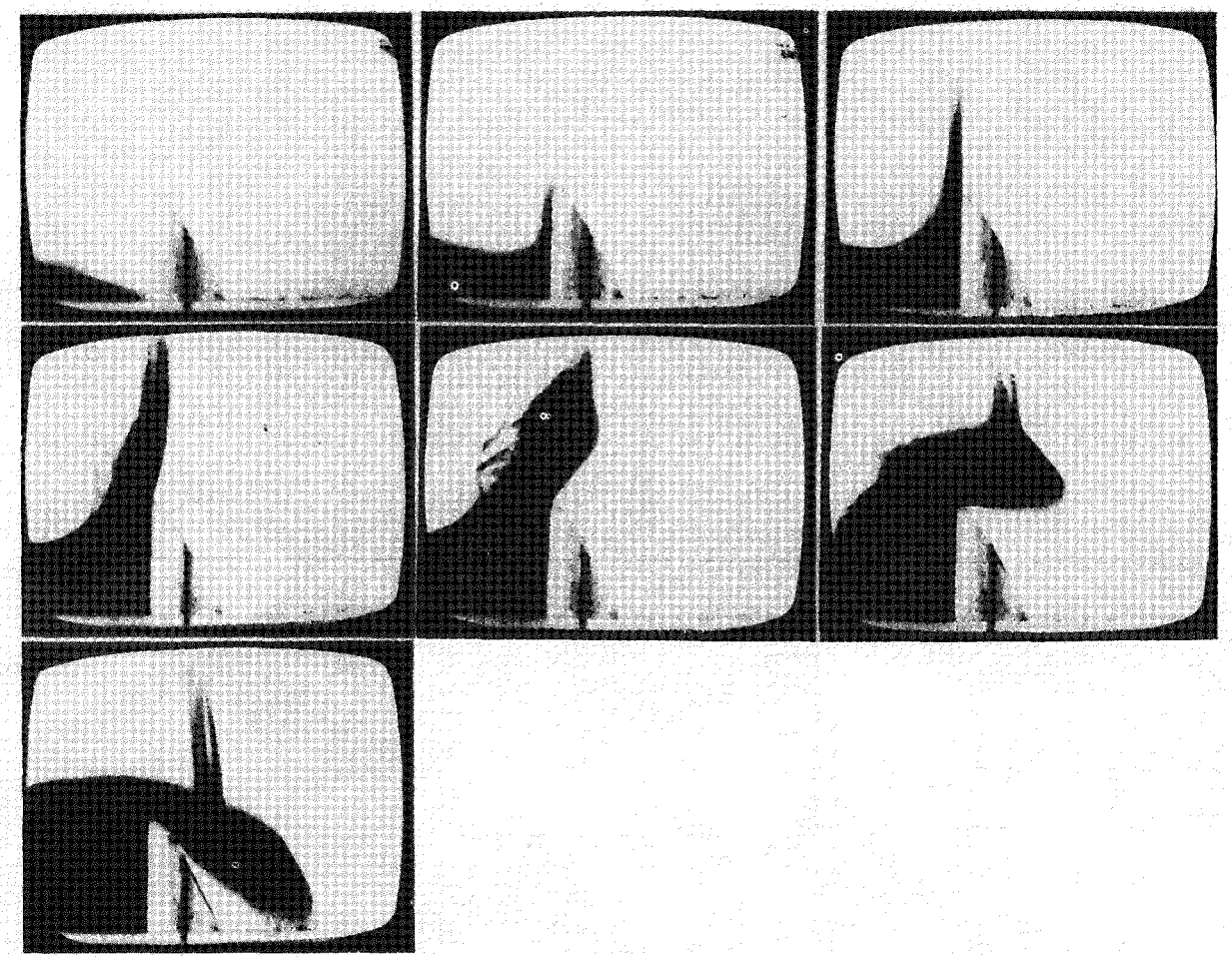


FIG. 5-7

DIKE OVERFLOW WHEN H=8", R=9", L=9", A=4", θ=90°. (CONTAINMENT VOLUME EQUALS STORAGE VOLUME.) PHOTO SEQUENCE CORRESPONDS, APPROXIMATELY, TO .07 SECOND INTERVALS.

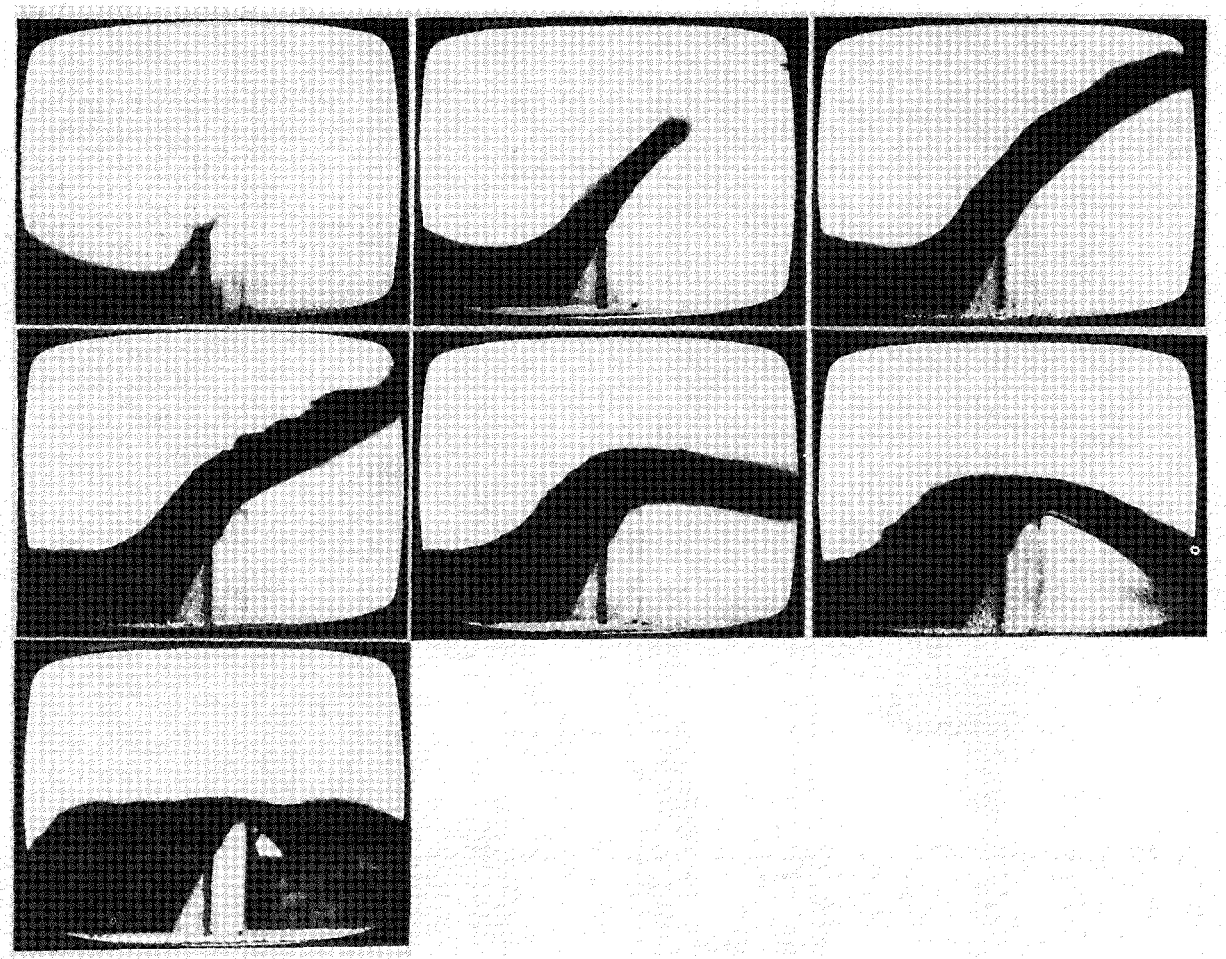


FIG. 5-8

DIKE OVERFLOW WHEN H=8", R=9", L=9", A=4", θ=60°. (CONTAINMENT VOLUME EQUALS STORAGE VOLUME.) PHOTO SEQUENCE CORRESPONDS, APPROXIMATELY, TO .1 SECOND INTERVALS.

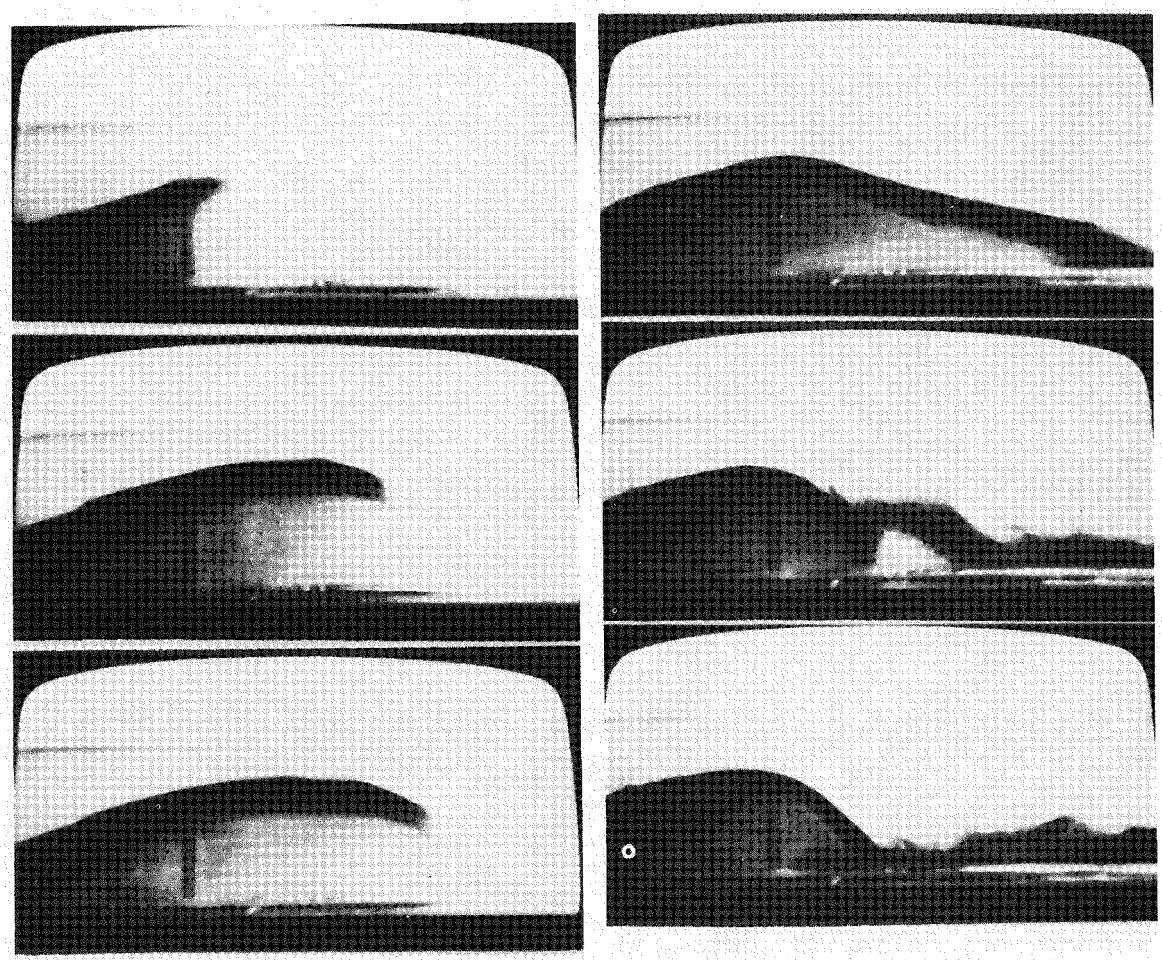


FIG. 5-9

SURGE VAULTING A 30° INCLINED DIKE, H=8", R=9", L=9", A=4".

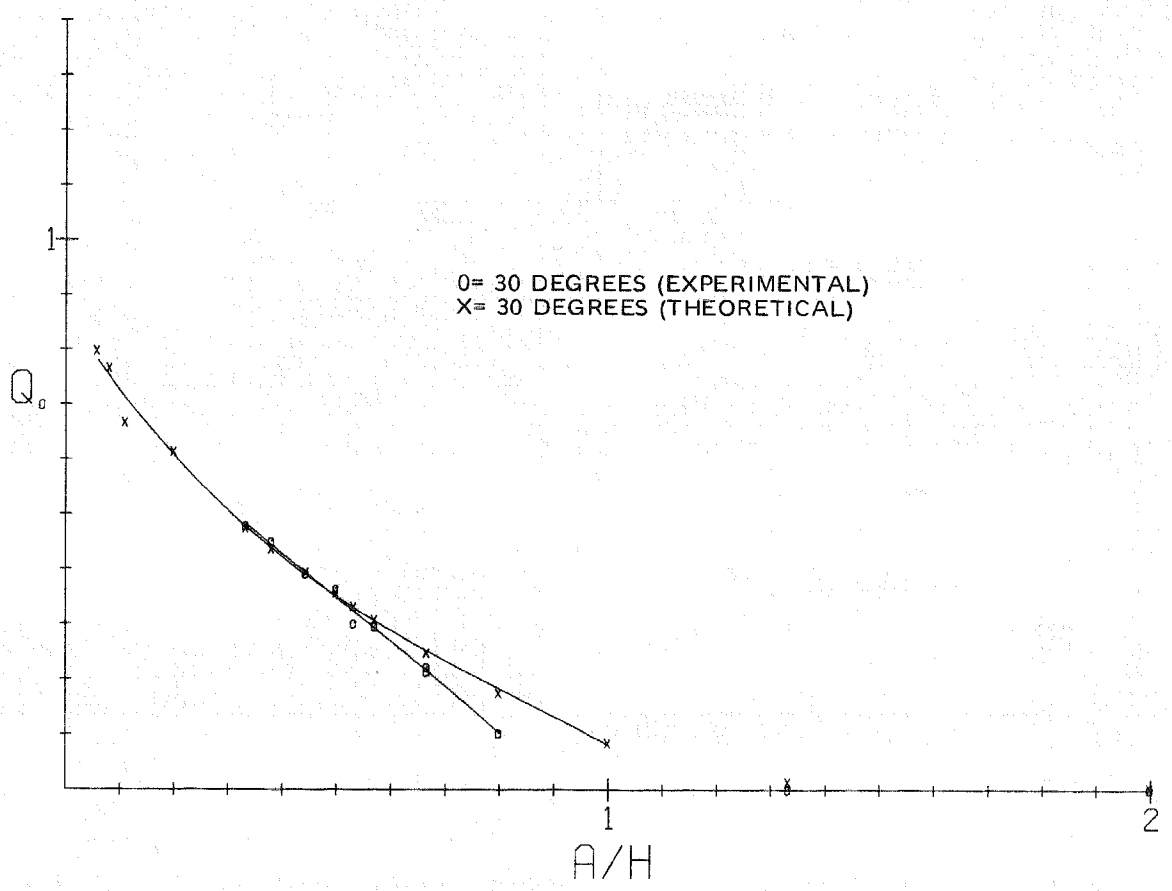


FIG. 5-10

COMPARISON OF EXPERIMENTAL DATA AND THEORETICAL CALCULATIONS FOR 30° DIKE, WHERE CONTAINMENT IS GREATER THAN OR EQUAL TO STORAGE CAPACITY.

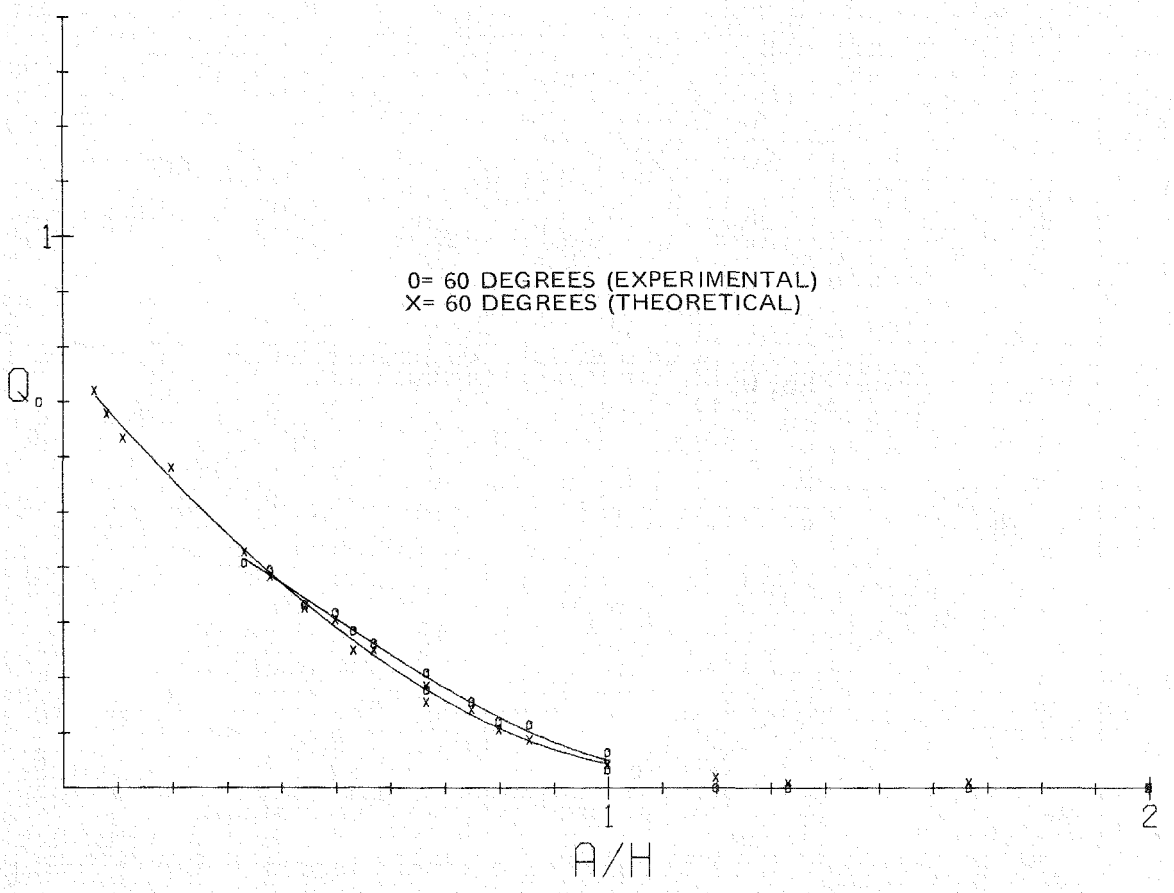


FIG. 5-11

COMPARISON OF EXPERIMENTAL DATA AND THEORETICAL CALCULATIONS FOR 60° DIKE, WHERE CONTAINMENT IS GREATER THAN OR EQUAL TO STORAGE CAPACITY.

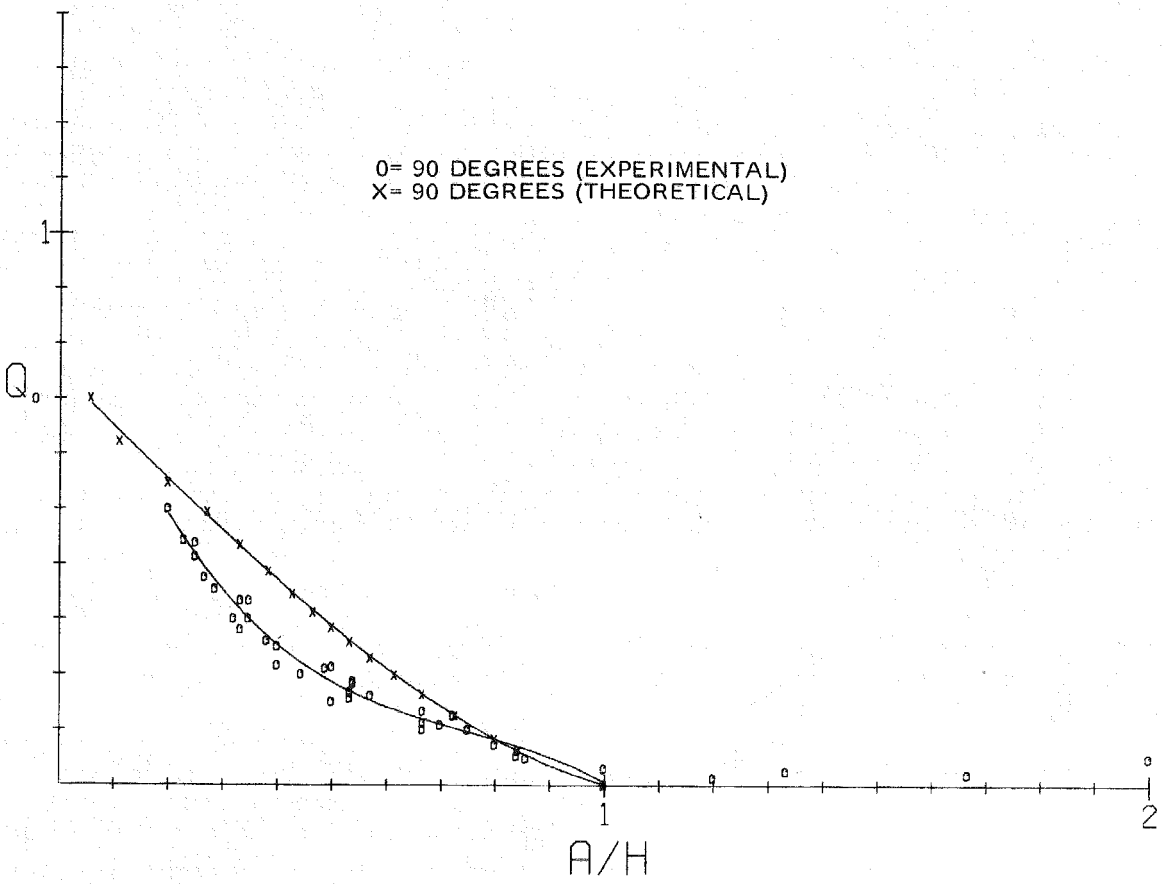


FIG. 5-12

COMPARISON OF EXPERIMENTAL DATA AND THEORETICAL CALCULATIONS FOR VERTICAL DIKE, WHERE CONTAINMENT IS GREATER THAN OR EQUAL TO STORAGE CAPACITY.

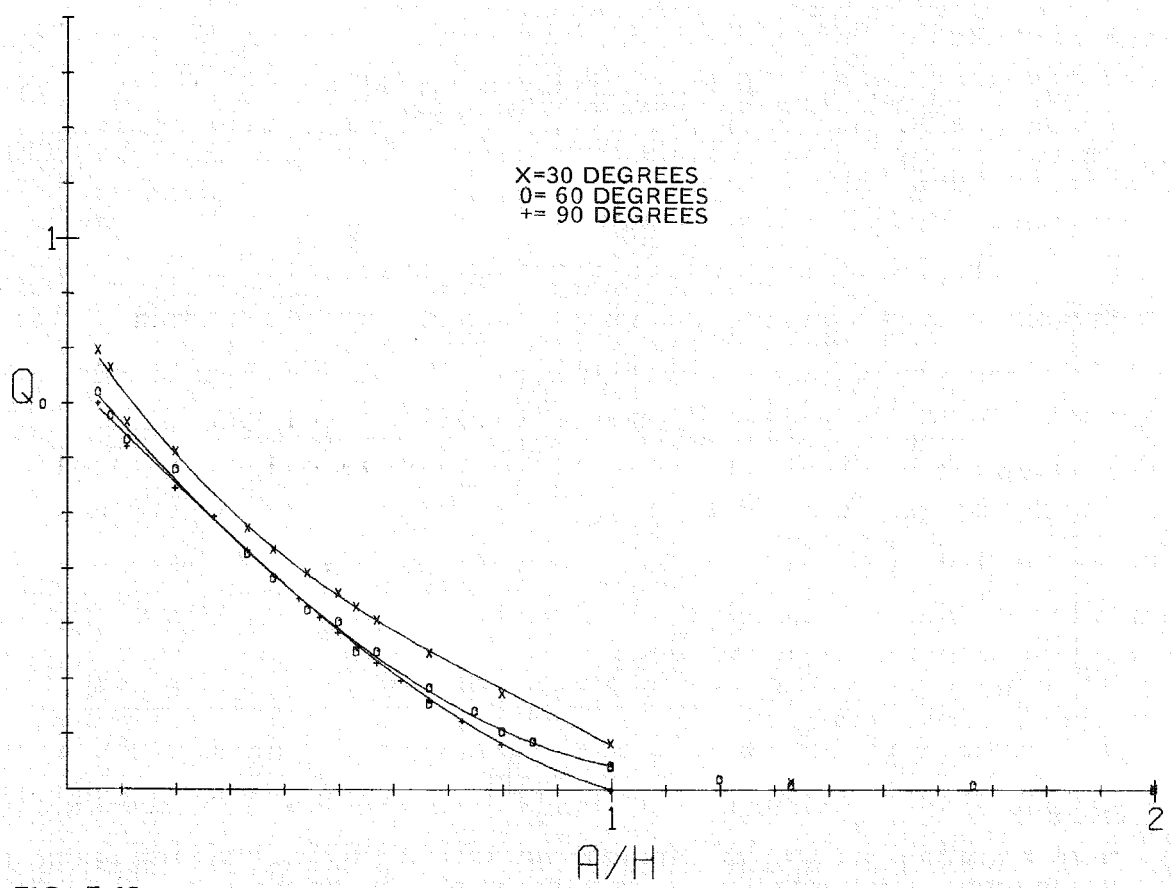


FIG. 5-13

COMPARISON OF THEORETICAL CALCULATIONS FOR DIFFERENTLY SLANTED DIKES – TWO-DIMENSIONAL– CASE–WHERE CONTAINMENT EQUALS STORAGE CAPACITY.

puncture at any location can clear a dike of height a_p (see Fig. 5-14). However, if these absolute criteria are not met, the fluid can arc over the dike. Dikes built under the NFPA standard, L>.6(H-a), therefore, do not necessarily prevent spigot overflows. The maximum possible spillage fraction Q_m (the ratio of spillage to storage volumes) is given as a function of R/H in Fig. 5-14. The same figure also shows the height, z, of the puncture that produces this maximum overflow. Slight modifications of configuration, to include a tank pedestal for example, lead to small changes in these results.

Table 5-1, based on spigot flow calculations in Appendix V-3, shows the maximum possible spillage from tanks at certain existing LEG facilities. The maximum spillage amount ranges from 0 to 46 percent of tank volume. Friction, viscosity, air resistance, and vaporization would reduce the amount of spill, but the effects are impossible to determine accurately, and are not included in the calculations. In double-wall tanks, the insulation could significantly affect the flow.

Table 5-2, based on the calculations in Appendix V-1 and V-2, shows the maximum calculated overflow from tanks at certain existing LEG facilities. The maximum overflow ranges from 13 to 64 percent of tank volume. The calculations do not include viscosity, ground friction, and turbulence. These would all lessen the overflow. In addition, since the calculations are two-dimensional, the spreading of the wave front is also neglected. This would also reduce the overflow. However, for a given tank and distance to a dike, the required height of the dike for a three-dimensional model is always less than the dike height in the corresponding two-dimensional case.

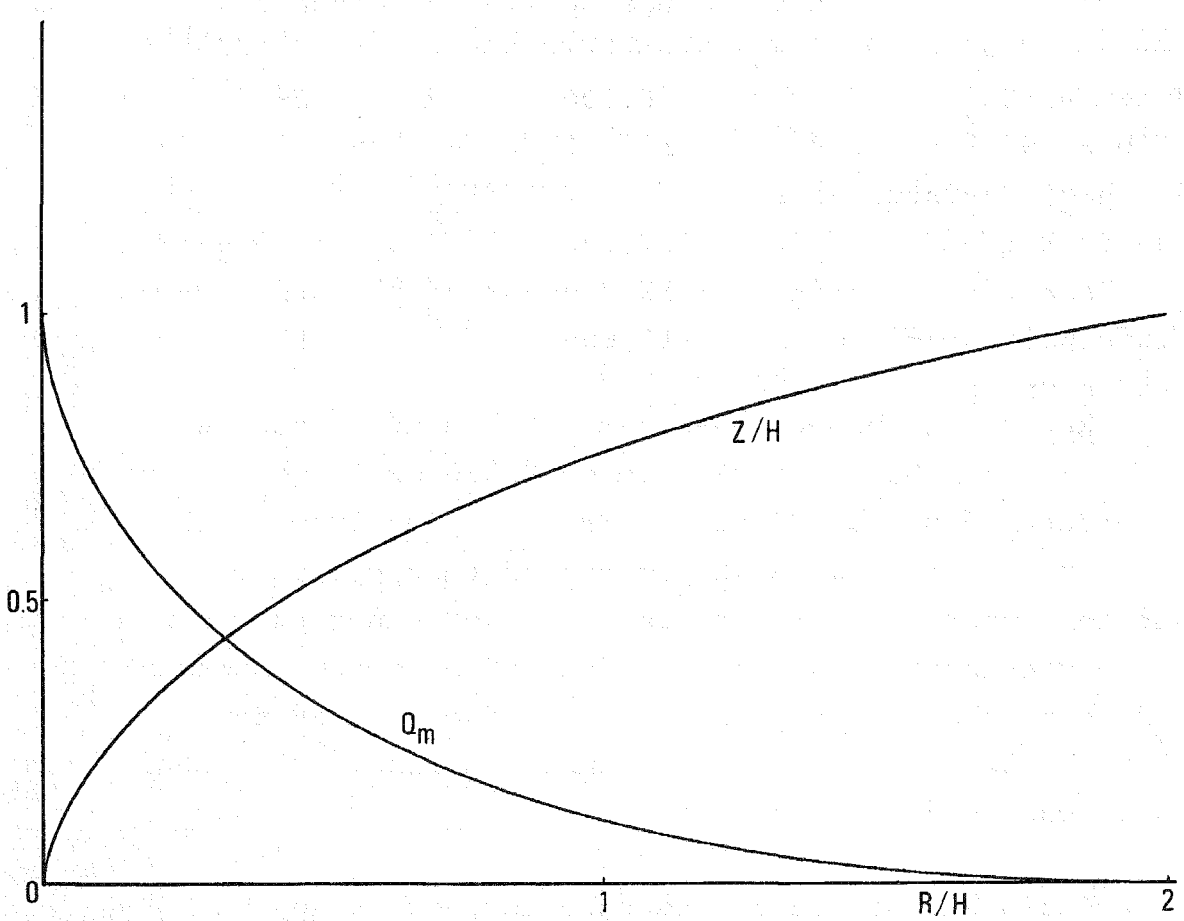


FIG. 5–14
MAXIMUM SPILLAGE FRACTION Q_M AND THE RELATIVE HEIGHT OF THE PUNCTURE VERSUS R/H. NO LIQUID ESCAPES THE CONTAINMENT AREA WHEN $a \geq a_p$ AND R/H> 2.

Table 5-1. Maximum Possible Spillage from Horizontal Spigot Flow for Tanks at Certain LEG Facilities.*

Facility	Volume Spilled (cubic meters)	Percent of Volume Spilled
Algonquin LNG	26,300	28
Columbia LNG	12,000	20
Distrigas, Everett, Mass.		
Tank 1	27,800	46
Tank 2	17,700	19
Philadelphia Electric	10,600	19
Southern Energy	0	0
Exxon LPG	0	0

* Friction, viscosity, air resistance, and vaporization would reduce the amount of spill, but the effects are impossible to determine accurately, and are not included in these calculations. The calculations also assume the optimal height for the hole on the side of the tank closest to the dike.

Table 5-2. Maximum Possible Spillage from Overflow After Tank Wall Rupture of One Tank at LEG Facilities.*

Facility	Volume Spilled (cubic meters)	Percent of Volume Spilled
Algonquin LNG	52,000	55
Columbia LNG	31,200	52
Distrigas, Everett, Mass.		
Tank 1	37,200	62
Tank 2	60,800	64
Philadelphia Electric	7,100	13
Southern Energy	36,500	58
Exxon LPG	36,500	58

NOTE: Excluding the close, high-wall Philadelphia Electric facility, the average percent of tank volume spilled is 58.2 percent.

* The calculations are based on two-dimensional experiments and theory (Figs. 5-10, 5-11, and 5-12), and do not include viscosity, ground friction, and turbulence.

We believe that this difference between two- and three-dimensional models more than makes up for the neglect of viscosity, ground friction, turbulence, and wave spreading. Thus, we think our results are at least as likely to understate as to overstate the amount going over the dike. In addition, we plot Q_0, the fraction of the original value that escapes upon initial impact, rather than Q_1, the total overflow. And in those cases where tanks rest on pedestals, we considered the pedestal height to be zero. These factors make the overflow estimates even more conservative. The calculation may not be conservative in the case of a high, close-in dike, such as at Philadelphia Electric, where shallow water theory is not as good an approximation.

CONCLUSIONS

- Dikes constructed to NFPA safety criteria generally cannot contain the surge of liquid from a massive rupture or collapse of a tank wall. Our calculations show from 13 to 64 percent of the tank volume can escape the dikes in six actual facilities. For the reasons given in the text, we believe these estimates to be conservative. A sloping dike permits a somewhat larger amount of spillage than a vertical dike. Low, distant dikes allow a greater overflow than high, near ones. If more than one tank ruptures within the same dike, the overflow would be even greater.

- Spigot flows from punctures high up on the tank may be able to arc over the dike and escape containment. The actual spillage depends on the dimensions involved and on the amount of friction in the hole. Since the friction is impossible to calculate accurately, the only safe criterion is one which ensures that no fluid will arc over the dike from the spigot effect, even if there is no friction in the hole. The NFPA safety criterion allows large amounts of fluid from a frictionless hole to arc over the dike wall. According to our calculations, from 0 to 46 percent of the fluid from a frictionless hole would arc over the dikes in the six facilities studied.

AGENCY COMMENTS AND OUR EVALUATION

The Department of Commerce comments that the methodology by which we calculated overflow for various facilities is unclear. The calculations are all based upon design specifications of the facilities, which we obtained from the facility operators or designers. The spigot flow was calculated with the theoretical results derived in Appendix V-3. The dike overflow was estimated by using Figs. 5-10, 5-11, and 5-12, which are based upon the theoretical calculations and experimental verifications described in this chapter and in Appendix V-1 and V-2.

Commerce suggests that we should estimate the chance of a massive failure occurring. We do not believe that such a probability can be calculated. For example, causes such as sabotage cannot be treated probabilistically.

Commerce also comments that dikes at new LEG storage facilities will generally be able to hold a volume greater than the volume of the enclosed tank. As we have shown in this chapter, it is not the volume contained by the dike which is the important factor in overflow, but the ratio of the height of the fluid in the tank to the height of the dike. Within the scale that LEG facilities are being built or planned, the distance from the tank to the dike has little effect on this overflow.

The Department of Energy asks what changes in dike design would ameliorate the overflow problem. Building dikes vertically and higher would be one improvement; but more research needs to be done to determine the most effective and efficient way to design enclosure systems.

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CHAPTER 6

SHIP DESIGN, PERSONNEL, AND OPERATIONS

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INTRODUCTION

Three factors determine the safety of transporting LEG over water: the design, personnel, and operation of ships carrying the fuel.

Safety features must be built into the vessels; some to prevent leaks and spills, others to control them should they occur.

LEG ships and terminals are sophisticated, complex, and expensive; highly trained personnel are required to operate them.

SECTION I. SHIP DESIGN[1,2,3,4]

LNG SHIPS

Only LNG carriers designated for the U.S. trade will be discussed here. Most of the LNG tankers flying the American flag in the next decade will carry about 125,000 cubic meters. A typical ship of this capacity is approximately 930 feet long, with a beam (width) of 140 feet, a draft (under water) of 36 feet, and a freeboard (above water) of 50 feet. Deadweight is approximately 60,000 long tons, displacement 95,000 long tons. (One long ton = 2240 lbs. = 1016 kg; one short ton = 2000 lbs. = 907 kg.) Service speed is about 20 knots with a main steam propulsion plant of 43,000 shaft horsepower.

An LNG tanker differs from a traditional tanker in several respects. Because its cargo is lighter, the LNG tanker has a higher center of gravity. The LNG ship's double hull gives it improved stability after one or more

compartments have been filled with sea water and provides it with greater collision resistance. The double hull is also used to carry ballast water, which allows the vessel to reach full draft when cargo tanks are empty.

LNG ships are usually equipped with bow thrusters, which improve maneuverability. Other measures that can improve maneuverability include precision position fixing equipment, bridge control of main engine, and collision avoidance systems. LNG ships built under the Maritime Administration program all have, or will have, this equipment on board. Ships that are not built under this program are not required to have it.

An LNG tanker's relatively high freeboard limits the view from the bridge and exposes a greater proportion of the ship to wind. Both characteristics could add to navigational risks.

Only limited inspections can be made of cargo containment systems, but several leak detection systems have been developed.

In U.S. waters, the U.S. Coast Guard has devised several navigational traffic control procedures which can reduce the chances of collision or grounding. (See Section III.)

Design Considerations for LNG Ships

From a designer's point of view, the most important hazards presented by the transportation of LNG are:

- The low temperature of the liquefied gas and its effect on the storage structure design.

- The volatility of the LNG and the resultant danger of fire or explosion.

In ship design, these problem areas are considered from two approaches—preventive and reactive safety.

Preventive safety hardware and operational features eliminate, control, or at least reduce the risk of an accidental cargo spill. Examples include secondary barriers, stronger cargo tanks, greater collision resistance, and better manueverability.

Reactive safety features reduce the effects of a spill after an accident has occurred. Examples include crack arrestors, leak detection devices, and fire fighting equipment.

While reactive safety features are necessary, the primary objective in LNG ship design should be the incorporation of preventive safety components.

Reactive Safety Equipment

A list of the reactive safety equipment carried by a typical LNG tanker is given in Appendix VI-1.

Most reactive safety equipment is required by Coast Guard regulations and differs only slightly from ship to ship. Aside from increased personnel training in the use of equipment (which will be covered later in this chapter), little can be done to significantly improve reactive safety.

Preventive Safety Design Characteristics

The containment system for an LNG carrier consists mainly of those structural and outfit items associated with the storage of cargo. It is made up of three major components—the primary barrier, insulation, and the secondary barrier.

Current LNG ships have one of two basic containment designs. In the self-supporting (or free-standing) design, the cargo tank itself has sufficient structural strength to withstand the loads imposed by the cargo. In a membrane (or integrated) design, the cargo is contained in a thin metallic liquid-tight lining supported completely by a load bearing insulation, which in turn is supported by the ship's structure.

Each of the basic designs has two variations. The self-supporting type is constructed either with spherical tanks (the Moss Rosenberg design) or with prismatic tanks (the Conch II design), both of which use aluminum alloy for the primary barrier. The difference between the two membrane designs lies in the material used to construct the primary barrier. In the Technigaz design it is made of corrugated stainless steel; in the Gaz Transport design it is made of flat Invar steel (an alloy of nickel and iron).

The primary barrier of an LNG containment system contains the cargo. The insulation protects the ship's hull from the extremely low temperatures of the liquefied gas and reduces the flow of heat into the cargo tanks, thereby cutting down boil-off (the generation of vapor). Many different insulation materials are used. The insulation must:

- be impervious to water;

- possess good aging properties;

- be flexible enough to withstand dimensional changes and remain elastic; and

- be able to bear heavy loads in some design systems.

Insulation is either loadbearing, such as balsa and plywood, or non-loadbearing, such as fiberglass, mineral wool, and perlite. Polyurethane foam and polyvinyl chloride may be loadbearing or non-loadbearing.

If the primary barrier fails, the secondary barrier must contain the cargo safely for at least 15 days, and insulate the ship's structure against the low temperatures of the LNG. Among materials used to construct the secondary barrier are hardwood, plywood, polyurethane, Invar steel, and stainless steel.

The size and shape of the spherical tanks, and the greater average transverse distance between the tank and the ship's side, suggest that they are the least vulnerable of all designs in the event of a collision (as discussed in more detail below). However, other designs offer other safety advantages. The Conch II's self-supporting design, with its internal bulkheads, reduces free surface effects* as well as the amount of LNG spill in case of a tank rupture. The membrane designs

*Free surface effects are those due to sloshing of fluid in the tanks.

provide good hull utilization, good visibility from the bridge, and a reduced windage area. Appendix VI-2 provides detailed descriptions and diagrams of the four containment systems.

LPG SHIPS

A typical LPG carrier is usually smaller and slower than its LNG counterpart. Because it has a lower center of gravity (higher cargo density) than an LNG tanker, an LPG ship has greater initial stability, better visibility from the bridge, and a reduced windage area.

LPG carriers are built in a great variety of sizes and designs. Unlike LNG ships, they are not required to have double hulls, and most do not. A typical ship has 50,000 cubic meters capacity, 34,000 tons deadweight, 615' length, 100' beam, 35' draft, and 26' freeboard. They usually have independent, prismatic cargo tanks, and the LPG is carried refrigerated at atmospheric pressure. Ship tanks are usually designed for a minimum temperature of $-58^{\circ}F$ and a maximum working pressure of 4 pounds per square inch above atmospheric pressure (psig). The tanks are of the A type in the Intergovernmental Maritime Consultative Organization (IMCO) gas code. This means that stress analysis is less stringent than for LNG ships. Typical tank material is 2.5% nickel alloy steel. A full secondary barrier is required. The tanks are usually divided into two compartments, liquid-tight below liquid level, to reduce free surface effects. The tanks usually rest on top of the double bottom tanks and are supported by wood-lined beds and longitudinal and transverse "slides."

Appendix VI-2 provides a detailed description and shows diagrams of an American-designed, double-hulled LPG tanker offered by Avondale Shipyard.

SHIP HAZARD SCENARIOS - TANK RUPTURES

As long as liquefied gas is contained in a ship's tanks, it poses no danger to the public. The hazard a gas carrier poses to people, ports, and surrounding facilities lies in the possibility of a spill or uncontrolled leak, which could lead to a fire or explosion.

The most serious potential accident would follow the rupture of a cargo tank. This can be caused by a collision, grounding, tank failure, or sabotage.

Collision Hazards

In order to minimize the danger of ship collisions, any U.S. Coast Guard's Captain of the Port (the commanding officer in each major harbor area) may require special vessel traffic control systems. These regulations are discussed in Section III of this chapter.

Nevertheless, the resistance of these vessels to a collision is an important consideration. So far as we could determine, the only published studies of collision resistance have been done on ships with spherical tanks, which appear to be the least vulnerable to collisions. Similar studies on the other three major tanks designs are needed.

Studies on theoretical collision damage to ships with spherical tanks have been carried out by the Norwegian classification society, Det Norske Veritas (unpublished, but discussed in Ref. 6); General Dynamics; and by P.S. Allan, A.A. Brown, and P. Athens.[5] The Coast Guard has done a study on Tanker Structure Analysis (NTIS AD-A03-103), but this also dealt only with spherical tanks.

Figure 6-1 shows some results of the Norske Veritas study. Two impact locations were assumed, one at a main transverse bulkhead between cargo tanks and one at the center of a tank. The latter case is worse because the distance between the shipside and cargo is least. The "hump" in critical speeds for striking vessels of more than 50,000 ton displacement is due to the bulbous bow fitted on the larger vessels.

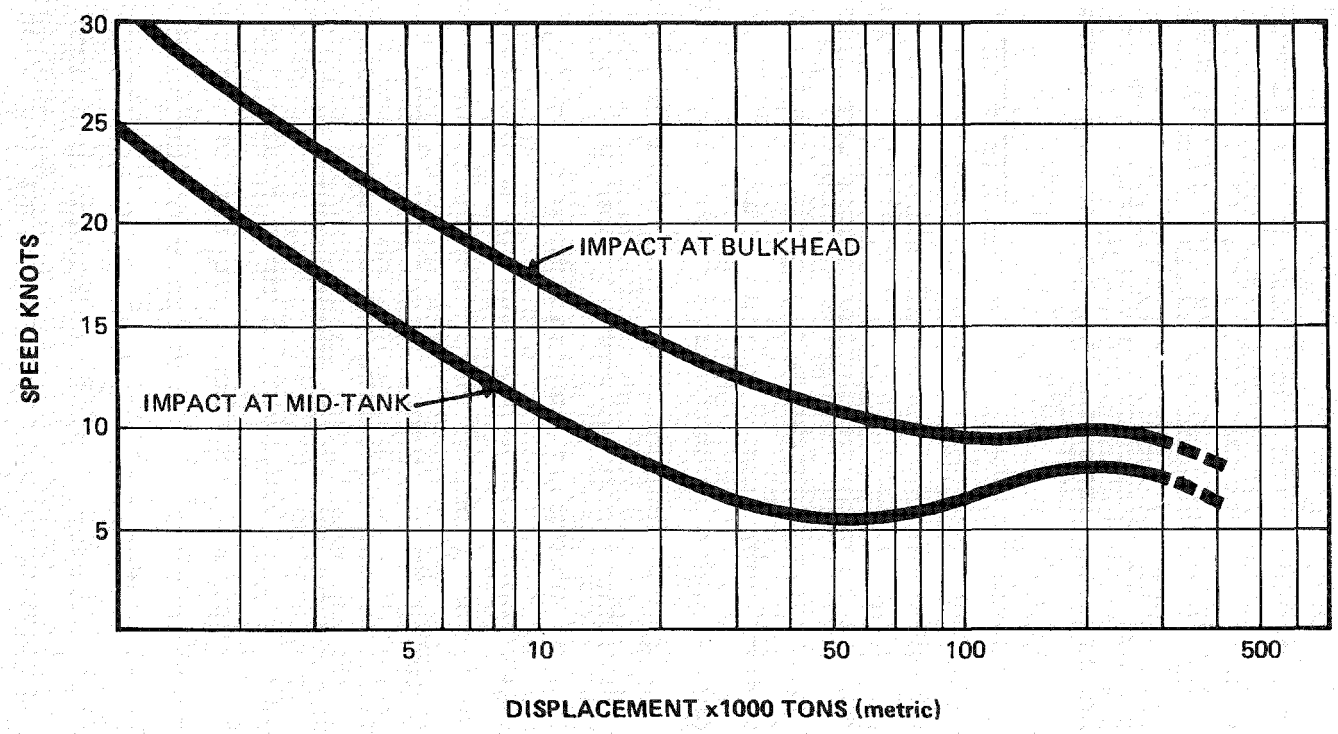
Two main observations may be made:

1) The critical speed and/or the displacement of the striking vessel would have to be much higher to penetrate an LNG vessel's tank than to penetrate an oil tanker.

2) Buckling and/or tearing of the side structure need not have any direct effect on the structural integrity of the spherical cargo tank.

Ship collision analysis must also consider ship survivability in the event of flooding. All new gas carriers must meet the IMCO and Coast Guard rules on two-compartment subdivision and limited heel stability.

FIG. 6-1 SOME RESULTS OF THE NORSKE VERITAS COLLISION RESISTANCE STUDY.



Critical Speeds of a range of vessels colliding with a 125,000m^3 Moss-Rosenberg type LNG Carrier, assuming a broadside collision into the LNG Carrier. The point of impact is assumed both at a transverse bulkhead and at the midpoint of a cargo tank. Critical Speed is maximum striking speed without touching cargo tank.

SOURCE: REFERENCE 6.

Tank Failure

Cargo tanks may also rupture from either general fatigue failure or over-pressure. Fatigue failure refers to the possibility of a defect, present in the tank on delivery, growing to a critical size as a result of fatigue from service. Howard and Kvamsdal[6] suggest that a crack of this type will grow slowly, leaving time to detect the leak through sampling instrumentation (gas detectors and liquid and temperature sensors in cargo holds) and remedy the situation. Under the Coast Guard's Letter of Compliance program and the proposed Coast Guard rules, tank design load calculations must include plastic deformation and fatigue life, combining strains from static, dynamic, and thermal loads. However, data on buckling of membrane designs are not required. (Proposed 46 CFR Parts 154.428 and 429). In 1969 the Polar Alaska experienced bulging of the Primary Membrane of No. 1 Cargo Tank "due to crew negligence during gas freeing operations ... Bulging caused by overpressuring the barrier space with nitrogen."[7] See Appendix VI-3.

Over-pressure

Pressure is one of the crucial factors affecting the safety of an LEG ship. The formation of a flammable mixture in the cargo tanks is prevented by maintaining a positive pressure differential between the cargo tanks and the atmosphere, and between the cargo holds and the atmosphere.

The required tank-to-atmosphere differential pressure is maintained by the vaporizer and the gas compressors control system (LNG) or the reliquefaction control system (LPG). The required hold-to-atmosphere differential pressure is maintained by a nitrogen make up system (LNG) or an inert gas generator system (LPG) and an automatic system of innerbarrier pressure relief valves. It is critical to maintain these differential pressures close to their design values.

An LEG carrier can be sabotaged by improperly operating the pressure control systems to overpressurize the cargo tanks or cargo holds.

According to their LNG ship specifications, a General Dynamics LNG ship's vaporizer can generate 12,000 cubic meters of LNG vapor per hour, with a vapor temperature of 184^{o}F, which can be handled by the safety valves. A saboteur would have to close the relief valves, either by blocking the valves (which can be done on some of the free-standing tank design ships), or by blind-flanging the vapor outlets. The actual bursting or buckling pressures of the cargo tanks are not published, since these calculations are not required by regulatory bodies.

Failure to Take Prompt Action

A minor LNG spill can escalate to a major spill through failure to take prompt corrective action. The ability to prevent a larger spill depends on a ship's operational and emergency procedures and the training of its crew.

Fire Hazard

The major threat of fire on an LNG ship comes from a collision with another vessel. During general LNG ship operations, small leaks in the cargo handling system usually will cause at most only relatively small gas fires on deck or near the ship. Because of the inert atmosphere maintained by nitrogen, it is unlikely that a fire would take place between the cargo tanks and the cargo hold. A collision, on the other hand, could lead to larger oil/gas fires enveloping major portions of the ship. Such large fires may be difficult to control and could endanger the ship.

Analyses done by Det Norske Veritas[8] show that most gas carriers can sustain extremely large fires without hull and tank breakdown as long as only one side of the ship is exposed to the fire. This study indicated that a free standing cargo tank would probably contain its cargo (LNG) during and after the fire. A membrane design, however, would release the cargo into the cargo hold or ballast tanks. This would probably cause the hull to rupture.

The effects of such a collision-induced fire on cargo tank insulation have also been studied. Results show that insulation, even fire-resistant insulation, may be subjected to temperatures that would cause it to deteriorate or to melt.

For example, Det Norske Veritas research showed that in the event of fire the ship's inner and outer hull might become hotter than 1,472^{o}F. At temperatures in the 212^{o}F

to 392°F range, most ordinary plastic foam materials experience deterioration of mechanical and thermal properties. At higher temperatures, such as over 572°F, complete thermal decomposition takes place.

The results of a similar study are discussed in the LNG Safety Manual issued by Energy Transportation Corp. for its LNG ships. If a tank fails, according to the manual, the spilled LNG will take six minutes to burn. The temperature at the wing tanks (ballast tanks between the inner and outer hull) could reach 700°F, and the temperature of the tank covers of the LNG cargo tanks could reach 716°F.

A possible way to reduce the effects of a fire might be to pump water rapidly into strategically located ballast tanks. This will require a higher ballast pump capacity than is presently common. Fire resistant insulation in critical places would also be useful.

REGULATION OF SHIP DESIGN

LEG ship design is influenced by a code adopted by IMCO and by regulations promulgated by the U.S. Coast Guard.

IMCO, whose purpose is to provide internationally agreed standards on design, construction, and operation of ships, adopted a code for gas ships (Resolution A.328 (IX)) in late 1975. Although IMCO resolutions are only advisory, they are usually incorporated into the national regulations of member governments and thus have a strong impact on the international shipping industry.

The Coast Guard, which was actively involved in the development of the IMCO Code, published its proposed rulemaking (46 CFR, Parts 31, 34, 54, 98, 154) in October 1976. Although the proposed Coast Guard rules correspond closely to the IMCO Code, they go beyond the Code in that they would require a lower ambient design temperature, better steel grades in crack arrestors, cargo venting restrictions in port, and a higher safety factor for allowable tank stresses.

Reaction to the stronger rules proposed by the Coast Guard included a joint protest from nine foreign governments. According to an Aide-Memoire received by the Coast Guard's Marine Safety Council February 17, 1977, the governments of Denmark, Finland, the Federal Republic of Germany, Greece, Italy, Japan, Norway, Sweden, and the United Kingdom joined in the opinion that national regulations concerning the design, construction equipment, and manning applicable to foreign vessels should be based on internationally agreed standards formulated after consideration within IMCO. They asked that the proposed regulations be amended so as not to exceed the code.

SECTION II. PERSONNEL TRAINING

Well-trained personnel reduce the chance of an unintentional release of LEG. They are also more capable of controlling the situation once an incident has occurred.

An LEG tanker is a highly sophisticated and expensive transportation system. Ships and terminals are complex and heavily instrumented; cargo handling is complicated and hazardous. Skilled operators are needed for safe operations.

Some companies have designed training programs that exceed the present and proposed requirements of regulatory bodies. Other companies, however, have done very little about personnel qualifications, particularly training. Some of the reasons are:

- Marine transportation of liquefied gas is a relatively new technology. Lack of operational experience is typical for the industry, including management personnel.

- Human factors are difficult to quantify. It sometimes seems easier to reduce the possibility of human error by increasing automation.

- Training regulations covering LEG personnel are lacking.

A study sponsored by the Maritime Administration, entitled "A Model Economic and Safety Analysis of the Transportation of Hazardous Substances in Bulk," concluded that marine transport was the safest method of moving such products. But the data collected on marine casualties also indicated that human error was the contributing factor in 85 percent of all casualties and operating problems.

TRAINING PHILOSOPHY

In order to establish qualifications needed by personnel involved in LEG marine transportation, it is necessary to know the design and operation of the ships, terminals, and equipment they will be dealing with, as well as the constraints under which their ships operate.

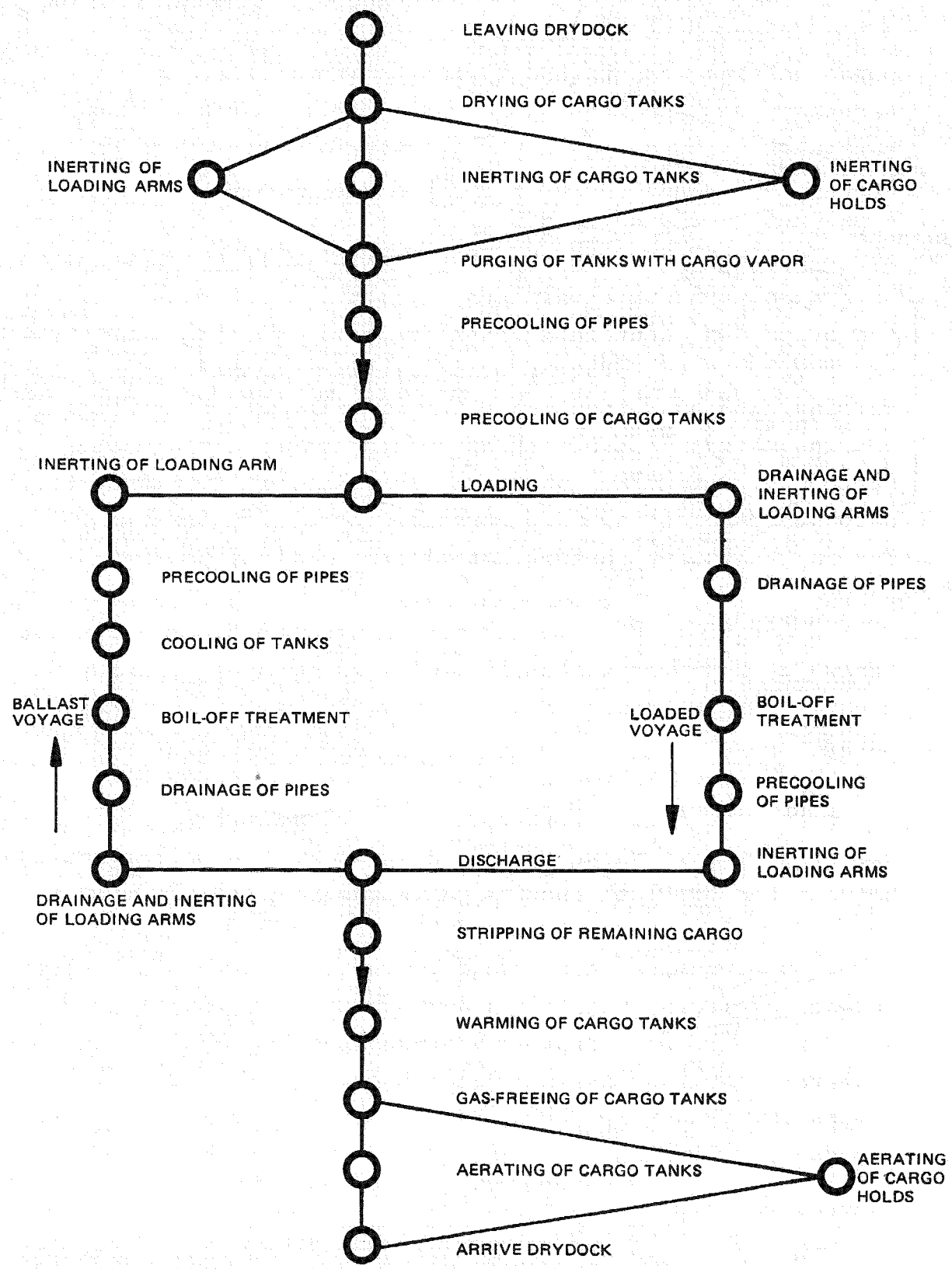
Design. Because LEG must be kept fully enclosed and separated from the atmosphere, monitoring internal pressures and maintaining them are extremely important to the safety of the system. The relationship between the LEG terminal and ship involves a two-way flow of information and an interconnection of safety and control subsystems. Therefore, a terminal operator should be familiar with the ship subsystems, and ship personnel should at least know the shore systems that will influence their actions.

Operation. A somewhat simplified typical operational schedule is shown in Fig. 6-2. The diagram demonstrates clearly the efforts made to prevent the mixing of air and cargo vapor.

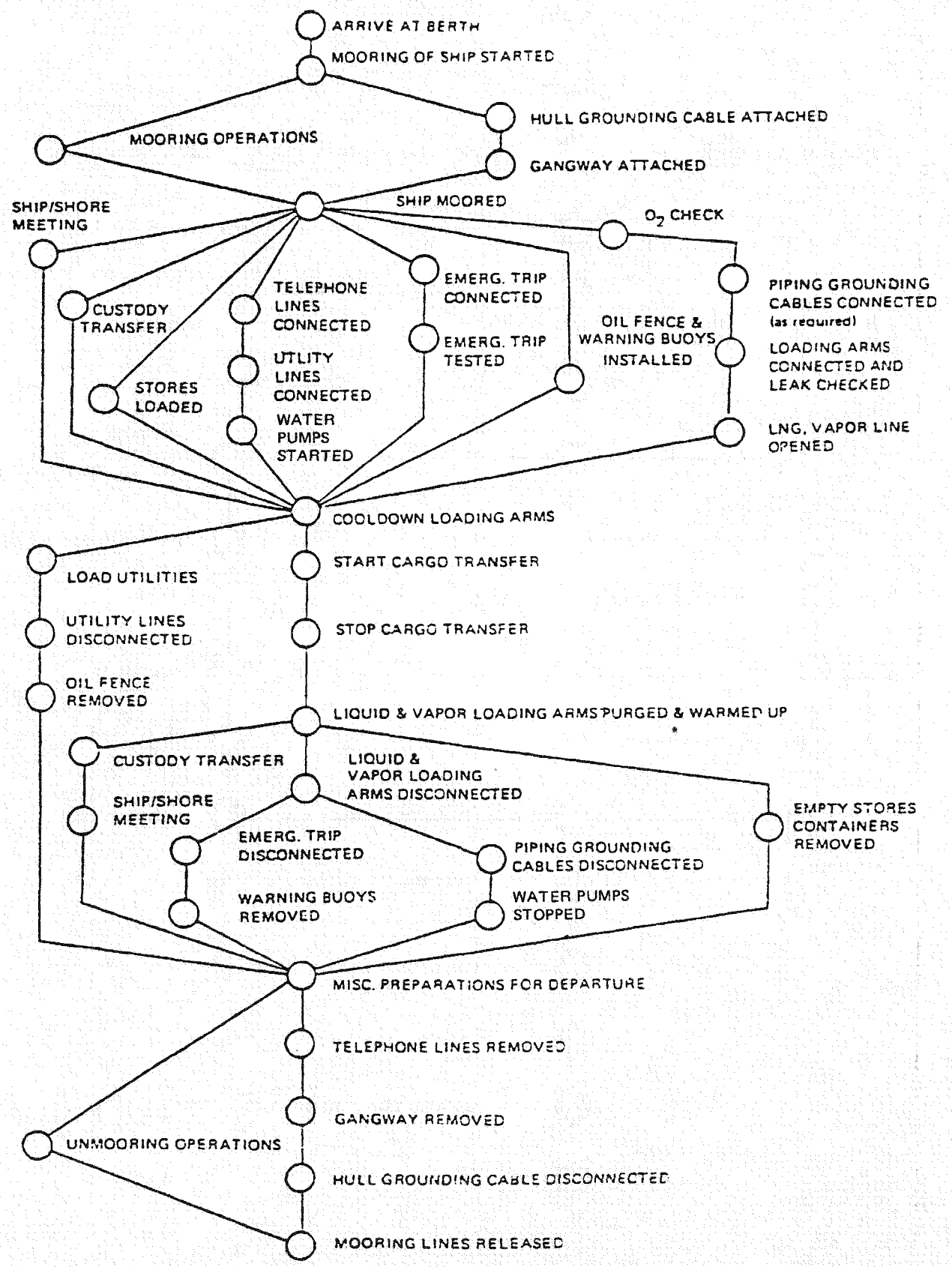
A cargo transfer is further subdivided into the different events shown on Fig. 6-3, where the relationship between the terminal and the ship is shown in some detail.

An extensive task analysis for personnel on LNG ships and barges (NTIS-AD-A026108) was sponsored by the Coast Guard in 1976. The project was conducted by Operations Research, Inc. and Engineering Computer Optecnomics, Inc. See the bibliography at the end of the references for other studies.

FIG. 6-2 – TYPICAL LEG CARGO OPERATION SCHEDULE



TYPICAL CARGO TRANSFER SEQUENCE
FIG. 6-3



CONSTRAINTS

Personnel aboard LEG ships operate under more difficult conditions than workers at LEG terminals. Hazards, for example, are greater aboard ship because a vessel operates in an environment that is continually changing and that cannot be accurately predicted. Nevertheless, many members of an LEG ship's crew have a less technical background than the engineers and technicians who typically operate an LEG terminal. Furthermore, members of a ship's crew may not have the same opportunity to specialize in LEG operations as do their counterparts ashore. A deck officer aboard an LEG tanker must consider gas cargo handling as only one of his many assigned duties, along with ship handling, navigation, and other tasks. In addition, there may be times when a ship's officers work longer hours than permitted under regulations, and may be physically and mentally less prepared for a given cargo handling operation.

On U.S. flag LNG ships the Coast Guard requires that the ship have a non-watchstanding Chief Mate to serve as the cargo officer, and a non-watchstanding 1st Assistant Engineer to serve as the cargo system engineer. The Coast Guard imposes these requirements, under 46 U.S.C. 222, in issuing the ship's certificate of inspection. Only two out of 38 current LNG ships are U.S. flag. There are no U.S. flag LPG ships.

There are no similar non-watchstanding requirements for cargo officers and engineers on foreign flag LEG ships. IMCO has not addressed this issue, although it may be discussed in its June 1978 meeting.

TRAINING CRITERIA

As part of our study we made an extensive review of existing and proposed industry training criteria and those proposed and required by U.S. and foreign governments. The criteria below seem to us to be particularly important.

1. Advanced, formalized shore-based training should be given to all personnel with duties connected with handling LEG.

2. The training should provide a basic understanding of LEG behavior under all conditions.

3. The unusual hazards of LEG and the preventive and reactive safety features involved should be emphasized throughout the training.

4. Hands-on training should be provided in fighting fires on water and high-pressure-vapor fires.

5. Supervisory personnel should be required to understand the operations of all components and instruments involved, even if they are actually operated by others.

6. Training in emergency procedures should be emphasized.

7. Training in teamwork situations should be provided, involving personnel with responsibility for different subsystems, such as ship and shore terminals, and personnel with different professional training. This

could be done on the job, but can be done more efficiently on a simulator.

8. Personnel should be trained to use their acquired knowledge in realistic operations, including troubleshooting and decision-making in emergency situations. This training can only be done in a simulated environment.

Although the above list indicates a sophisticated and demanding training program, the general concept is accepted by the industry; each of the criteria can be found in existing and planned training programs, even if few companies have adopted all of them. They should be required for both marine terminals and the ships.

PROPOSED REGULATIONS

Shore Terminals Two regulations concerning personnel qualifications at LNG terminals have been proposed:

1. The Coast Guard is considering a proposal developed by the Chemical Transportation Industry Advisory Committee (CTIAC) for revising 33 CFR Part 126, entitled Waterfront Facility Regulations, Liquefied Natural Gas in Bulk, October 1977. The proposed revisions describe three levels of training for supervisory, operating, and maintenance personnel respectively. According to the Coast Guard, however, no "approval" of training programs is envisioned, and the training "requirements" will not be enforced. The proposed revisions are general in scope, and do not cover criteria 7 and 8, above.

2. The Office of Pipeline Safety Operations' proposed rules (49 CFR Part 193), Liquefied Natural Gas Facilities, cover operations only to a limited extent. They state that an initial training program shall provide instructions in the characteristics and hazards of LNG, in the operation of plant equipment, and in emergency procedures. The Office of Pipeline Safety Operations has not proposed requiring that training programs be approved. Finally, criteria 2, 4, 7 and 8 are not covered.

No regulations setting forth qualifications of personnel working at LPG waterfront facilities have as yet been proposed. However, CTIAC is planning such work for all liquefied gases, including LPG, after the final LNG regulations are adopted.

Ships Both the U.S. Coast Guard and IMCO have developed proposals for the training of LEG ship personnel. IMCO's detailed recommendations will be evaluated by the government members before the IMCO Convention in London, June 1978.

Acceptance by the Convention is important to the United States; if IMCO member governments in turn incorporate the training recommendations in their national regulations, their enforcement would assure that personnel operating foreign flag carriers have received acceptable training. The Coast Guard need not wait, however, for member governments to take this step. Once the IMCO Convention has adopted these recommendations, the Coast Guard could require that all foreign flag vessels operating in U.S. ports meet the new IMCO standards.

The IMCO recommendations include three levels of training directed at:

a) all crew members;

b) those with duties specifically involving the cargo; and

c) the person in charge of cargo handling.

All crew members would receive a basic shore-based training course, including hands-on fire fighting, prior to assignment to a ship. Those involved in cargo handling would have more in-depth training and would be required to serve aboard a gas carrier for at least two months. This training for group "c" would satisfy all of the criteria except No. 8.

The U.S. Coast Guard has proposed training regulations (46 CFR Parts 10, 12, 30, 31, 35, 70, 90, 98, 105, 151 and 157), Tankerman Requirements. These regulations would attempt to put IMCO approved recommendations into effect. However, the proposed Coast Guard regulations differ from the proposed IMCO rules in that:

- Formalized training would be required only for a limited number of personnel who have duties in connection with the cargo. The regulations are unclear on this point, but they would probably include only the person in charge and his assistant.

- Instructions concentrate on cargo transfer operations (loading and discharging). The regulations do not

reflect the fact that these operations are only a part of LEG carrier operations.

- Instruction in emergency procedures is not required.

In addition, the Coast Guard's proposed requirements for practical experience would enable a person to qualify by participating in relatively brief discharge operations. The proposed regulations are not found to cover satisfactorily training criteria Nos. 1, 6, 7, and 8.

EXISTING AND PLANNED TRAINING

Training of both ship and shore personnel is characterized by the lack of regulatory guidelines and the wide variety of training approaches. Comments on some approaches follow.

Shore Terminals. Most operating LPG receiving terminals use principally on-the-job training without any specified training schedules. Key personnel are given hands-on fire fighting training in designated schools. The Distrigas LNG terminal in Everett, in addition to on-the-job training, periodically conducts a 16-hour formalized course in safety and plant operation. All operating personnel are sent to fire fighting school.

Columbia LNG's Cove Point terminal provided a six-week course for all operating personnel, including four hours a day of classroom instruction and four hours a day of hands-on experience. Further training was given in a "simulated" cargo transfer operation, using an empty LNG ship berthed at the dock. Cove Point also held three two-day fire fighting sessions, which included small LNG pool fires.

Southern Energy's Elba Island LNG terminal is planning a similar training program. An interesting feature is the intended use of the control room console in training exercises, simulating plant conditions by means of a computer.

Improved training courses are now being conducted by the equipment manufacturers. All of the training criteria discussed above are satisfied collectively by the planned training programs of the Cove Point and Elba Island terminals. This indicates that these criteria are realistic.

Ships A great majority of the LPG carriers and approximately 50% of the LNG fleet to be involved in U.S. trade will be of foreign flag. The French Gazocean Company, one of the largest gas ship operators in the world, is representative of the companies that offer no organized training in the field, except on-the-job indoctrination.

The British P & O Steam Navigation Company provides a one-week classroom course in handling of liquefied cargoes at the Southhampton School of Navigation, operated by the General Council of British Shipping. In addition, P & O requires two months of on-the-job training and a four-day safety course in Leith, Scotland.

Norwegian companies also provide on-the-job training in addition to a two-week gas carrier safety course at the state operated School of Ships Safety and Damage Control in Haugesund. Some of the companies sporadically offer a one week cargo-handling course, conducted by the shipping industry.

The Algerian state-owned company, CNAN, is expected to carry about 20% of the expected LNG to be imported to the United States. In sharp contrast to the more established European companies, CNAN is planning a training institute outside Arzew to provide a 1-1/2 year extensive training program for deck officers, marine engineers, shore officers, and management personnel. The institute plans to have a $2 million cargo handling simulator, as well as fire fighting facilities, a number of laboratories, and a complete loading arm set up. The simulator will provide training in teamwork situations for all personnel involved with the cargo. Training in troubleshooting and emergency situations will be emphasized. As far as we know, the training program is the most extensive planned today.

In the United States, maritime training at this level is generally provided by the maritime unions. Since 1974 the Maritime Institute of Technology and Graduate Studies, operated by the International Organization of Masters, Mates, and Pilots, and the shipping companies, has had a four-week course in gas carrier operations, including fire fighting. The school plans to incorporate a simulator comparable to the Algerian model.

More recently a six-week LNG fundamentals course, including fire fighting, has been offered by the Calhoon MEBA Engineering School, operated by the Marine Engineers Beneficial Association. The Energy Transportation Corporation requires its deck, engine, and radio officers to be graduates of this program.

Both of these courses seem to meet the standards contained in the IMCO recommendations as well as the proposed Coast Guard Tankerman Requirements.

The Seafarers International Union's Harry Lundeberg School also gives a four-week LNG program for unlincesed ship personnel.

In addition to these training facilities, the El Paso Company will conduct its own training program. Expected to cost $9 million over a five-year period, it will be carried out on the ships and at shoreside facilities. It will include the use of a LNG cargo handling simulator and a shiphandling simulator, both to be operated by Marine Safety International.

SECTION III. SHIP OPERATIONS

The safety of domestic LEG ship operations depends heavily on the Coast Guard's management of LEG traffic and off-loading operations. Assessing the quality of that management is the purpose of this section.

LPG maritime traffic in this country is steadily growing and involves many ports, but until early 1978 the only active LNG import terminal was in Boston Harbor, where one LNG ship docks every three weeks. An LNG export terminal at Kenai, Alaska has been operating since 1968. Consequently, the Coast Guard has had limited operating experience with LNG. It is important for the Coast Guard to promptly develop operating and contingency procedures for LNG, because LNG traffic is beginning to grow. The new LNG terminal at Cove Point, Md. has received its first shipload of LNG, and will eventually be receiving one LNG ship every 2-1/2 to 3 days. The Elba Island, Georgia terminal is also expected to begin operations in 1978.

LPG vapor has significantly different density, vaporization temperature, detonatability, and burning characteristics than LNG vapor. Current Coast Guard operating procedures do not reflect these differences.

Under Title I of the Ports and Waterways Safety Act of 1972, the Coast Guard has certain powers to prevent damage to land structures and shore areas immediately adjacent to U.S. navigable waters resulting from vessel or structure damage, destruction, or loss. The Coast Guard informed us, however, that it is not currently capable of monitoring all the land-side dangers from hazardous materials. In the case of LNG storage tanks, for example, it examines only the peril the tanks pose to ships and docks but not to surrounding communities. After more than three years of discussions, the Coast Guard and the Materials Transportation Bureau have recently agreed on a two-page Memorandum of Understanding which clarifies their respective responsibilities for regulation of waterfront LNG facilities and sets forth procedures for cooperating in carrying out those responsibilities. A more extensive discussion of this issue is given in Appendix XVI-3.

HISTORICAL BACKGROUND

Large-scale petrochemical trade between America and Europe and Japan began in 1964. The Coast Guard soon became concerned that the ships involved in the trade, all of which were of foreign registry, would not be equipped with the safeguards necessary to ensure containment of hazardous cargo. Consequently, the Coast Guard required that any ship planning to carry hazardous cargo in U.S.

ports submit plans of the vessel's containment area, related piping, and electrical systems for review and approval by the Coast Guard's staff of technical personnel.

This submission of plans was the forerunner of the Coast Guard's current Letter of Compliance (LOC) program. Under the LOC program all foreign vessels of novel design that carry hazardous bulk liquid cargo must be inspected by Coast Guard personnel and issued a Letter of Compliance before they are permitted to transport these cargoes in U.S. waters. The inspection takes about 4½ hours and the Letter of Compliance is valid for two years. All foreign tankers are given a navigation safety examination at least once a year.

NEED FOR SPECIFIC LEG DIRECTIVES FROM COAST GUARD HEADQUARTERS

Discussions with senior officials at Coast Guard Headquarters showed their awareness of the agency's statutory responsibilities for the safe operation of vessels transporting hazardous materials such as LEG. The Coast Guard's publication CG-478, "Liquefied Natural Gas - Views and Practices, Policy and Safety," dated February 1, 1976, gives a comprehensive, technical discussion of most aspects of the procedures recommended for the movement and transfer of LNG in U.S. ports. However, this publication is a statement of policy and not a directive. It specifically states that implementation of the policies contained therein is at the discretion of the local Captain of the Port (COTP). Since each port has different geographic features, patterns of harbor traffic density, and prevailing weather conditions, a large delegation of authority and responsibility appears to be justified.

Furthermore, most local regulations issued by the COTP's encompass the guidance in CG-478. (See the discussion below on LNG inspections in Boston Harbor.)

On September 22, 1977, the Coast Guard published an amendment that more clearly defines the jurisdiction of each COTP and Officer in Charge, Marine Inspection (OCMI), and delegates more authority to each COTP. One of the changes strengthens the COTP's ability to manage LEG and other hazardous materials moved or stored in his area. The Commandant of the Coast Guard, however, has retained the authority to prescribe minimum safety equipment requirements.

While most regulations generally conform to the policies set forth in CG-478, there are inconsistencies. One involves the means by which COTP's redirect harbor traffic when an LEG vessel is arriving or departing. Some COTP's alert ships in the area through publication of a local Notice to Mariners. A Notice to Mariners becomes a matter of record. It also is likely to be received by vessels that may not be monitoring local harbor radio frequencies. Local security broadcasts, on the other hand, provide instantaneous information. Using both of these methods would enhance navigational safety.

The Coast Guard is experienced and capable in carrying out its responsibilities for vessel traffic, communications, and compliance with accepted marine navigational procedures. It is less experienced in dealing with LEG cargo transfer operations. It presently has insufficient resources for supervising these operations and preparing to deal with LEG emergencies.

Planning for a local disaster such as a major LEG spill varies among the COTP's but generally places heavy reliance on industrial (terminal) resources and local fire departments. No specific plans exist for coping with a major LEG spill and there appears to be little agreement among responsible officials as to what should be done if one occurs.

Although some COTP's have adapted CG-478 for LPG as well as LNG, no similar document has been issued by the Commandant, U.S. Coast Guard, specifically for the movement and transfer of LPG.

COAST GUARD PERSONNEL TRAINING

The Coast Guard has no mandatory training program in LEG hazards except that included in the Marine Safety Basic Indoctrination Course required for officers and warrant officers. This is a 12-week survey course. The only safety training offered to enlisted personnel is a five-week Marine Safety Petty Officer Course.

The Coast Guard has several times offered a four-day training course on liquefied gas carriers in Yorktown, Va. It has also offered a three-week hazardous chemicals course in Yorktown of which one week focuses on LEG training. Both courses cover cargo operations only superficially. The Coast Guard is also aware of and has recourse to the training courses being given outside the Coast Guard, described earlier.

The Coast Guard does not require the officers and enlisted personnel who are involved in LEG ship operations to attend any of these specialized LEG courses. Of

particular concern are the qualifications of the Hazardous Materials Officers (HMO's) on the staff of each COTP. Although some of the HMO's we interviewed were well-qualified by experience or education, most had little training in the hazards of LEG. For example, the HMO of a port that imports both LNG and LPG told us, incorrectly, that propane is lighter than air at ambient temperatures and that the vapors from a spill would rise up and disperse in the upper atmosphere as it warmed up. On the basis of this he said his advice to the COTP would be the same for an LPG spill as for an LNG spill.

Coast Guard people responsible for LEG ship movements may be unaware of the conclusions of the Coast Guard's own research. Coast Guard researchers told us, for example, that, if there is a large LEG spill (25,000 cubic meters or more) from a ship, nothing useful can be done about the resulting vapor cloud, whether or not it is ignited. If Coast Guard personnel were aware of this and other pertinent information, they would understand better the need for extreme care in LEG cargo handling.

The Coast Guard's annual operational readiness inspection at each port is only an administrative evaluation of prescribed procedures, rather than an actual test at ports handling LEG. An adequate test would require manning of Coast Guard emergency stations and equipment in a simulated LEG spill situation, in order to judge the training and performance of personnel and the efficiency of equipment.

COAST GUARD PORT ACTIVITIES

The discussion in this subsection is based on meetings with personnel on the headquarters staff of the Commandant, and with COTP's or their designated representative at the following six ports: Boston, New York, Philadelphia, Baltimore, Houston, and Savannah. We made several visits to Boston Harbor, since it was the only port through which LNG was then being imported.

In addition, we reviewed various documents including the regulations on LEG safety issued by the COTP's, and harbor navigational charts for the ports, issued by the National Oceanic and Atmospheric Administration.

LNG Offloading in Boston Harbor

During our visits to the Port of Boston we observed offloading from three LNG carriers: the Descartes, a 50,000-cubic meter French flag ship, owned by Gazocean; the Kenai Multina, a 35,000-cubic meter Liberian flag ship, owned by Multi-Meyer; and the Lucian, a 29,000-cubic meter Norwegian flag ship, owned by Reksten.

Security Authority

Under 33 CFR Parts 125 to 127, the Commandant, U.S. Coast Guard, is authorized to require certain precautions against the sabotage of vessels and waterfront facilities handling explosives, or flammable or combustible liquids or fuels. Nevertheless, no COTP has made any specific provisions to prevent or mitigate the consequences of sabotage of an LEG ship or terminal. They rely on the

minimal industrial security forces at each terminal and on the ship's masters. The inadequacy of the present security arrangement is discussed in Chapter 9.

Minor LNG Spills

On both the Lucian and the Kenai Multina we observed small leaks due to malfunction of equipment. The Lucian had two minor gasket leaks, both of which were stopped by tightening bolts.

On April 3, 1977, we saw several gallons of LNG spilled on the deck of the Kenai Multina as the result of a leaky gasket in the liquid line from tank no. 5. The crew sprayed water throughout the discharge operation, which probably prevented the deck from cracking.

Last winter the Descartes spilled about one cubic meter (264 gallons) of LNG, when valves in the ship's liquid lines were left open. The ship's plates did not crack, although a similar accident in Stade, Germany, involving ethylene ($-155^{o}F$) caused damage which required replacement of several steel plates on the deck and the ship.

The Lucian had a minor spill on March 8 caused by a poor connection with the loading arms; another occurred on March 9, due to open valves in the ship's liquid lines.

Smaller ships, such as the Kenai Multina and the Lucian, face an additional hazard. The berth and mooring system at the terminal is designed for larger ships, such

as the Descartes, and does not provide the same support for shorter vessels, which can use only one of the two 52 ton breasting dolphins.

Coast Guard Inspections

The Coast Guard carries out a 2-1/2 hour inspection before an LNG ship is permitted to enter Boston Harbor, but it does not include the operating condition of ship control equipment such as steering engines, propulsion machinery, and electronic devices. Coast Guard policy also leaves critical safety decisions to the discretion of the COTP.

The inspection itself is one of the 18 requirements which the COTP, at his discretion, may place upon LNG transit operations, according to CG 478.[9] In Boston, under the LNG-LPG Operation/Emergency Plan, the COTP has the right to prohibit a ship from entering the port, if there are serious discrepancies in safety systems. If a safety subsystem is not in good working order, it is the COTP who decides whether the condition is serious enough to warrant keeping the ship out of the harbor.

This arrangement is unsatisfactory for three reasons. (1) Since Coast Guard personnel do not have to be trained in LEG properties, hazards, technology, and cargo operations, they may not be fully qualified to judge the significance or consequences of a malfunction. (2) Without specific requirements, there may be a tendency to give undue weight to the large, certain, economic impact of the ship's delayed entry against the uncertain possibility of harm posed by the malfunction. (3) The lack of specific

requirements results in confusion in the world shipping industry as to the U.S. Coast Guard's safety standards for admitting LNG ships.

The following two examples illustrate the kind of decision a COTP must make under current regulations. Each involved a fault in one of the major safety subsystems of an LEG carrier.

The LPG carrier Faraday, carrying 27,500 cubic meters of propane, was inspected on March 5, 1977, outside Boston Harbor. The ship uses inert gas consisting of 85 percent nitrogen and 15 percent carbon dioxide in the cargo hold surrounding cargo tanks. The carbon dioxide absorbed infrared light, triggering the ship's gas alarm. This problem was discovered on a previous trip to the United States by the Faraday. With a crew member visually monitoring the gas detector dial, the ship was allowed to enter the port. This decision involved some risk. If propane did begin leaking into the hold, the gas indication could have been difficult to separate from the "false" reading caused by carbon dioxide. A sufficient leak of cargo can cause the hull to crack, thus allowing cargo to spill.

On April 3, the Coast Guard inspected the Lucian, which was carrying 28,000 cubic meters of LNG. Although the seals on two of the ship's relief valves were broken, it was allowed to enter. In such instances, there is a risk, however unlikely, that the relief valves have been tampered with, rather than that the seals were accidentally broken. There is no way to check whether the relief valves have been changed to a higher pressure setting which, as discussed in Section I, could lead to tank rupture and cargo spill. The incident underscores the need for a

regulation requiring pressure switches that automatically shut off relevant equipment in case of high differential pressures.

These were both difficult decisions which worked out satisfactorily, but we believe the COTP should not have had to make them. Coast Guard requirements should specify which faults are sufficiently serious to prevent a ship's entry. The COTP should not have to weigh the dollar costs of a delay against the potential risk posed by a safety fault. Although it is true that, if the COTP is undecided, he may request the Commandant to advise him or to furnish a technical representative, a COTP may be reluctant to admit more technically qualified assistance is needed.

As noted, specific requirements would also be to the advantage of the LEG shipping industry. Otherwise, the present confusion may increase as more ports are involved in LNG shipping, and ship captains may face the possibility of inconsistent implementation of the guidelines by various COTP's.

Visibility Considerations

According to the Coast Guard's regulations for Boston Harbor, if the visibility is less than 2 miles, an LEG ship is not permitted to enter the harbor. However, if a ship has reached a point east of Fort Point Channel, and the visibility drops below 2 miles, the ship is allowed to continue to the ship's berth. This was the case last winter when the Lucian arrived in a heavy snowfall.

According to the visibility requirements, a vessel must begin transit of the harbor at least 2 hours before sunset. The 10 miles from Broad Sound to the Everett Terminal usually takes 1-1/2 hours. On April 4, the Lucian arrived at the dock at 6:35 p.m. and was moored at 7:15 p.m. Sunset on that day was 6:13 p.m. If the trip took 1-1/2 hours the Lucian would have had to begun transit almost an hour beyond the Coast Guard deadline. Although local port regulations call for a minimum of 3 tugboats, the Lucian was assisted by only two on that transit.

Aircraft Hazard Assessed

While on board one of the LNG carriers, we noted how close the ship was to Boston's Logan Airport. On investigation we found that planes approaching the airport's Runway 4-R fly over the ship channel used by both LNG and LPG tankers. On July 31, 1973, a Delta DC-9 executing an instrument landing approach to this runway crashed into the seawall.[10] We examined the circumstances of this crash to assess the danger of an airplane colliding with a gas tanker in the channel.

In Fig. 6-4 the prescribed flight path and the flight track of the crashing plane are plotted on a nautical chart of Boston Inner Harbor. The numbers given on the map are channel depths. The flight profiles are shown on Fig. 6-5.

Correct flight procedure calls for altitude to be maintained within 100 feet of prescribed altitude during initial approach. This should decrease to approximately 50 feet at decision height (DH), the height at which the pilot should decide whether to continue or abandon his approach.

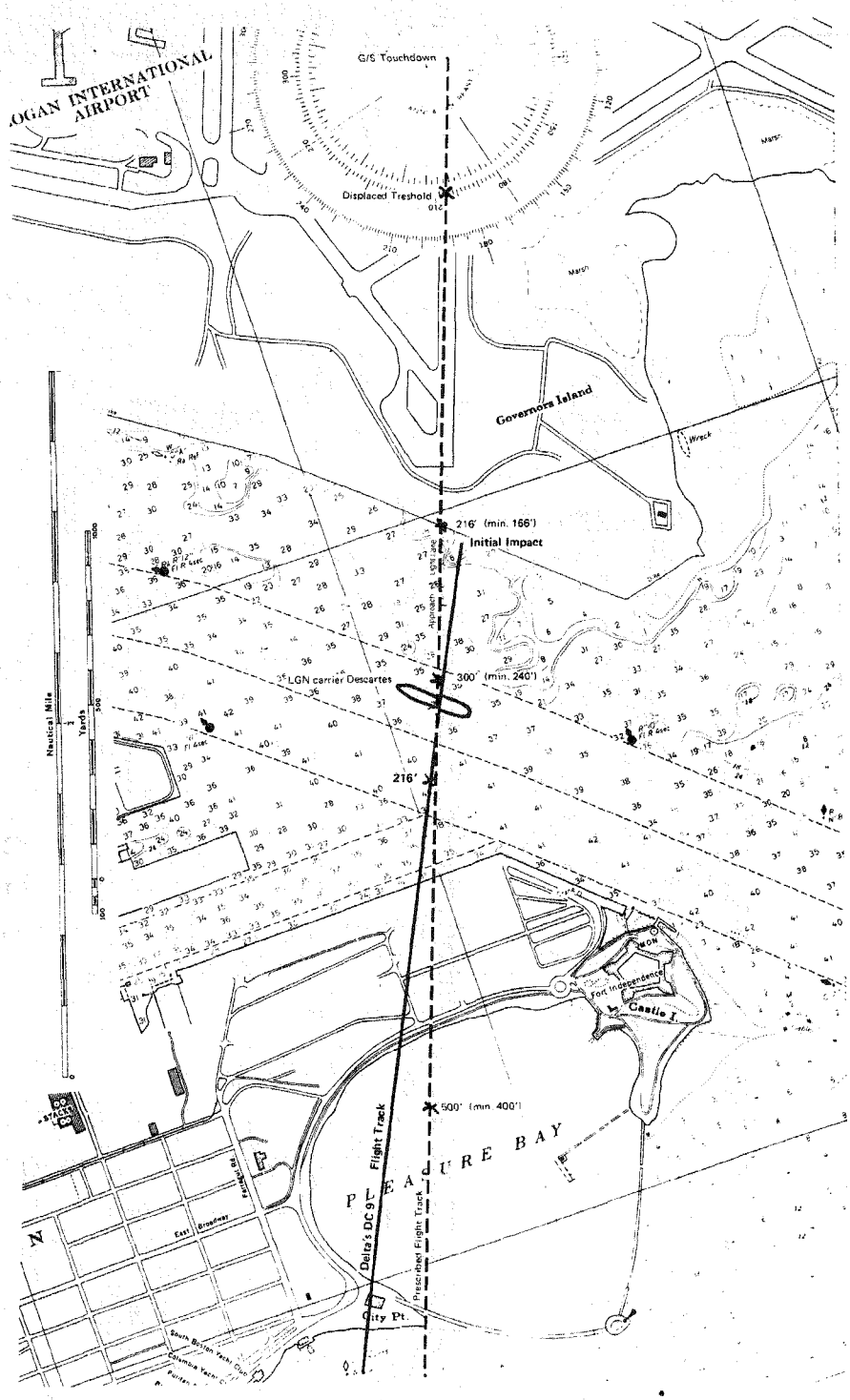
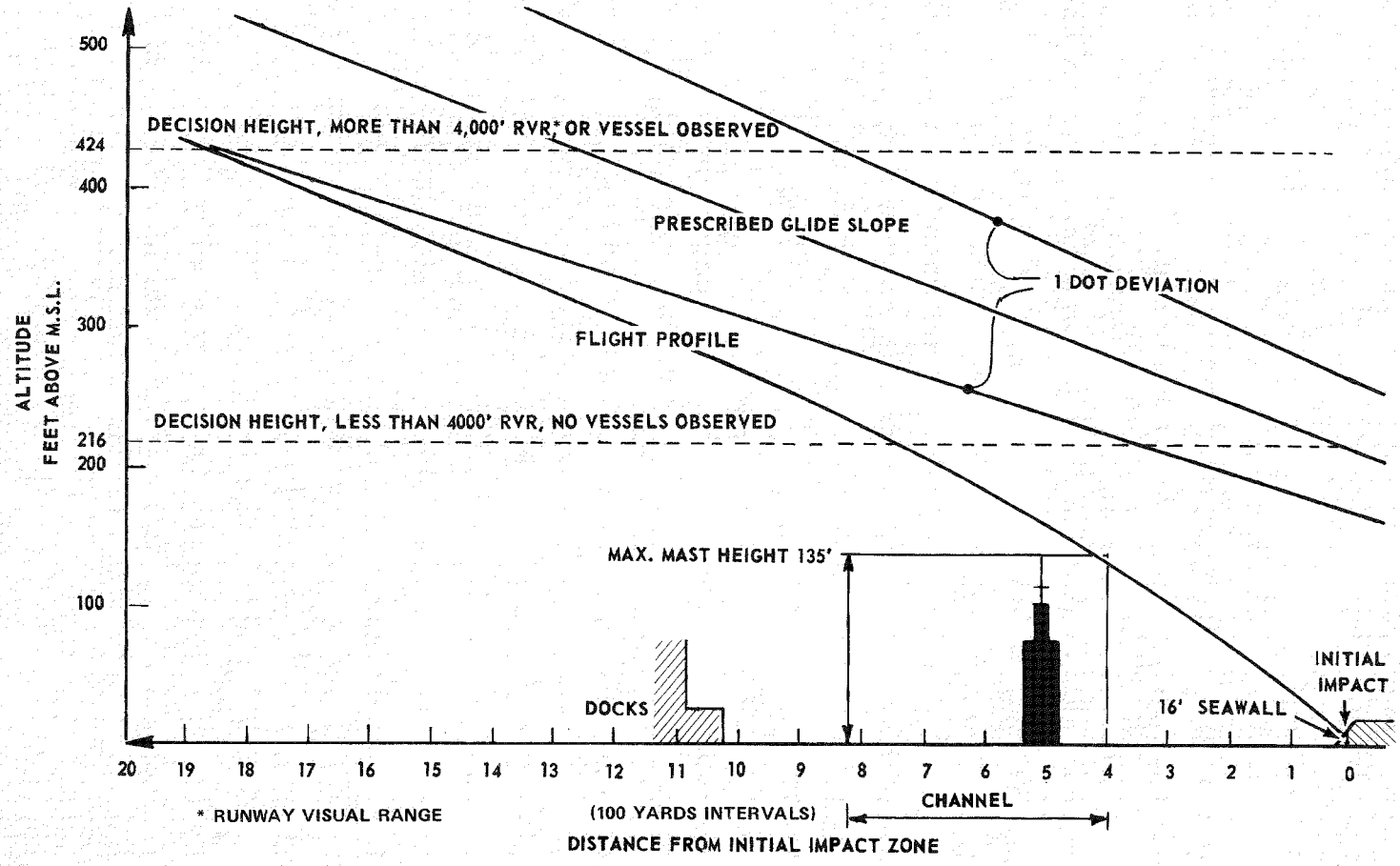


FIG. 6-4

PRECRIBED FLIGHT PATH AND FLIGHT TRACK OF THE PLANE CRASH INTO LEG SHIP CHANNEL SEAWALL.

FIG. 6-5 LANDING APPROACH FOR RUNWAY 4R, LOGAN INTERNATIONAL AIRPORT AND FLIGHT PROFILE FOR CRASH.[1]



1/IN NOVEMBER 1977, AFTER IMPROVEMENTS TO RUNWAY 4-R, THE FAA LOWERED THE NORMAL DECISION HEIGHT FROM 424 FT. TO 359 FT. WITH MORE THAN 5000 FT. RVR.

The horizontal distance is given from the edge of the seawall, where the crash took place. As can be seen from the diagram, the ship will never be closer than 400 yards from this point.

The maximum mast height is set to 135 feet, which is the vertical clearance under the Mystic River Bridge. Some ships are slightly taller, such as the Charles Tellier (137 feet). These taller ships have to lower their masts and/or be brought under low tide conditions.

If an LEG tanker had been in the channel, would the DC-9 have crashed into it? According to our calculations, probably not, but clearance could have been a matter of only a few feet.

When an LEG ship is scheduled to pass through the channel, the airport will be notified.[11] When visibility is better than 2 miles, however, no advisories to aircraft are issued. A "regular" flight profile could bring a plane in as low as 100 feet above the mast of an LEG ship. This clearance seems to be in accordance with our visual observations. It is interesting to note that the airport considers vessel height of 132 feet or greater to constitute a hazard,[12] indicating it is aware of the danger posed by ships to aviation traffic.

Flights approaching Runway 33-L also go over the ship channel, further east. These flights do not seem to represent a hazard to LEG ships in transit.

There is no planning or coordination with the Federal Aviation Administration or the Department of Defense to

minimize the chance of a disaster resulting from the crash of an aircraft into an LEG ship or facility.

OFFLOADING GROUNDED LEG TANKERS

There are no contingency plans or pre-positioned equipment to partially offload and thus lighten an LEG ship that has gone hard aground in inland waters. Because LNG is extremely cold, special cryogenic equipment and ships must be used to offload it. LPG also requires special equipment for offloading. They must be planned for and positioned in advance if they are to be available on short notice.

COMPARATIVE RISKS IN SELECTED PORTS

Based on our examination of local harbor conditions, traffic density, and navigational features, we believe that the potential for the collision or grounding of LEG ships varies for each port. A detailed summary of port characteristics is given in Appendix VI-5. Here are our findings in brief:

- Because of the depth and wide expanse of Chesapeake Bay the approach to the terminal at Cove Point, Md., appears to be the safest of the ports we examined from a navigational standpoint. The transit of the lower Chesapeake Bay, with its large volume of commercial and naval traffic in and out of the Hampton Roads area, may be more of a problem.

- The Savannah River Channel's record of collisions and groundings is excellent to outstanding, but because the channel is serpentine, special precaution should be taken for the passage of LNG ships.

- The harbor depths and minimal current conditions indicate that the ports of Boston, Mass., and Staten Island, N.Y., are low to medium navigational risks.

- The proposed sites in Los Angeles Harbor and Oxnard, Calif., seem to have a relatively low navigational risk.

- Ports with long, narrow, or winding channels and dense shipping present high risks of collisons and groundings, as shown by the recent accident history of the Houston and Philadelphia channels.

- The Houston Ship Channel is one of the ports for which the Coast Guard has installed a Vessel Traffic Service (VTS). The service—manned by Coast Guard personnel—utilizes radar, radio, closed circuit television, and a computer information system for monitoring traffic in the 55-mile ship channel. VTS appears to be a valuable and effective aid in support of safe navigation, not only for LEG shipping but for all sea-going ships. Its use is not mandatory. However, Coast Guard personnel in Houston say that 95 percent of the ships do use it. Coast Guard personnel also told us that there are so many LPG barges operating in the port that the Coast Guard does not attempt to introduce all of them into the service.

- There is no specific requirement which spells out the conditions under which an LEG ship with a malfunctioning safety system should not be allowed to enter a port.

- Local COTP regulations are not necessarily reviewed by or approved by the Commandant, U.S. Coast Guard.

FINDINGS

Ship Design

- Cargo containment systems for LPG ships are not built to the same safety standard as LNG carriers. A double hull is not required.

- The critical speed and/or the displacement of the striking vessel would have to be much higher to penetrate an LNG vessel than to penetrate an oil tanker.

- To our knowledge, the only collision resistance analysis for LNG ships has dealt with spherical tanks. Yet the size and shape of these tanks, and the greater average transverse distance between the tank and the ship's side suggest that they are the least vulnerable of all designs in the event of a collision.

- Other designs, although presumably less collision-resistant, offer other safety advantages. The Conch II's self-supporting design, with its internal bulkheads, reduces free surface effects as well as

the amount of LNG spill in case of a tank rupture. The membrane designs provide good stability, good hull utilization, good visibility from the bridge, and a reduced windage area.

- The Coast Guard's proposed rules for LEG ship design do not require that tank design load calculations for membrane tanks include data on buckling. A relatively low overpressure of the cargo hold could cause buckling and possibly rupture of the primary barrier.

- LNG ships are vulnerable to sabotage through tampering with their safety relief valves and pressure control systems.

- Research suggests that a large fire on an LNG ship exposes present cargo tank insulation to temperatures that cause it to partly deteriorate or to melt.

Crew Training

- LEG ships need highly skilled operators for safe operation. Data collected on general marine casualties show that human error was a contributing factor in 85 percent of all casualties and operating problems.

- The CTIAC proposal being considered by the Coast Guard for Waterfront Facility Regulations for LNG in Bulk (which would revise 33 CFR Part 126) do not meet two of the criteria we believe necessary: team work

training, and training in trouble-shooting and emergency decision making.

- The rules for LNG terminal facilities proposed by the Office of Pipeline Safety Operations (49 CFR Part 193) cover operations only to a limited extent. They omit the same criteria as the CTIAC proposal, do not include training to provide a basic understanding of LEG behavior under all conditions, and do not specifically provide for hands-on training in fighting fires.

- Both sets of proposed rules will lack effectiveness, because neither the Coast Guard nor the Office of Pipeline Safety Operations plans to require that training programs for waterfront facilities be submitted for approval.

- Regulations for personnel qualifications of LPG waterfront facilities have not yet been proposed.

- The U.S. Coast Guard's proposed tankerman regulations will require training only for one or two crew members responsible for cargo handling, and will concentrate on loading and discharging operations. Instruction in emergency procedures is not required, and requirements for practical experience are inadequate. The proposed rules do not satisfactorily meet four of our eight criteria.

- Private training of both ship and shore personnel is characterized by the lack of regulatory guidelines

and the wide variety of training approaches.

- All of our criteria are satisfied collectively by the training programs of the Cove Point and Elba Island terminals. Some ship companies have designed training programs that far exceed the present and proposed requirements of regulatory bodies.

- Because of the variety of LEG ships and ports and because crew training depends so heavily on the company operating the ship and the flag under which it sails, we believe that studies done for one port, ship design, and flag cannot be used to judge the safety of any other combination of port, type of ship, and flag.

Ship Operations

- To effectively supervise LEG cargo transfer operations in U.S. waters and ports, the Coast Guard will need more money and manpower, revised regulations, and new plans and policies.

- Existing procedures for handling LPG need more attention. The Coast Guard has not issued any document, similar to CG-478, as guidance for the movement and transfer of LPG.

- LPG vapor has significantly different density, vaporization temperature, detonatability, and burning characteristics than LNG vapor. Current Coast Guard

operating procedures do not reflect these differences.

- No COTP has used his authority under 33 CFR Parts 125 to 127 to require that guards provided by the owner or operator of an LEG facility be in such numbers and of such qualifications as to assure adequate surveillance and to prevent unlawful entrance, nor to designate an LEG facility as a security zone.

- The Coast Guard does not require the officers and enlisted personnel who are involved in LEG ship operations to attend any specialized LEG courses. Although some Hazardous Materials Officers are well-qualified by experience or education, most have had little training in the hazards of LEG.

- The Coast Guard carries out a lengthy inspection before an LNG ship is permitted to enter Boston Harbor, but the inspection does not include the operating condition of ship control equipment such as steering engines, propulsion machinery, and electronic devices.

- If a safety subsystem is not in good working order, it is the COTP who decides whether the condition is serious enough to warrant keeping the ship out of the harbor. This arrangement is unsatisfactory for three reasons. (1) Since Coast Guard personnel do not have to be adequately trained in LEG properties, hazards, technology, and cargo operations, they may not be fully qualified to judge the significance or consequences of a malfunction. (2) Without specific requirements, there may be a tendency to give undue

weight to the large, certain, economic impact of the ship's delayed entry against the uncertain possibility of harm posed by a malfunction. (3) The lack of specific requirements results in confusion in the world shipping industry as to the U.S. Coast Guard's safety standards for admitting LNG ships.

- There are no contingency plans or pre-positioned equipment to partially offload and thus lighten an LEG ship that has gone hard aground in inland waters. Both LNG and LPG require special equipment.

- No specific plans exist for coping with a major LEG spill, and there appears to be little agreement among responsible officials as to what should be done, if one occurs.

- The Coast Guard's operational readiness inspections are not actual tests of the training and performance of LEG personnel and the efficiency of equipment.

- The Delta Airlines DC-9 which crashed into the seawall of Boston's Logan Airport on July 31, 1973 would probably have cleared an LNG tanker in the adjacent channel by only a few feet. We believe this represents an unnecessary and unacceptable risk.

- There is no planning or coordination with the Federal Aviation Administration or the Department of Defense to minimize the chance of a disaster resulting from the crash of aircraft into an LEG ship or facility.

RECOMMENDATIONS

Ship Design

To the Commandant, U.S. Coast Guard

We recommend that the Commandant, U.S. Coast Guard:

- require calculations on collision resistance for all vessels carrying hazardous cargoes.

- require an analytic and accurate determination of tank stresses be made on all types of LEG carriers to provide a better understanding of fatigue life and tank bursting and buckling pressures.

- require a double-hull for all LEG carriers.

- conduct a study of the different ways a tank might be ruptured by pressure. This could lead to development of protection systems, such as pressure switches that would automatically shut off relevant equipment in case of high differential pressures, in addition to existing safety relief valves.

- require precision position fixing equipment, bridge control of main engine, and collision avoidance systems as a means of improving the maneuverability

of gas carriers, many of which already have this kind of equipment.

- require that cargo containment systems be able to contain the cargo during and after a specified fire, and that insulation in critical places be able to withstand high temperatures; the Coast Guard should sponsor research if necessary to meet this goal.

Crew Training

To The Commandant, U.S. Coast Guard

We recommend that the Commandant, U.S. Coast Guard:

- expand the Coast Guard's proposed tankerman requirements to include a wider scope of training for all personnel involved in cargo handling, and enforce the expanded requirements.

- include in the Coast Guard's training requirements for LEG marine terminals and ships the 8 criteria we list in the Training Criteria section.

- continue to require that the deck officer and engineer in charge of cargo operations aboard U.S. flag LNG ships be non-watchstanding, and work through IMCO for similar requirement for foreign flag LNG ships.

- assure that licensed officers are in compliance with codes which limit their working hours (46 USC 235 and 46 USC 673).

- assure that employees and advisers who write and those who enforce training regulations have a thorough understanding of LEG ship operations and LEG properties.

- assure that any LEG safety analyses of a particular port be based on studies of that specific port and the type and nationality of ships used.

- continue the Coast Guard's efforts to bring about the adoption of new IMCO training standards for ship personnel.

To the Secretary of Transportation

We recommend that the Secretary of Transportation through the Office of Pipeline Safety Operations:

- require and enforce for LEG terminal personnel the same 8 training requirements we have recommended for LEG ship personnel, possibly including the licensing of supervisory personnel.

- consult with the U.S. Coast Guard about the means both agencies could employ to familiarize terminal and ship personnel with each other's LEG operations.

To the Secretary of State

We recommend that the Secretary of State:

- give strong support to the Coast Guard's efforts to bring about the adoption of new IMCO training standards for ship personnel.

To the Commandant, U.S. Coast Guard

We recommend that the Commandant, U.S. Coast Guard:

- issue a policy document for LPG, similar to CG-478 for LNG. The document should clearly reflect the differences between LPG and LNG in density, vaporization rate, detonatability, and burning characteristics. The policy should be mandatory except where differences in port conditions clearly make flexibility desirable.

- vigorously exercise the Coast Guard's authority, pursuant to 33 CFR Parts 125 to 127, to improve security at LEG facilities adjacent to navigable waters. In particular, it should enforce subsection 126.15(a) and require owners and operators of waterfront LEG facilities to have guards in such numbers and of such qualifications as to assure adequate surveillance and to prevent unlawful entrance.

- make the guidance in CG-478 mandatory, except where differences in port conditions clearly make flexibility desirable.

- establish a formal, mandatory training and qualifications program for officers and enlisted personnel involved in LEG ship operations.

- require an examination of the operating condition of ship control equipment such as steering engines, propulsion machinery, and electronic devices as part of its inspection of LEG ships before they enter a U.S. port.

- issue specific requirements that spell out which faults are sufficiently serious to prevent a ship's entry into a U.S. port.

- require the preparation of contingency plans and the pre-positioning of equipment to partially offload an LEG ship that has gone aground in inland waters.

- require the preparation of specific plans for coping with a major LEG spill, both when the vapor ignites at the ship and when it does not.

- require that surprise operational readiness inspections be conducted, including simulating serious problems, to evaluate the LEG personnel and resources assigned to COTP's.

- review local port regulations to assess their adequacy.

- arrange with the Federal Aviation Administration and the Department of Defense to prohibit landing and taking off planes from flying low over LEG tankers and storage tanks.

- require pressure-activated switches on LEG ships entering U.S. waters that automatically shut off relevant equipment in case there is too high a

differential pressure between the cargo tanks and the atmosphere, or between the cargo holds and the atmosphere.

- improve control of ships carrying hazardous cargo in U.S. coastal waters and harbors through selective implementation of Vessel Traffic Services, and use both Notices to Mariners and local security broadcasts when LEG ships are in transit.

To the Administrator, Federal Aviation Administration

We recommend that the Administrator, Federal Aviation Administration:

- halt landing approaches to Runway 4-R of Logan International Airport in Boston during the time an LEG ship is in transit in the ship channel beneath the flight path. (Following our recommendation, the Federal Aviation Administration plans to prohibit aircraft from flying directly over large LEG vessels to land on Runway 4-R.)

AGENCY COMMENTS AND OUR EVALUATION

The detailed comments of the Departments of Commerce and Transportation on this chapter deal principally with regulations and the hazards of overpressure, fire, and collisions.

Regulations

1. Commerce states:

> ". . .The thrust of the GAO report on directives is that hard and fast rules need to be established and that these safety rules must be applied rigidly in all instances. We disagree. We believe that a more flexible approach with the Coast Guard's Captain of the Port having the final decision based on regulations, guidelines, experience and the events at hand is proper and has proven effective in the past. . ."

DOT makes a similar comment.

GAO response:

We do not suggest totally rigid regulations. We suggest, rather, that the Coast Guard guidelines on LNG be made mandatory except in instances where flexibility is clearly desirable. In those instances the Captain of the Port would be the controlling authority.

2. DOT makes the following comments on our recommendations that the Commandant of the Coast Guard issue a similar guideline statement on LPG:

> ". . .The report emphasizes the fact that CG-478 addresses only LNG and not LPG. The reason for

this is the inordinate public, Congressional, and news media interest in LNG. The Coast Guard found it beneficial to publish this information to satisfy repeated inquiries. The Coast Guard is aware of the hazards of LPG and many other liquefied gases, but because there has not been the same overwhelming cry for information, it has not been deemed necessary to publish a pamphlet for each liquefied gas carried in bulk marine shipments. . ."

". . .The Coast Guard is revising CG-478 and will include a chapter on LPG. . ."

GAO response:

DOT seems to be of a divided mind on this issue. In these comments DOT argues that there is no present need for publishing LPG guidelines, but it announces that it also plans to publish them.

3. DOT states:

". . .Since Coast Guard regulations and operating procedures are all directed at preventing the release of liquefied gases, it is unclear how the properties of LPG in the vapor phase (i.e., after release) should influence these procedures. . ."

GAO response:

This is not true. Part II of the Coast Guard, Port of Boston LNG-LPG Operation/Emergency Plan concerns procedures to be followed after an LNG/LPG incident has taken place.

4. DOT states:

> ". . .{The} instruction, training, experience {of key Coast Guard personnel} combine to provide a COTP with sufficient expertise to make rational decisions concerning vessel and facility safety. . ."

GAO response:

This is contradicted by our interview with the Hazardous Materials Officer stationed at a major LNG port, which is included in this chapter.

5. In another comment DOT does not contradict our statement that, although local port regulations call for a minimum of 3 tugboats, the Lucian was assisted by only two on the transit we observed. DOT does say, however, that:

> ". . .Perhaps the fact that LUCIAN is a much smaller vessel (29,000 m^3 compared to the 50,000 m^3 DESCARTES) was considered when allowing two tugs {instead of} three. . ."

GAO response:

The Coast Guard's LNG-LPG Operation/Emergency Plan for the Port of Boston requires that "a minimum of (3) tugs of suitable horsepower will attend the needs of each LNG ship regardless of size." (The words are underlined in the Operation Plan.)

Overpressure

6. Commerce states:

> ". . .Even where the safety valves were locked closed, a tank would not rupture anywhere from a few days to a couple of weeks depending on the type of containment system. . ."

GAO response:

This is true only if pressure is built up solely by normal evaporation. It does not contradict our suggestion that saboteurs could manipulate the pressure control system to overpressurize the cargo tanks or cargo holds.

7. DOT states:

> "The Coast Guard does not directly require bursting pressure calculations for LNG tanks or pressure vessels. The design of an LNG tank (or pressure vessel) inherently limits the maximum allowable stress experienced by the tank to a specified percentage of the ultimate strength of the tank material, leading to a safety factor of at least four on tank bursting pressure. Requiring the submission of a calculation for the actual bursting pressure would be superfluous."

The issue is not the maximum allowable stress experienced under normal conditions but the stress that could be produced by someone purposely misusing the pressure control systems to overpressurize the cargo tanks or cargo holds. It is necessary to know the bursting

pressure in order to tell how long it would take a saboteur to rupture a tank by such means and to devise appropriate protective measures.

8. DOT also states:

> ". . .There are high pressure alarms on the ship to indicate excessive tank pressure. There is no 'relevant equipment' to be shut down in the event of high pressure on the LUCIAN. The only equipment affecting tank pressure on the LUCIAN serves to lower tank pressure; therefore why shut it down?. . ."

> ". . .Finding 6 is oversimplified and indicates a basic minunderstanding of liquefied gas ship design. There are many ways that a gas ship could be sabotaged--just as there are many ways that any ship could be sabotaged. The method indicated is probably one of the most unlikely. It is very difficult to tamper with relief valves to the extent necessary to cause catastrophic destruction of the ship. Pressure alarms are available to alert the crew that something is wrong. Pressure control systems on gas ships are installed to reduce pressure, not increase it. . ."

GAO response:

High pressure alarms can be disabled. The statement that the only equipment affecting tank pressures serves to lower it is not true. Two systems raise pressure. The system for purging cargo tanks sends vaporized LNG into the tanks, and the emergency cargo discharge system uses a compressor to overpressurize the tanks after the safety valves are manually closed.

Fire

9. Commerce states:

> "It is unlikely that insulation, except for that on the tank dome, would be exposed to fire except where the hold was already breached."

DOT states:

> ". . .a cargo fire around an LNG ship is described while the findings mentioned a fire on the LNG ship. Only the tank dome extends above the deck and the safety valve calculations consider the fire situation. . ."

GAO response:

As ship drawings in Appendix VI-1 illustrate, the statement that "only the tank dome extends above the decks" is not true for three of the four types of LNG ships -- Moss-Rosenberg, Technigaz, and Gaz Transport.

10. DOT states:

> ". . .Cargo containment systems are required to be able to withstand fire exposure without failure. Cargo vapors, however, will be vented by relief valves. Insulation is normally protected by steel sheathing or the vessel's hull. The scenario the recommendation envisions apparently is one where fire is surrounding the ship, the inner and outer hulls have been breached, and the tank insulation is exposed. To design to such criteria is not practical. . ."

GAO response:

We did not suggest that insulation would be exposed directly to fire. We suggested that it might be exposed to high temperatures that could cause it to deteriorate. The Det Norske Veritas analyses discussed in the "Fire Hazard" section show that in a fire where neither the outer nor inner hulls has been breached, the insulation might still be subjected to temperatures far higher than those needed to decompose it completely.

Collision

11. Commerce states:

> "Presently, there are no requirements or criteria for determining what {collision} resistance is needed. . .The assumptions concerning the structural configuration, speed, angle of incidence, and a number of other factors make such calculations largely an academic exercise. . ."

GAO response:

We do not agree. We are disturbed by the lack of requirements or criteria for determining what resistance is needed, and we believe collision analyses can be done with sufficient precision to aid rulemaking and design.

12. DOT states:

> ". . .It is not clear what would be achieved with similar studies on other designs. The minimum distances between outer hull and tank boundaries are, by regulation, the same for all types. The difference lies in some variation in

probability that a tank boundary will be involved with certain penetrations onto the LEG vessel. . ."

GAO response:

The comment is not relevant. We recommend that the Coast Guard calculate collision resistance for all vessels carrying hazardous materials. Vessels of different design have different tank suspension systems, and these affect their collision resistance. Det Norske Veritas calculated the resistance of LNG ships with spherical tanks. We believe the Coast Guard should develop similar data for all ships carrying highly hazardous cargoes.

13. DOT states:

". . .Delete the sentence, 'However, data on buckling of membrane designs are not required.' Membranes by definition cannot withstand compressive loads. . ."

GAO response:

The buckling of the Polar Alaska's membrane suggest that it would be worthwhile to know what pressures will buckle particular tank construction.

OTHER COMMENTS

LEG Crew Training

14. Commerce states:

". . .The draft report stresses the need for formal training of all shipboard personnel

having LEG responsibilities and in this we concur. Eight criteria for training are given. While the majority of the criteria are acceptable and reasonable, we find that the references to 'simulator' and 'simulated environment' to be vague with regard to meaning. Simulators can be extremely costly, both to create and to operate. . ."

GAO response:

Several simulators are in operation, and we believe their cost is justified by their value in training key personnel in critical areas of safety. The value of simulators has long been recognized in training aircraft pilots.

Aircraft Collision Hazard

15. Commerce states:

". . .The extent of control of air traffic alluded to in the report is excessive. The fact that one aircraft crashed in making a landing should not lead to the conclusion that it can be expected that additional crashes will happen further from the airport in the ship's channel. . ."

GAO response:

The Federal Aviation Administration, on the other hand, agrees with our recommendation. FAA states:

"We agree that there is a potential for widespread disaster in the event of an accident involving an aircraft landing on Runway 4R at Boston and a Liquefied Energy Gases (LEG) ship in transit through the shipping channel.

"The air traffic control tower at Logan International Airport has a program for detection of ships in Boston Harbor. The system makes use of radar, closed circuit television, and verbal communications to detect, track, and identify ships with tall masts. Such vessels can be an obstruction to aircraft making instrument approaches to Runway 4R. We will expand our tall mast detection program and clear aircraft landing on Runway 4R at Logan Airport so that the aircraft will not fly directly over large LEG vessels operating within the boundaries of the instrument landing system protected airspace trapezoid. The Captain of the Port, U.S. Coast Guard, has assured us the U.S. Coast Guard will provide sufficient advance warning of the LEG vessels with cargo. Implementation of the service will require at least two months for completion of procedural arrangements and controller training.

"We are confident that establishment of this additional service will meet the GAO safety recommendations and reduce to the minimum any chance of incident between aircraft and surface vessels."

LNG Vapor Boiloff

16. DOT states:

". . .the cited value of 12,000 cubic meters of liquid per hour is much larger than any reasonable estimate. . ."

GAO response:

The final report refers to the 12,000 cubic meters of LNG vapor that can be generated by a ship's vaporizer. This value is from the specifications for General Dynamics' LNG ships.

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1. Several blueprints and operation manuals for gas carriers.

2. "Whither the LNG Ship," W. B. Thomas; paper given at Royal Institution of Naval Architects, October 1974, London.

3. Update: Domestic LNG Vessel Construction, T. G. Conners; Maritime Administration, May 1977.

4. U.S. Gas Shipbuilding—Present and Future Prospects, E. M. Hood, F. P. Eisenbiegler, A. O. Winall and M. Lee Rice; a panel discussion at GasTech Conference, October 1976, New York City.

5. Risks Associated with an LNG Ship Operation, P.S. Allan, A.A. Brown and P. Athens; paper given at Fourth International Symposium on Transport of Hazardous Cargoes, October 1975, Jacksonville.

6. LNG Ship Safety Enhanced by Research and Development, J. L. Howard and R. Kvamsdal; paper given at SNAME Spring Meeting, May 1977, San Francisco.

7. Analysis of LNG Marine Transportation for the Maritime Administration, Booz-Allen Applied Research, Inc., November 1973, COM-74-11684.

8. Gas Carriers—Effects of Fire on the Cargo Containment System, T. K. Authen, E. Skramstad and J. Nylund, GasTech 1976, New York City.

9. The Coast Guard's authority to require these safety measures by an LNG vessel or waterfront facility owner or operator comes from 33 CFR 6.04 and 6.14.

10. Aircraft Accident Report, National Transportation Safety Board (NTSB-AAR-74-3), Delta Airlines DC-9, Boston, July 31, 1973.

11. Prior to and during an LEG ship's harbor transit a security broadcast will have been issued by the Coast Guard on Channel 16 FM. The Coast Guard will also notify Logan (Massport) Fire Department of each LEG vessel transit. Logan Fire Department is responsible for notifying the flight tower of any incident that possibly could affect flight patterns. In addition to these communication channels, the airport uses radar and closed circuit television to detect, track, and identify ships with tall masts.

12. Letter to Airmen 77-3, Subject: Boston Tower Advisories of Tall Masted Vessels.

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Handbook for the Development of Qualifications for Personnel in New Technology Systems, Operations Research, Inc., February 1976, AD-A027-525.

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CHAPTER 7

TRUCK SHIPMENTS

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LNG trucks that move routinely through highly populated cities are vulnerable to accidents and sabotage that could cause major damage. The far more extensive trucking of LPG, in single-walled trucks under pressure, is also vulnerable to major accidents and sabotage. The main features of the trucks are shown in Figures 7-1a and 7-1b.

LNG TRUCKING

Each LNG truck working out of the Distrigas terminal in Everett, Massachusetts, carries 40 cubic meters of LNG in a vacuum insulated tank at -260°F. More than 90 such truckloads may come out of the Everett terminal in a single day. The gas companies which purchase LNG from Distrigas Corporation transport it from the Everett terminal to their own satellite tanks which tie into their distribution systems. When an LNG ship arrives at the terminal, the gas companies notify their truckers who usually run every available LNG trailer on a 24-hour schedule until the transfer is completed. The Distrigas contracts call for customers to remove half of their allotment within the first 10 days after the LNG ship's arrival and to remove the second half before the ship returns with another cargo (approximately one month).

LNG can be hauled by companies which have Interstate Commerce Commission (ICC) authority for the bulk transport of petroleum products or liquid chemicals. These companies can lease the trucks and drivers of other companies which do not have such authority. The ICC also certifies companies specifically for LNG transport.

The ICC has granted specific LNG rights in the Northeast to three companies: Gas Incorporated,[1,2]

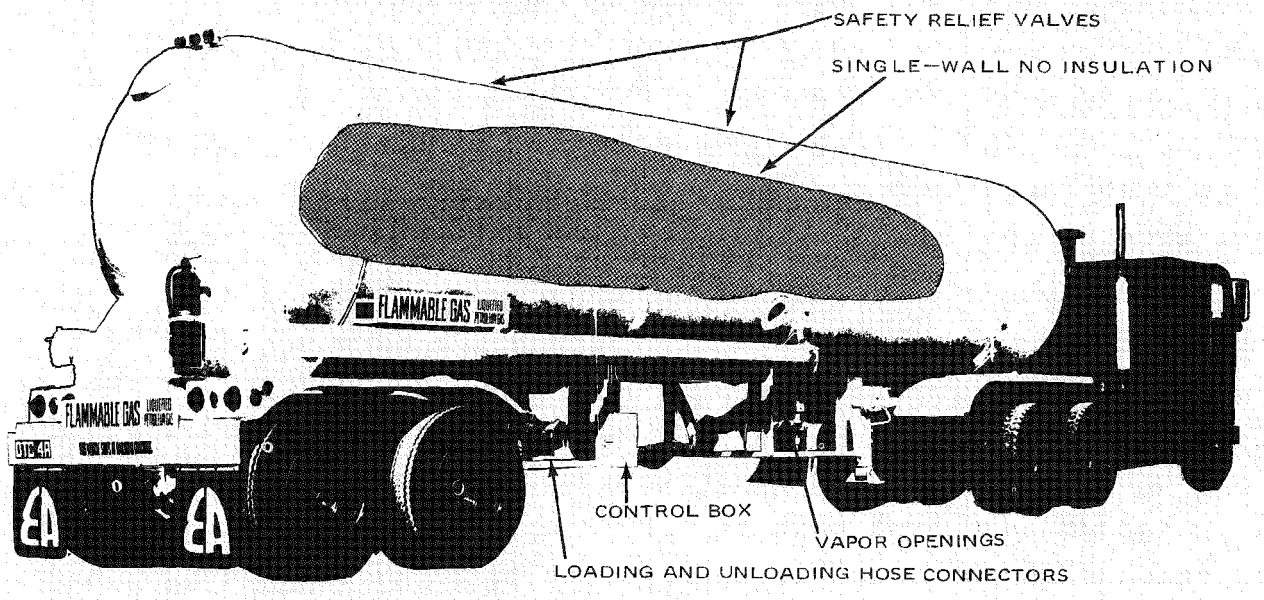


Fig. 7–1a **CROSS–SECTION OF AN LPG TRUCK TRAILER**

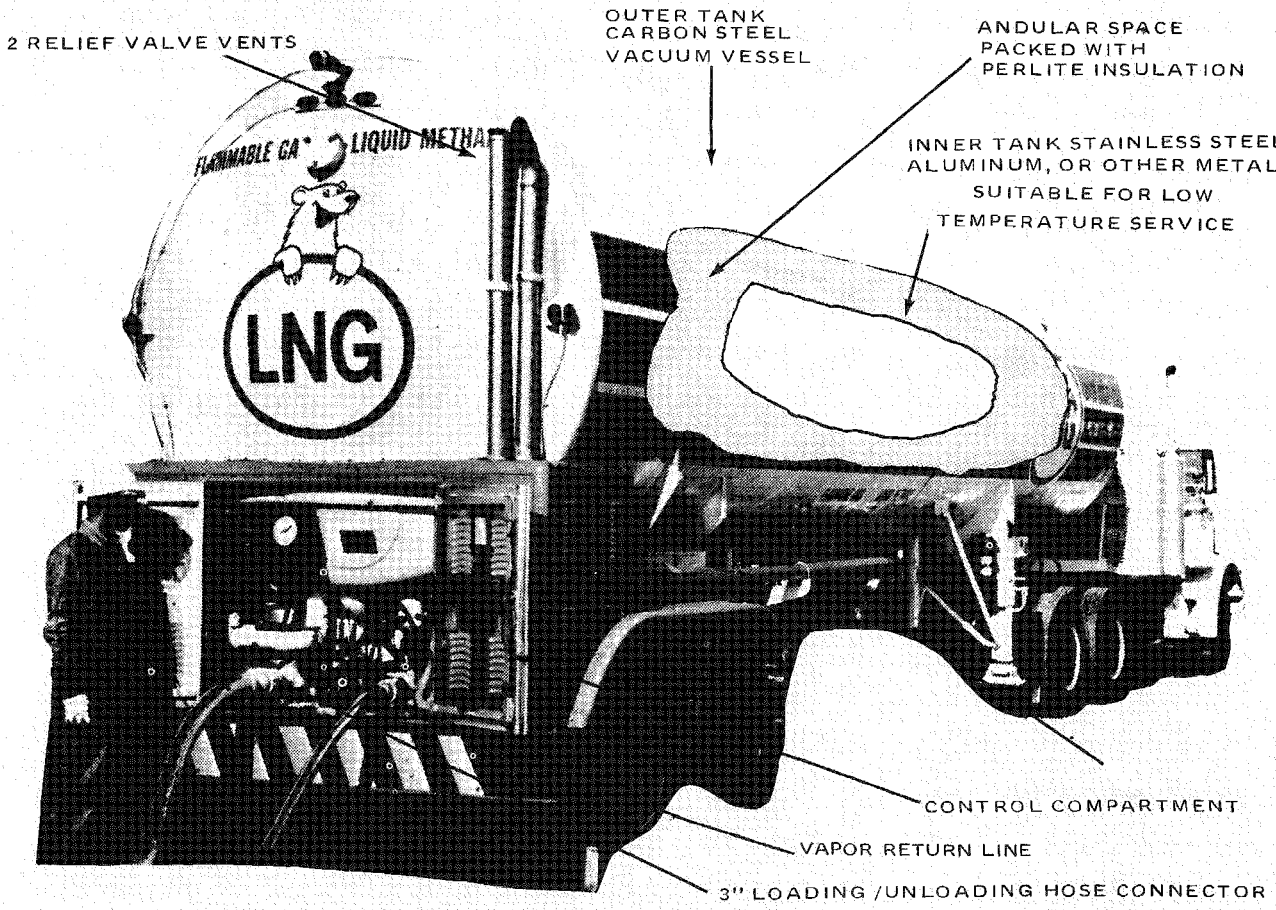


Fig. 7–1b **CROSS–SECTION OF LNG TRUCK TRAILER**

Indianhead, and Capitol Truck Lines. They all own their own trailers. Most LNG trucking in the Northeast under ICC authority for bulk transport of petroleum products is done by either Chemical Leaman or Gault Transportation. Chemical Leaman[3] for the most part uses its own tractors and specially trained drivers, but supplements its small fleet of cryogenic trailers by lease arrangements. While it does subcontract some business to "leased operators", Chemical Leaman deals directly with the gas companies in making arrangements for LNG transportation.

Gault Transportation Company[4] owns no LNG trailers and does all LNG business through "leased operator" arrangements with other trucking companies. In these cases, the gas company makes arrangements with a trucking company[5] which will operate under Gault's ICC certification. Gault assumes major financial responsibility in the case of an accident, provides liability insurance for injuries, fatalities, and property damages, and receives 10-15 percent of the trucking revenues. It is also Gault's duty to ensure that drivers are familiar with the Motor Carrier Safety Regulations of the Federal Highway Administration. In most cases, these "leased operators" have no LNG trailers but lease them from the gas company for which they are moving the LNG.[6,7] With this arrangement, the lessee is responsible for all aspects of the trailer including operation, maintenance, and vehicle insurance.

LNG trailers are far more resistant to ruptures than those carrying fuel oil or gasoline, but the potential danger from an LNG accident is far greater than from one involving a less volatile petroleum product. We believe that LNG should be hauled exclusively under a certificate

specifically for LNG.

An LNG trucker usually carries about one million dollars in liability insurance.[4,5,6,8] These policies name the gas company for which the gas is hauled as co-insured. The gas company also requires that the trucker, or the company holding the ICC certificate, carry additional liability insurance of $10-30 million.[1,3,4] The gas company may have additional liability insurance to cover the losses in a major catastrophe.[8,9]

The ICC does not allow companies transporting LPG to ship it by trucking subsidiaries. Such subsidiaries are considered separate entities in terms of accident liability. If a company does ship LPG by a subsidiary, the subsidiary automatically becomes a contract carrier which must meet full ICC financial and disclosure requirements.

In Massachusetts the tariff for LNG trucking is set by the State's Department of Public Utilities. Half of this revenue goes to the truck driver as salary, and another 10-15 percent passes to the common carrier. The remaining 35-40 percent goes to the trucking company.

Vulnerability to Human Error

Many trucking companies in the Northeast have viewed LNG transport as an auxiliary enterprise to keep men and equipment in use during the slower winter months. The erratic nature of this business has made drivers prefer the more regular hours and income of gasoline tank trucking.[1] Trained dependable drivers have therefore been hard to keep in the LNG business.

LNG truck drivers may be better trained and supervised if companies licensed by the ICC to carry LNG are not allowed to lease drivers and trucks from companies which do not have such a license.

It may be that the drivers' lack of experience was responsible for some highway accidents, since the high center of gravity of LNG trailers makes them difficult to handle and prone to rolling over.[1,10] With the increased availability of LNG in recent years, many companies have found LNG transport to be a full-year dependable business. This may improve the LNG trucking safety record.

Vulnerability to Accidents

Because LNG trailers have an inner and an outer tank with insulation in between, they are quite resistant to puncture and cargo loss. In several accidents they have withstood rollovers, head-on collisions, and fires which have destroyed the tractors. The trucks are also equipped with heavy rear bumpers which can withstand considerable impact.

Nevertheless, two accidents in 1971 which did involve cargo loss point up two vulnerable features. (1) While the tractor provides considerable protection in a head-on collision, a portion of the trailer face remains unprotected and vulnerable. (2) Even if the tank does not rupture, rear piping may be punctured. One of the accidents also demonstrates the role of human error.

The accidents occurred in Vermont[11] and New Hampshire.[12] In the Vermont countryside a tractor tire blew out at 50 mph. The driver lost control and the head

of the trailer hit a rock ledge on the side of the road. This tore a hole in the head of the trailer, which lost approximately 8 cubic meters of LNG. The remaining cargo could not be pumped out because the punctured tank could not hold pressure. The remaining LNG had to be slowly drained through several connected hoses into a nearby gully, where it vaporized and eventually dissipated. Fortunately, there was no ignition source and no nearby city sewers. An industry official involved in this emergency operation recently said that, while each accident had to be dealt with individually, an urban accident like this might best be handled in the same way by slowly dumping the LNG into the streets. He stated that pumps were neither safe nor available in most locations.[13] An industry group is currently looking at this problem.

The New Hampshire accident occurred a few months later when the driver "either fell asleep or blacked out for reasons unknown". His LNG truck ran off the side of the road, rolled over down an embankment, and finally landed on its wheels. The rolling apparently twisted the rear bumper and loosened some fittings in the control section at the rear of the trailer. The resulting LNG leak never ignited and was sealed off when representatives from the trucking company arrived. A DOT investigator found that the driver had been on duty 60 hours in 6 days, and had probably been driving 10½-11½ hours at the time of the accident.[12] The DOT report noted that the driver had falsified the Driver Log, and that other LNG truck drivers were also violating limits on hours of service.

A similar (insulated, double-wall) cryogenic trailer carrying ethylene crashed into a brick house in Spain in 1974. The small amount of material that escaped eventually

caught fire, causing the tank and remaining cargo to explode. A similar accident involving an LNG trailer is possible.[14]

Since LNG has a low density, LNG trailers can be built higher than most tank trucks to provide extra volume, without violating the legal limits on length, width, and cargo weight. The resulting high center of gravity[10] makes them particularly susceptible to rolling over in high-speed turns, when swerving to avoid other vehicles, or when struck from the rear.

An ammonia tractor trailer which rolled over a bridge barrier in Houston (1976) had a center of gravity of 68.5 inches high.[15] A typical propane tractor trailer's center of gravity is 84 inches high.[16] An LNG tractor trailer has a center of gravity 93 inches high.[12] There have been at least 12 LNG trailer accidents, as described in Appendix VII-1.

While the LNG trailers have been able to withstand the few rollovers that have occurred so far, tank rupture is still quite possible in such accidents. If a rolled LNG truck was struck by a fast moving car or truck it might cause cargo loss and fire. If a truck went over the barrier of an elevated roadway and fell to the street below it would almost certainly rupture. This is particularly significant since the majority of LNG trucked out of the Everett facility travels through Boston on the elevated Southeast Expressway.[13] These trucks pass within a few blocks of the crowded Government Center area, which is laced with sewer and subway tunnels as well as other subterranean structures. Since very cold natural gas is heavier than air, both the LNG and the vapor will go down

into sewers, subways, and basements through any opening available. Due to its very low boiling point, the LNG will quickly vaporize, generating a pressure that will spread the invisible, odorless gas throughout the structure. In enclosed spaces, appropriate mixtures of natural gas and air are explosive.

In the first 6 months of 1977, there were four serious accidents involving tractor-trailer trucks on the Southeast Expressway.[17] One of these trucks went over the guard rail, plunged to the streets below, and overturned. Although none of these trucks were carrying hazardous cargoes, they could have been. If the truck which fell had been carrying LNG instead of paper products, the consequences could have been very serious.

Trucking LNG over expressways is not unique to Boston. In New York City during February, 1977, for example, LNG was trucked across the Goethals and Verranzano-Narrows bridges and the Staten Island Expressway. A Brooklyn Union Gas spokesman noted that although the trucking of LNG may be somewhat unusual for New York City, it is common throughout the country.[18]

Vulnerability to Sabotage

LNG trucks are highly vulnerable to mischief and sabotage. A large unlocked cabinet houses the control piping and valves. Inside, a large, clearly labeled main valve is attached to an exit pipe which is loosely capped by an easily removed dust cover. Opening the main valve allows the entire contents of the trailer to run out on the ground. A remote controlled shut off valve is also built into this line. Regulations (49 CFR 177.840 (9)) require

that the valve be closed during transportation, but we were told that it is routinely left in the open position. If the "pressure building valve" (a smaller but well-labeled valve) were opened, the tank would empty at a rate of 350 gallons per minute (total tank load in 1/2 hour). Some trailers also carry flexible hoses to connect to the exit pipe and use of these hoses can direct the LNG flow into any nearby opening. However, since most storage areas have hoses, many trucks do not bother to carry them.

No special effort is made to prevent LNG trucks from being hijacked. When a driver leaves the Distrigas terminal, for example, he is entirely on his own. There is no surveillance, scheduling, or communication system associated with his trip. Drivers are given no protective equipment or instructions to deal with a hijacking. LNG trucking firms believe that the LNG cargo is not marketable and therefore not attractive to hijackers.

If two trained drivers were required for each tractor, safety would be improved. One could remain with the trailer at all times in the event of an accident or maintenance problem.

There have been no cases of LNG hijacking, but vandalism and sabotage of energy and petrochemical facilities is common. LNG is an increasingly publicized commodity. It would not take great scientific knowledge to realize that a great deal of damage could result from dumping a 40 cubic meter truckload of LNG into sewer lines or subways. LEG truck sabotage is also discussed in Chapter 9.

Hazards of Spills into Sewers

The National Fire Protection Association in 1975 published a list of recent accidents involving explosions in underground structures. These accidents are described in Appendix VII-2.

The accident on the list involving the most casualties is the one in Cleveland, Ohio, in 1953. One person was killed and 58 were hospitalized after a tremendous underground explosion in a combination storm and sanitation sewer.[19,20]

The Cleveland disaster of October, 1944, in which LNG spilled into sewers and basements, was not on the list. The Bureau of Mines investigation[21] found that the gas from the LNG "mixed with the air in the storm sewer system and formed an explosive mixture which subsequently ignited." One-hundred thirty people were killed and millions of dollars of damage was done. The Bureau of Mines report concluded that: "Extreme precaution should be taken to prevent spilled liquefied gas from entering storm sewers or other underground conduits."

An LNG truck carries 40 cubic meters. Vaporized and mixed with air in flammable proportions, the resulting mixture could fill a 6-foot diameter sewer line for a distance of 110 miles.

The subway system of Boston consists of 16-foot diameter tunnels.[22] A flammable air-gas mixture from one LNG truck could fill such tunnels for 16 miles, virtually the entire subway system of Boston. In practice the vapor would leak out of openings and would not go this far.

Since some methane is normally found in sanitary sewers, all buildings are required to have a trap in their sewer lines leading to the sewer system.[23] The trap is a U-shaped pipe which normally contains a few inches of water as a seal to prevent the backup of gas into the building. An LNG spill into a sanitary sewer would vaporize very quickly, generating high gas pressures which might blow out the water seal and lead to easy gas access into basements.

The entrances to Boston's Sumner and Callahan tunnels are only a few hundred feet downhill from the elevated Southeast Expressway. Although LNG trucks are not allowed in these tunnels, a major spill could lead to the flow of LNG or cold vapor into both of these openings.

LPG TRUCKING

Pipelines handle most long-distance transportation of LPG, but in 1976, 3.4 percent of long-distance LPG movement (2.6 million cubic meters) was completed solely by trucks. The average haul was 122 miles.[24,25] Trucks carry at some time over 90 percent of the LPG produced in the U.S., and most local distribution is by truck. Truck shipment is the only practical means of delivery for many LPG users, especially small ones.

Since 1963, about 4,600 LPG tank trucks with capacities between 28 and 46 cubic meters have been manufactured.[24] These are mostly class MC 331 tanks, as specified by 49 CFR 178.337, and most of them are still active today. There are also many smaller tank trucks.

Accidents

In 1976 there were 25,666 commercial motor carrier accidents; of these, 1,427 involved hazardous materials and led to 168 deaths, 1,385 injuries, and 14.1 million dollars worth of damage. In 475 accidents, some hazardous material was released. LPG is one of these hazardous materials and is involved in about one percent of all hazardous materials accidents. Statistics for previous years are very similar.[26]

The dangers inherent in LPG truck accidents are illustrated by the following two examples.

At 2:30 p.m., May 24, 1973, an MC 331 tractor-semitrailer carrying 34 cubic meters of LPG was traveling north on U.S. Route 501, a winding, two lane mountain road above Lynchburg, Virginia.[27] While rounding a 48 degree curve to the left at 25 miles per hour, the driver moved the truck into the opposite lane in order to maximize the turning radius. However, the driver soon saw a car approaching in this lane, and, in a violent maneuver to return to the proper lane, the truck overturned and slid twenty-five feet into a rock outcropping. The impact ruptured the tank and the LPG began to evaporate, the vapor spreading along the road and down the hill adjacent to the roadway. Approximately two minutes later, the vapor cloud was ignited and formed a fireball about 135 yards in diameter, enveloping the fleeing driver and three occupants of a house down the hill from the accident. Radiant heat burned three more people who had stopped on the road because of the mishap. The house, several outbuildings, and about twelve acres of wood also burned down.

A much more destructive accident occurred near Eagle Pass, Texas, on April 29, 1975.[28] At 4:20 p.m., a 38 cubic meter, MC 330 tractor-semitrailer, filled with 33 cubic meters of LPG, heading west at 55 miles per hour on U.S. Route 277, swerved to avoid a slowing car. The tank separated from the tractor during the evasive maneuvers, overturned, crashed into the concrete headwall of an irrigation canal, and split open. Two explosions quickly followed: the front section of the tank rocketed 1,650 feet and demolished three mobile homes; the aft section broke into three pieces which each flew about 800 feet. The resulting fireballs destroyed a nearby used car facility and fifty cars. In all, 16 people were killed and 35 were injured.

LPG trucks are subject to many of the hazards which can affect LNG trucking. For example, LPG trucks have a destabilizing high center of gravity, though not as high as LNG trucks. LPG trucks have exterior valves which are vulnerable in accidents. Furthermore, LPG tanks are pressurized, have single wall construction, and have no insulation. This makes them more vulnerable to cracks and punctures than LNG trucks, and more likely to explode in fires.

In addition to traffic accidents, many incidents happen during deliveries or during repair work to trucks.[29] Drivers sometimes pull the truck away after making a delivery without disconnecting the supply hose.[30] Often an accident of this sort releases only a few gallons of LPG which harmlessly disperse. However, the conjuntion of a spill and an ignition source can be disasterous. Valves are sometimes accidently or mistakenly opened, with similar results.

LPG is often delivered to populated areas. An accident in West St. Paul, Minnesota, on January 11, 1974, illustrates how residential areas can be affected.[31] Around midnight a tank truck carrying 36 cubic meters of LPG was transferring its load into a 42 cubic meter storage tank serving an apartment complex. Auxiliary equipment to the tank included three vaporizers. After twenty minutes of pumping, a leak developed. LPG vaporized and was ignited by one of the vaporizers. Firemen responded to the resulting fire and attempted to shut off the flow of LPG. Before they could stop the flow, a connecting hose burned through and created a torch directed on the storage tank. The firefighters worked to establish cooling sprays on the tank and to evacuate nearby apartment buildings. Thirteen minutes later, a BLEVE (Boiling Liquid Expanding Vapor Explosion) occurred. Sections of the storage tank demolished apartments and fire vehicles. Four people were killed, ten injured, and large sections of three apartment buildings were destroyed. The local fire department had detailed plans to deal with an LPG fire at this location, but snow conditions prevented carrying them out.

Sabotage

LPG trucks are even more vulnerable to sabotage than LNG trucks because they have a single wall and are under high pressure. LPG is heavier than air at ambient temperatures, thus it will flow down into sewers, subways, basements, or any other opening below ground. The gas is odorless and colorless, and can detonate.

Misleading Odorization Labels

At a California LPG storage terminal we observed trailer trucks, carrying non-odorized propane, that were painted with large signs saying "ODORIZED". We were told by one driver that this was common practice in California, because the signs have to be painted on the trucks, although the trucks carry odorized or non-odorized propane at random. The implications of this are serious. Firemen approaching an accident which had caused a leak from such a truck would not be able to see the extent of the invisible, explosive cloud. Seeing the sign "ODORIZED" they would assume that they could smell any cloud that was concentrated enough to burn or explode. Such misinformation might cause a large number of unnecessary deaths. All signs should indicate that the LPG might not be odorized.

LEG TRUCK MOVEMENT

LEG truck movement is not generally restricted. Local officials can prohibit LEG movement through tunnels, but further restriction is governed by Federal regulation 49 CFR 397.9, which states:

> "Unless there is no practicable alternative, a motor vehicle which contains hazardous materials must be operated over routes which do not go through or near heavily populated areas, places where crowds are assembled, tunnels, narrow streets, or alleys. Operating convenience is not a basis for determining whether it is practicable to operate a motor vehicle in accordance with this paragraph."

Local Federal Highway Administration officials apply this regulation in negotiating an agreement with trucking companies and local governments on satisfactory routes for

regular truck movement. Enforcement, as such, or legislation specifically prohibiting certain routes is usually left to local governments.

It is virtually impossible for action to be taken on irregular or infrequent truck shipments. Furthermore, the above regulation is limited by the tacit recognition that once a need for LPG or LNG has been established, it has to be delivered. The safest possible route is not necessarily a safe one.

The ICC regulates entry into the interstate trucking industry. Certificates issued by it have not restricted LEG truck routes. Instead, ICC has granted "irregular" route authority.

FINDINGS

- LNG truck trailers have a higher center of gravity than most tank trucks, which makes them particularly susceptible to rolling over. This leaves the tank vulnerable to collisions with other traffic.

- Because LNG trailers have an inner and outer tank with insulation in between, they are quite resistant to puncture and cargo loss.

- A portion of an LNG trailer face is not protected by the tractor and is vulnerable to head-on collisions with other traffic or fixed objects.

- LPG trucks have a high center of gravity, although not as high an LNG trucks.

- LPG trucks are more vulnerable to cracks and punctures and more likely to explode in fires than LNG trucks.

- Many LPG accidents occur during transfer operations.

- LPG trucks in California sometimes carry painted signs saying "ODORIZED", when their LPG is not odorized. In the event of an accident, this misinformation could lead to many otherwise avoidable casualties.

- By opening a few valves in an unlocked cabinet at the back of an LNG trailer, anyone can empty the tank at a rate of 350 gallons per minute. Using the flexible hose that some trailers carry, one can direct the LNG into any nearby opening. LPG trucks are equally easy to empty.

- LNG trucks are vulnerable to sabotage. LPG trucks are more vulnerable than LNG trucks.

- LEG trucking companies take no precautions to prevent hijacking or sabotage.

- The intentional urban release of LEG from one or more trucks by terrorists could cause a catastrophe.

- LEG truck accidents occur frequently and often involve losses of life and property.

- Driving LEG trucks on elevated urban highways is very dangerous because one might go through the guard rail and split open on the street below. This could fill sewers, highway tunnels, subways, and basements with invisible, odorless, explosive gas. The LNG traffic on the Southeast Expressway through Boston is an example.

- The 40 cubic meters of LNG in one truck, vaporized and mixed with air in flammable proportions, could fill 110 miles of 6-foot diameter sewer line, or 15 miles of a 16-foot diameter subway system.

- ICC certificates for LEG trucking have not restricted truck routes.

- LEG trucks move routinely through large cities.

CONCLUSION

- The dangers present in trucking LEG are far greater than those involved in trucking petroleum products such as fuel oil, naphtha, and gasoline. The trucks are highly vulnerable to sabotage, hijacking, and certain types of accidents. LEG trucking in densely populated areas is very dangerous.

RECOMMENDATIONS

We recommend that the Interstate Commerce Commission:

- not allow LEG to be carried under a certificate for petroleum products. ICC should require a special certificate for LNG and a separate special certificate for LPG. This would limit LEG transportation to fewer carriers with more experience.

- not allow trucking companies which are licensed to carry LNG to lease trucks and drivers of other companies which have not demonstrated their competence to the ICC.

We recommend that the Secretary of Transportation:

- prohibit trucking of LEG through densely populated areas and any areas that have features which are very vulnerable to a major LEG spill (e.g., sewer systems, tunnel openings, subways) unless delivery is otherwise impossible. DOT should also give particular attention to restricting travel on routes with highway configurations which make tank rupture accidents likely (e.g., elevated roadways, overpasses, high-speed traffic, roadside abutments).

- require that the relatively vulnerable front end of LEG trailers be protected with heavier steel, and cushioning material or shock absorbing equipment. Similarly protecting the entire tank should be considered.

- require that the cabinet housing the control valves of LEG trucks and the valves themselves be kept locked.

- forbid LNG trucks to carry hoses. The hoses should remain attached to the storage facilities.

- require LEG hoses to have positive coupling devices which would override a required check valve in the exit line. The check valve would prevent the outflow of the fluid into anything other than the special coupline hoses.

- develop emergency procedures, teams, and equipment to deal with LEG trailer rollovers and spills. Equipment should include empty trailers and portable

pumps suitable for transferring LEG from a ruptured vessel. Different equipment will be needed for LNG and LPG.

- require LEG truck drivers to receive more extensive instruction on the properties of LEG, proper handling of LEG trucks, proper transfer procedures, and appropriate damage and fire control procedures.

- require LPG trailer tanks to be insulated to help prevent explosions.

- require all LPG trailers to have an easily visible sign on each side indicating that the LPG may not be odorized.

- require that all LEG trucks have a radio communications system.

- require that all long-distance LEG truck shipments be made with two drivers.

AGENCY COMMENTS AND OUR EVALUATION

The Department of Commerce comments that, before describing the effects of LNG truck spills into sewers, GAO should present evidence that such accidents could occur. We have presented such evidence. LNG truck rollovers are described in this chapter and in Appendix VII-1. One incident of a large trailer-truck falling off an elevated roadway is mentioned in this chapter, and other accidents of this type have occurred on roads where LNG trucks are known to travel. Spills into sewers and their effects are described in Chapter 9 and Appendix VII-2.

Commerce says further that "the record seems to indicate that present construction of trailers is rather good and seems sufficient for the service," and that "no fires or explosions resulted" from the accidents listed in Appendix VII-1. We agree that LNG truck trailers are sturdy, but rollovers and spills have occurred, and LNG trailers are vulnerable to more serious accidents. Because of the potential consequences of an accident, we believe our recommendations are warranted.

We recommend that the Secretary of Transportation prohibit LEG traffic in densely populated areas, unless delivery is otherwise impossible. Both the Materials Transportation Bureau and the Federal Highway Administration suggest that this type of routing be done by local jurisdictions. We agree that local governments should take an active role in this area, but local power is limited by Federal prerogatives in interstate commerce. For this reason it is important that DOT impose the restrictions we suggest.

MTB claims that our recommendation that hoses remain attached to LNG storage facilities could be financially burdensome to small facilities and could aggravate vandalism problems at unattended facilities. We do not think that the cost of a hose would represent a major expenditure in relation to any LNG facility. Securely stored hoses at unattended facilities would be no more vulnerable to vandalism than other equipment at the facilities.

MTB says that requiring LEG hoses and truck valves to have positive coupling devices would be carrying sabotage protection to an extreme, because the other measures we recommend should be enough to discourage vandalism. Although removing the hoses from the trucks would be a step in the right direction, LEG could still be released from a truck just by opening the valves, unless positive coupling devices are installed.

The cost of insulating LPG trailer tanks would not be justified when compared to the "good safety record of these vehicles," according to FHWA. We do not believe the safety record has been that good, as the accidents discussed in the chapter indicate. FHWA itself points out the benefits of insulation: longer exposure to fires necessary to produce BLEVE's and less severe explosions when they do occur. It is for the same reasons that the Federal Railroad Administration is requiring insulation of LPG railcars on an accelerated schedule.

The Interstate Commerce Commission, in its comments, questions the need for requiring LEG haulers to have a specific certificate to do so. The ICC notes that companies hauling chemicals and petroleum products have

extensive experience with specialized carriers carrying dangerous commodities. We do not believe this is sufficient. Expertise in handling gasoline, for example, is not proof of expertise in handling LNG, which involves unique problems. If a company does have special competence, it can qualify for an ICC certificate for LNG.

The ICC also comments that, because more than half of the trucks carrying petroleum products are in private or exempt operations, these companies would be unaffected by such a restriction. Further, according to the ICC, leasing arrangements for trucks and drivers are necessary to provide flexible operations, to meet urgent demands for equipment, and to eliminate deadhead mileage.

We do not believe these points are relevant to LNG trucking. Most LNG trucking is not private nor exempt from ICC regulation. The LNG trailers, however, are often owned by the gas companies, rather than by the truckers, which allows the flexible use of the equipment.

The ICC suggests that safety regulations should focus on the driver-equipment level. We have recommended improvements in the training of LEG truck drivers and in the equipment, but supervision of drivers has proven to be difficult. We believe that LNG truck drivers are likely to be better trained and supervised if they are employed by companies certified by the ICC specifically to carry LNG.

The ICC also urges greater emphasis on DOT's participation in safety fitness proceedings before the ICC. We agree.

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CHAPTER 8

TRAIN SHIPMENTS

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INTRODUCTION

Railroads handle about 5 percent of the primary long-distance LPG transportation in the United States, approximately 4 million cubic meters annually.[1] Total railroad movement in 1977 involved about 100,000 carloads of LPG.[2] The percentage carried by railroad and truck has been decreasing as LPG pipeline systems have been expanded and extended. Nevertheless, railroads continue to have a part in LPG movement because of easy access to some locations and the convenience of using tank cars for on-site storage.

Ten percent of America's 1.7 million freight cars are hazardous materials tank cars.[3] About 16,000 of these, each with a capacity of approximately 115 cubic meters, carry most of the railroad LPG. The movement of hazardous materials is the most dangerous aspect of railroad cargo transportation.

All LPG railroad traffic is part of interstate commerce and not subject to local regulation. Federal regulations[4] (see Chapter 17) are enforced by the Hazardous Materials Division (HMD) of the Federal Railroad Administration, (FRA), of the Department of Transportation. HMD has eighteen full-time inspectors and uses the 180 general railroad inspectors employed by the FRA on a part-time basis.

HMD works closely with the Association of American Railroads (AAR), an industry organization which is given large oversight responsibilities by 49 CFR 179.3. Under this regulation, the AAR's Tank Car Committee approves all designs of tank cars to ensure that they conform to Federal

and industry standards. The Railway Progress Institute, an organization established by railroad equipment manufacturers, also cooperates with the FRA in testing tank cars and developing better regulations and designs.

ACCIDENTS

In 1976 there were 10,248 railroad accidents, which caused 158 deaths and 1,282 injuries--a rate of 1.54 deaths and 12.52 injuries per hundred accidents. There were 1,368 collisions and 7,934 derailments. Human error led to 2,360 accidents, while 6,434 resulted from defects in railroad equipment or in the track and roadbed. These statistics are representative of the past several years.[5]

In the six years, 1971-1976, an average of 129 accidents occurred annually involving one or more hazardous materials tank cars, which led to a yearly average of 2.5 deaths, 250 injuries, and 10,750 persons evacuated--a rate of 1.7 deaths and 166 injuries per hundred accidents.[6] Many other hazardous materials incidents produced spillage or leakage of material without further damage. The following two examples show the danger of LPG railroad accidents.

On February 12, 1974, at 1:55 p.m., freight train NWB-4, consisting of three locomotives and 122 railcars, left Binghamton, N.Y., bound for Mechanicville, N.Y. Cars 20 through 27 were 115 cubic meter tank cars filled with LPG. At 4:20 p.m. while rounding a $3^{\circ}30'$ curve near Oneonta, N.Y., at 32 mph, the fourth car, a grain hopper, fell over and derailed. The locomotives and first three cars proceeded down the track, but the cars behind the hopper derailed and piled up. Car 21 was crushed and split open, releasing LPG which quickly ignited and formed a

fireball. Firemen from local departments moved in to try to cool down the remaining LPG cars, but fire officials decided that the situation was dangerous and thirty minutes after the fire began, ordered them to withdraw.

The absence of an efficient communications system caused the order to come too late. As the firemen began to pull back, one of the LPG tanks exploded: 54 men were injured in the blast. Three more explosions occurred in the next half-hour. Some tank car halves were propelled a quarter-mile away from the fire site. One ruptured tank car continued burning for seven days.[7]

The second accident took place in a railyard in Decatur, Illinois, on July 19, 1974. At 4:50 a.m., 5 freely-rolling 115 cubic meter LPG cars were switched onto a track where the lead car collided with an empty, freestanding box car, punching a 22" x 26" hole in the LPG car. For 13 minutes LPG vaporized. Then the cloud ignited and exploded over an area one-half by three-quarters of a mile. The explosion was felt 45 miles away. Fire fighters' efforts to control the yard fire were largely successful; more tank car explosions were prevented. There were 7 deaths, 349 injuries, and $24 million of damage. Litter and debris from the fire and explosions covered 20 blocks of the city.[8]

THE RAILROAD TANK CAR

The Code of Federal Regulations specifies the various classes of tank cars and their permitted cargo. LPG is mostly carried in 15,000 Class 112 and 114 cars and sometimes in 1,000 Class 105 cars. The 112 cars and the 114 cars, which differ only in their loading and unloading

apparatus, were not required to be insulated until recently. Class 105 cars have been so required.

All LPG cars are cylindrical and made from 9/16- or 11/16-inch thick steel. They are designed to hold pressures of 500-1000 psi, although safety relief valves generally release at 250-300 psi, depending on the sub-class. The maximum volume is 130 cubic meters, but most cars hold only 115 cubic meters. The maximum loaded gross weight is 263,000 pounds. All cars carrying LPG are required to carry diamond-shaped placards 10-3/4" on a side saying "Flammable Gas," and to be labelled on both sides with 4" lettering identifying the gas.[9]

Originally, all LPG tanks were required to have insulation to keep the gas cool under ordinary conditions. However, it was shown that in normal circumstances insulation is superfluous, which led to the creation of the uninsulated 112/114 Class in 1959. The absence of insulation permitted bigger and cheaper cars to be built, but has led to serious problems after accidents.

The following is a typical scenario of an LPG railroad accident, fire, and explosion. In a collision or derailment a tank car is crushed or punctured by a disengaged coupler, and the LPG begins to vaporize. If ignition of the LPG cloud is delayed for several minutes, the initial explosion can cover an extensive area, such as occurred in Decatur. If ignition is immediate, there is usually no imminent danger from the first car alone. The danger arises if the fire impinges on a second, unpunctured LPG car, which is not unlikely since the cars often run in groups of more than ten. The heat raises the pressure inside the second car; after some time the safety valve

will release, but, if the fire continues, the second tank will rupture and cause a "Boiling Liquid Expanding Vapor Explosion," or BLEVE.[10] Each explosion contributes to the heating and weakening of neighboring tanks and makes additional explosions more likely. As noted previously, a BLEVE can rocket a 45,000 pound steel section of the tank for a quarter of a mile.

It is not a massive build-up of internal pressure which causes a BLEVE. Tests have shown that the required safety valves are generally adequate to maintain the pressure close to some threshold value, usually 250 psi, in most LPG fires. Indeed, prior to explosions, observers have seen safety valves close during fires, indicating that the internal pressure had dropped below the threshold value. Rather, the weakening of the steel wall as the temperature rises is the immediate cause of the explosion. The steel attains its maximum strength near 400°F, but the wall weakens as the temperature rises, and at 900-1100°F it is not able to contain the pressure maintained by the relief valve, and the BLEVE occurs.

When the tank does begin to fracture, no matter what the orientation of the initial crack, the internal structure of the rolled steel forces the rupture to propagate circumferentially.[11] This makes the end of the tank car rocket forward.

ACCIDENT RESPONSE

Firefighting at LPG accidents is directed toward cooling undamaged tanks, since an LPG-fed fire is virtually impossible to extinguish. Several factors inhibit the safe and efficient application of cooling water streams:

accidents often occur far from adequate water supply; many fire departments have not been trained to recognize and respond appropriately to LPG fires; and the timing of a BLEVE is unpredictable. Explosions have taken place from several minutes to several hours after a fire's commencement. Misjudgment can be fatal. For the past several years, the National Fire Prevention Association has sponsored a program to teach fire fighters how to handle LPG fires, alerting them to the danger of BLEVE's and demonstrating the most effective cooling maneuvers.[12]

Explosions can occur without the presence of a fire, as demonstrated by an accident in Waverly, Tennessee, on February 22-24, 1978. There, two LPG cars were scraped and dented in a derailment, but there was no leak and no fire. Two days later, a few hours before transfer operations to empty the damaged cars were scheduled to begin, one of the tanks ruptured. The vaporizing gas ignited and the resulting fireball caused 15 deaths and more than 40 injuries. Prompt and courageous action by the volunteer fire department (which was trained in LPG fire fighting procedures) helped to prevent a BLEVE of the second tank car.

The probable cause of the rupture was an internal crack produced by the derailment. When the ambient temperature at Waverly reached $52^{\circ}F$, 20° higher than the previous day's, the weakened tank shell was unable to withstand the 50 percent rise in internal pressure and exploded.

The apparent stability of the LPG tank cars and the absence of a leak had persuaded officials at the accident scene, including local firemen, Tennessee Civil Defense

personnel, and railroad employees, that there was no immediate danger from the derailed LPG cars. As a result, there was no water deluge of the tanks (which would have had little effect, in any case); evacuation limits were relaxed; and equipment to transfer LPG with pressure pumps was brought in. Even if the temperature had remained low, the increase in pressure during transfer might have split the tank.

The Waverly incident points up several deficiencies in emergency response to LPG train accidents. First, there is no way to test quickly the structural integrity of a derailed tank car. A technique for this purpose would also be a valuable adjunct to the regular static pressure test, which may not reveal small cracks or weaknesses that could be dangerous in extreme conditions. Second, there is no safe and efficient method for quickly unloading a tank car, without moving it and without pressure. Strategically-placed, quick-connecting fittings and valves and easily transported, temporary tanks could provide an alternative to permitting damaged cars to remain full for several days. Finally, with a large number of independent organizations present at railroad accidents, it is not always clear how lines of authority run and who has final responsibility for directing an operation. These problems suggest the need for Railroad Disaster Control Response Teams, which would be capable of reacting immediately to hazardous materials accidents with the special expertise and equipment necessary to prevent disasters.

Several sources of information are currently available for firefighters approaching hazardous materials accidents. The NFPA's Fire Protection Handbook and the Coast Guard's Chemical Hazards Response Information System

both detail the properties and dangers of, and recommended emergency responses to, hundreds of hazardous materials. Additionally, several groups, such as the Manufacturing Chemists Association, maintain 24-hour emergency response centers, which can be called for immediate information.

NEW SAFETY REQUIREMENTS

The LPG industry, HMD, and the railroads recognize the danger in LPG movement and have collaborated in identifying and correcting deficiencies in tank car design. On September 9, 1977, as a result of a long inquiry, HMD, through the Materials Transportation Bureau (MTB), amended the specifications for 112/114 LPG tank cars (Docket No. HM-144). The new regulations require all LPG tank cars to have a three-part safety system--consisting of shelf couplers, a tank head puncture resistance system, and thermal protection--designed to prevent accidents and leaks, and to prevent explosions if a fire does occur.[13]

The new regulations specify a schedule for the retrofitting of older tank cars, which requires shelf couplers to be installed by June 30, 1979, and the tank head and thermal protection by December 31, 1981. However, after the Waverly accident, subsequent recommendations from the National Transportation Safety Board, and congressional inquiries, MTB has proposed to shorten the retrofit schedule to require shelf couplers by December 31, 1978, and the other equipment by December 31, 1980. A complete retrofit will cost $9-12,000, and new cars--current price about $50,000--will cost $4-8,000 more.

Shelf couplers inhibit the vertical separation of railroad cars more effectively than standard couplers.

Since most punctures are made by free couplers, the use of shelf couplers should help prevent releases. The tank head puncture resistance system will generally be a head shield, a steel plate mounted on either end of a tank car in a position to resist most coupler thrusts. If an LPG railcar is in a fire, thermal protection, such as insulation, can prevent BLEVE's by retarding the heating of the steel walls. This allows more time to extinguish the fire and to vent the tank before the steel is weakened enough to fail. All the new features must meet strict performance standards. HMD expects these measures to reduce significantly tank car accidents and LPG spills.

Shelf couplers and thermal protection systems are already used by railroads and are proven technologies. HMD has listed four commercially available thermal protection systems as conforming to the new standards. The LPG and railroad industries favored the standards for shelf couplers and insulation, but had reservations about the head shield requirement. They believed that head shields were not proven and could break or fall off and themselves cause tank car accidents. Tests run by the FRA and the AAR-RPI suggest that these fears are unfounded.[14]

There are several problems which the new regulations do not address. No actions have been taken to improve the strength or fracturing properties of the steel used, or to protect the sides of a tank car from punctures. Present regulations requiring static pressure testing of tank cars every 10 years, and safety valves every 5 years, do not ensure that tank cars are safe in extreme conditions.

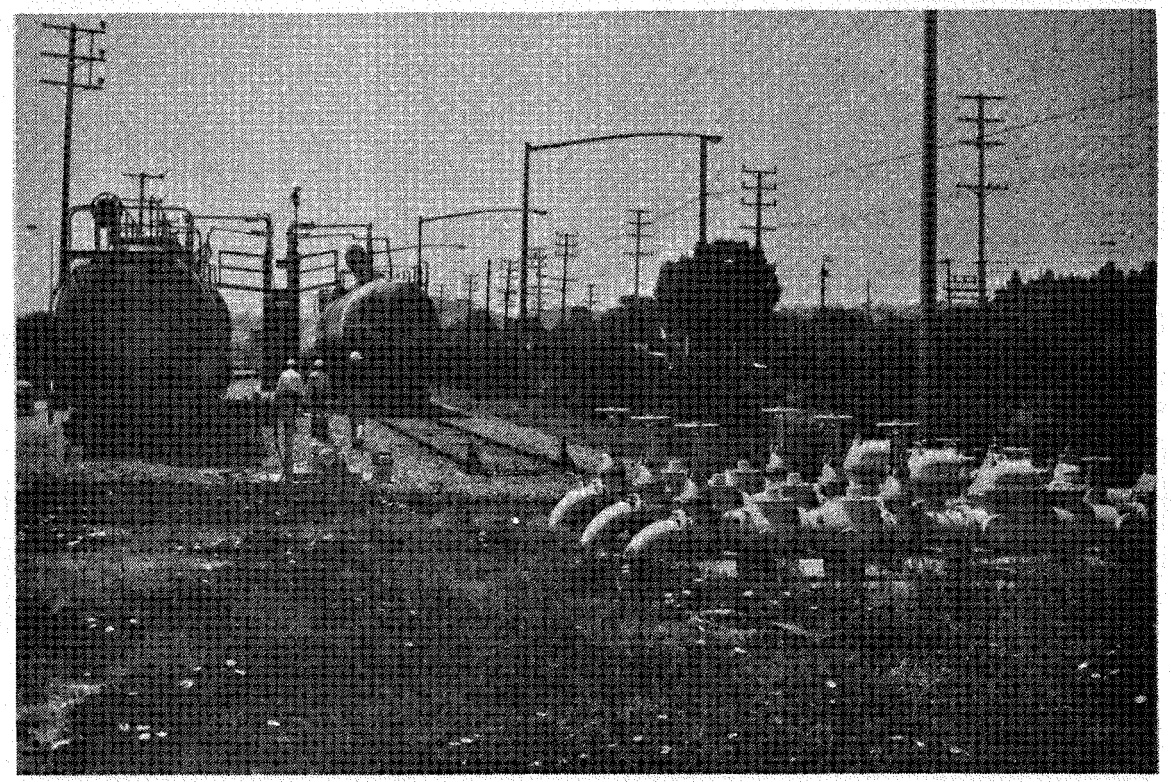
TANK CAR MAINTENANCE

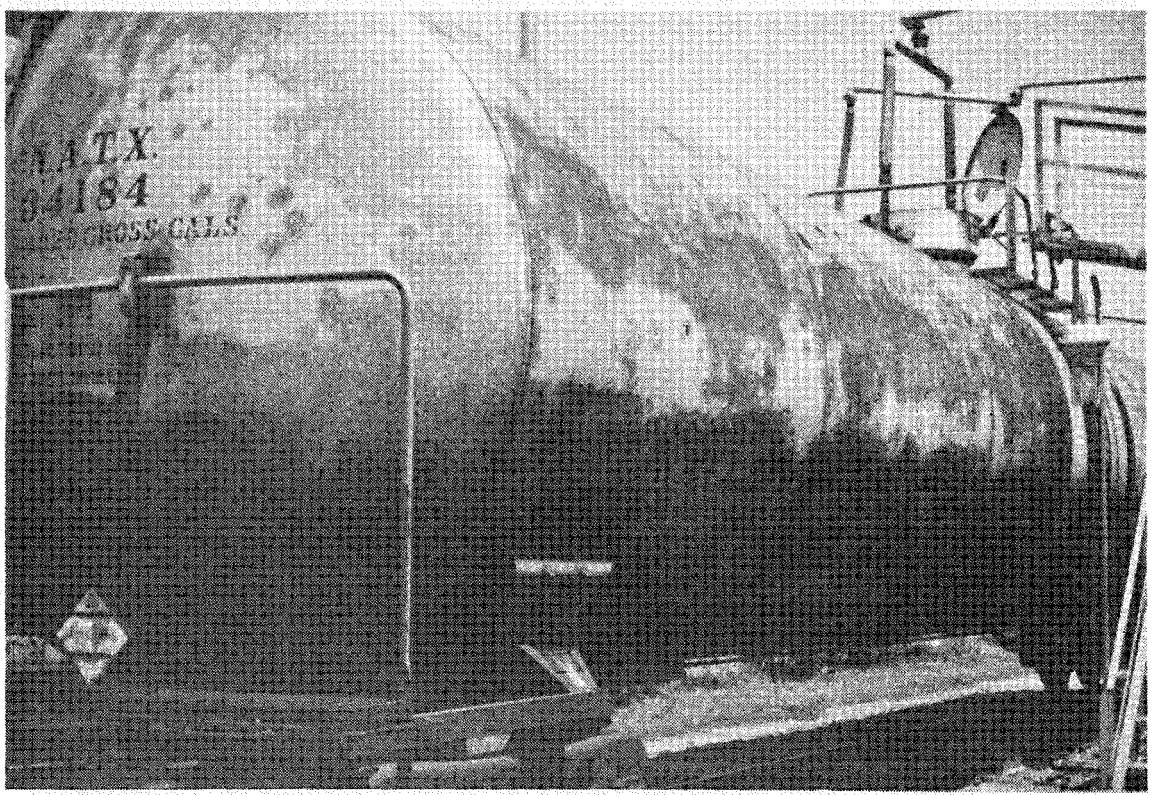
If tank cars receive proper maintenance and are not in an accident, the tank shell should easily last 40 years. Tank cars are not necessarily maintained well, however. At one site we found rusted propane cars waiting to be loaded. See the photographs on the next page. We were told by the management that since the cars had arrived they would have to be loaded, but that the company would ask never to have those particular cars sent again. They could, of course, be sent elsewhere. We did not determine the depth of the rust. Improperly maintained tank cars holding hazardous materials under high pressure are a sizable and unnecessary danger to the public.

TANK CAR MOVEMENT

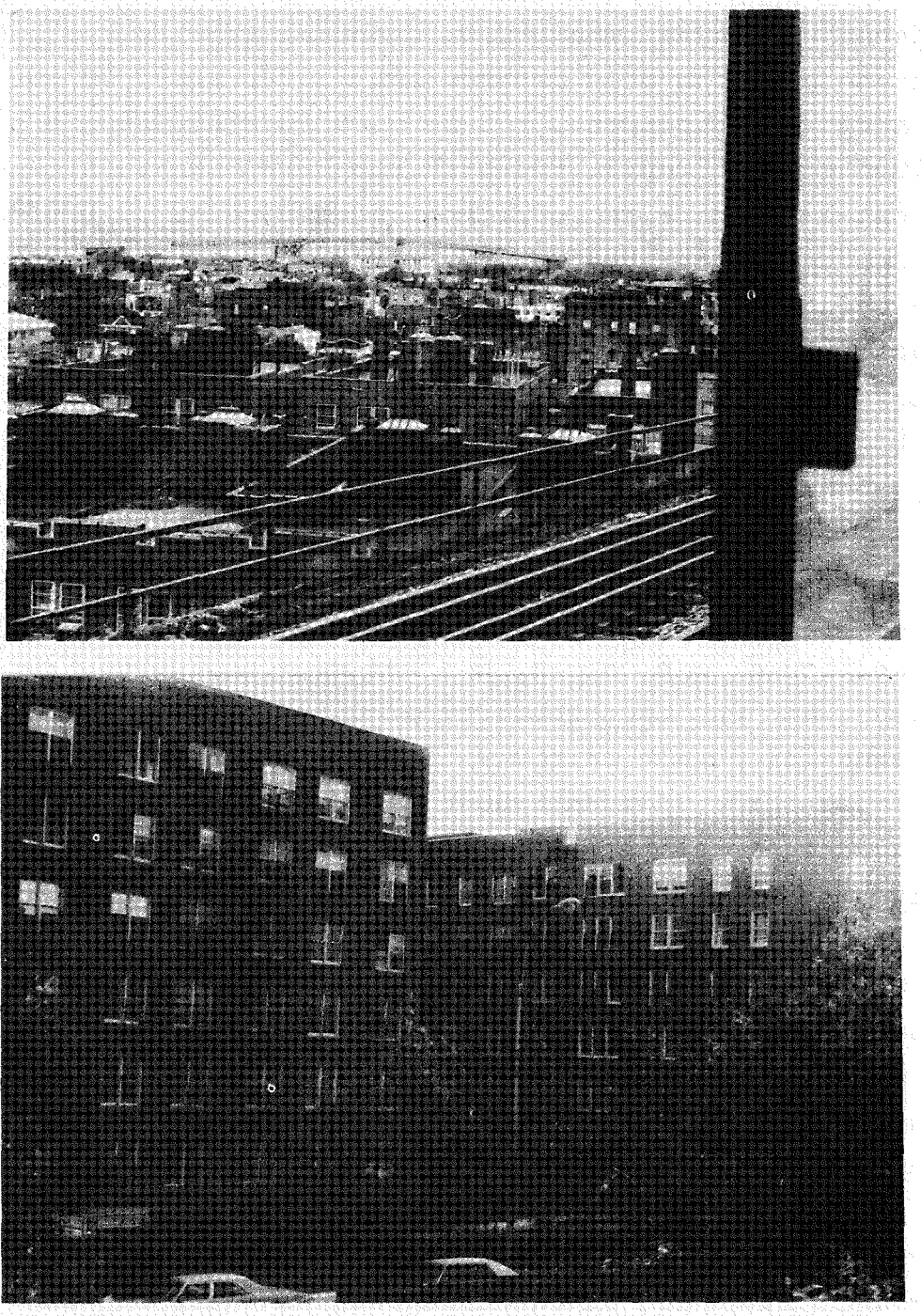
Most freight cars are owned by the railroads, but tank cars are owned by shippers or tank car companies which lease the cars to shippers. Railroads charge the shippers for hauling the loaded cars on a per ton-mile basis. Once a tank car meets the design and loading specifications set out in Title 49 of the Code of Federal Regulations, there are few restrictions on its actual movement. Therefore, the most direct route is usually chosen, although both the shipper and the carrier have some discretion in specifying alternatives. The average distance of an LPG railroad shipment is 276 miles.[15]

The free movement of LPG is sometimes in apparent conflict with local restrictions. For example, with one exception, the New York City Fire Department (NYCFD) prohibits storage of LPG in the City. Nevertheless, as shown in the photographs, LPG cars have traveled through





THESE RAILROAD TANK CARS FOR CARRYING PROPANE WERE PHOTOGRAPHED ON GAO'S SITE VISIT IN JULY 1977. NOTE THE RUST ON BOTH CARS.



TWO VIEWS OF DENSELY POPULATED AREAS IN THE QUEENS THROUGH WHICH LPG TANK CARS HAVE TRAVELED. THE TOP PICTURE SHOWS THE THROGS NECK BRIDGE AND MANHATTAN IN THE BACKGROUND. THE APARTMENTS IN THE BOTTOM PICTURE ARE LESS THEN 50 YARDS FROM THE TRACKS.

densely populated areas of the city, over bridges and elevated railways. The NYCFD is not alerted to the passage of these cars and only becomes aware of a specific movement if there is an accident. There have been LPG incidents, including derailments, to which the Fire Department has had to respond. The Fire Department has objected to LPG transportation through New York City, but has been unable to prevent it because that would be interference with interstate commerce. Although there apparently has been no LPG rail traffic through New York City in the past year, the Fire Department is still concerned. There is nothing to prevent such traffic from resuming at any time.

The danger from an LPG spill would be particularly acute in a densely populated area, such as New York City: propagation of explosions in urban canyons, sewers, or subways, and the impossibility of quickly evacuating thousands of people multiply the hazards. It is fortunate that most large accidents have occurred in relatively unpopulated areas; that they do not always do so is shown by the Decatur fire.

As shown in Chapter 9, sabotage of LPG cars would not be difficult. Youth gangs frequently place obstacles on tracks which delay freight trains in New York City just to harass the trainmen. The potential danger from moving LPG through urban areas is very great.

HMD has jurisdiction in this area, but opposes restrictions on LPG movement for several reasons with which the industry generally agrees: it is simpler and more economical to regulate tank car design than tank car movement; trains move more slowly in congested areas, decreasing the chance of an accident; there is an accident

rate associated with handling and switching cars, more of which would be necessary in circuitous routing. For similar reasons, there is little regulation of the position of LPG cars in a train. Although LPG cars cannot be placed next to explosives, radioactive materials, or poison gas, LPG cars are shipped consecutively, which has frequently caused a domino effect in accidents. HMD believes that the new regulations for tank car construction are sufficient for their safe operation. We believe restriction of routes is also necessary.

FINDINGS

- Boiling Liquid Expanding Vapor Explosions (BLEVE's) are not caused by overpressurized LPG tanks, but by the steel of the uninsulated, single-wall tanks weakening from intense heat to the point where it can no longer hold the normal tank pressure.

- By December 31, 1981, all 112/114 LPG cars will be required to have shelf couplers, tank head resistance systems, and thermal protection. DOT has proposed to shorten this schedule.

- DOT has taken no action to improve the strength or fracturing properties of the steel used in tank cars, or to protect the sides of tank cars from punctures.

- The static pressure tests required of tank cars every 10 years and of safety valves every 5 years are not adequate to ensure that the cars are safe in extreme conditions.

- Rusted tank cars holding propane under high pressure are currently being used.

- LPG cars travel through densely populated areas of cities, even cities which prohibit LPG storage. If large amounts of LPG or its vapor get into the sewers, subways, and other subterranean ducts in a big city, it could lead to a catastrophe.

- Sabotage of LPG cars or the trains they are part of would not be difficult.

- Current practices of emergency response to railroad LPG accidents are inadequate to protect the public.

RECOMMENDATIONS

We recommend that the Secretary of Transportation:

- require a large increase in the size of the placards saying "Flammable Gas" so that they can be more easily read from a considerable distance in the jumble and possible fire of a train wreck.

- require that all LPG cars be prominently labeled "Insulated" or "Non-Insulated" until thermal protection is required on all of them. This information will be of great help to firemen confronted with a train wreck involving LPG cars and may save many lives.

- consider requiring tougher steel in tank cars, or additional puncture protection for the sides of tank cars.

- take immediate action to inspect hazardous materials tank cars and remove from service those that are obviously not being maintained properly.

- require more frequent inspection and testing of all safety-related features of LEG tank trucks and railcars.

- prohibit the travel of LPG railroad cars to or through densely populated areas unless it is impossible to deliver it without going through densely populated areas.

- require that the Bills of Lading on any train containing hazardous materials have detailed instructions on fire fighting and other emergency measures which should be taken in the event of a wreck. The telephone numbers of 24-hour emergency response centers, such as the Manufacturing Chemists Association "Chemtrec", should also be shown. If the train is to go through any densely populated areas, the instructions should explicitly address the dangers peculiar to such areas.

- establish Railroad Disaster Control Response teams, capable of quickly responding to railroad hazardous materials accidents with the knowledge and equipment necessary to prevent disasters.

- investigate methods of quickly determining the structured integrity of damaged tank cars and methods of emergency transfer of material.

AGENCY COMMENTS AND OUR EVALUATION

We recommend that the size of identifying placards on LPG tank cars be increased. The Materials Transportation Bureau in DOT comments that "because of the unique shape and current size of the placard, it is recognizable from a distance sufficient, in most cases, to provide safety to the viewer." On the other hand, the Federal Railroad Administration, also in DOT, comments that "there is no practical size placard that can be read safely in an accident," and that the placard is for other purposes.

We stand by our original recommendation. Enough train accidents involving LPG cars have occurred in just the last few months to underline the importance of being able to identify quickly and clearly derailed LPG cars.

Both MTB and FRA comment that a requirement for tougher steel in tank cars would not be cost-effective. The accidents we have noted, especially the one in Waverly, Tennessee, demonstrate that improving steel properties could be an important step in reducing injuries and deaths. We have made no attempt to calculate the value of reducing injuries and deaths.

FRA states that our recommendation—requiring immediate action to inspect hazardous materials tank cars and remove those not being maintained properly—is not needed since such action is already being taken.

FRA also says that "firefighters would receive no useful information" if LPG cars were labeled 'Insulated' and 'Non-insulated', and that they "do not believe there

need be special information for handling accidents in densely populated areas."

We disagree. MTB's new regulations point out the advantages of insulated tank cars, and firefighters should be aware of the conditions of railcars they approach. We have also shown that populated areas present especially hazardous situations (e.g., sewers), and special precautions do need to be taken to prevent catastrophes.

FRA disagrees with the recommendation to prohibit LPG rail traffic through densely populated areas unless it cannot be delivered by another route. MTB also notes that we have not defined precisely "densely populated area."

In this report we identify movements and storage of LEG through major urban areas. In implementing our recommendation, the responsible Federal agency will have to define densely populated areas.

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CHAPTER 9

VULNERABILITY OF LEG FACILITIES TO SABOTAGE

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INTRODUCTION

We have tried in this chapter to discuss the possible effects of sabotage on LEG and naphtha transportation and storage facilities in a way which does not substantially contribute to the ability of malicious persons to carry out such acts.

To consider the possible effects of sabotage on LEG and naphtha transportation and storage facilities we:

a. Assessed the current security levels of trucks, tank cars, terminals, storage sites, and processing facilities.

b. Evaluated the sabotage vulnerability of ships, trucks, tank cars, pipelines, terminals, and storage sites.

c. Determined what weapons, explosives, and other materials are available to potential saboteurs.

d. Assessed possible effects on ships, trucks, tank cars, pipelines, terminals, and storage sites of various sabotage scenarios.

e. Conducted charge calculations for ships, trucks, tank cars, pipelines, and storage tanks to determine the type, configuration, and amount of explosive materials/weapons required to accomplish the necessary penetration.

f. Conducted experiments with munitions known to be in the hands of terrorist organizations to

validate certain of our calculations and evaluations.

To collect the data for this chapter, we made a comprehensive literature review, visited sites and facilities, studied detailed company plans and blueprints, and held discussions with industry, government, and other personnel.

THE THREAT TO LEG FACILITIES

A typical sabotage threat analysis would characterize potential saboteurs according to their attributes, capabilities, and motivations. Although the potential threateners to LEG facilities have not been previously studied, there is no reason to believe they would constitute a very different group than those for nuclear or other large facilities. Detailed threat studies have been done for nuclear facilities.[1] In addition, there are many documents available which discuss typical perpetrators of malicious actions. Thus, we have concentrated our efforts on assessing the resources available to saboteurs and the vulnerability of LEG transportation and facilities to sabotage.

Groups which might try to sabotage LEG transportation or facilities can be divided into four categories: foreign governments, foreign subnational groups, domestic criminal groups, and domestic political dissident groups. There are elements in each category which have the necessary capabilities and might have the motivation.[1,2] In addition, an isolated, knowledgeable, capable psychotic might try LEG sabotage.

Appendix IX is a compilation of recent bombing incidents obtained from the FBI Bomb Data Program Incident Summaries for the period 1974 through 1977, including a selected list of incidents which occurred on public utility and oil company properties. The number of attempted and actual bombing incidents reached a peak of 2,074 in 1975 and then dropped to 1,314 in 1977, the lowest number in several years.

Availability of Weapons

In addition to commercially available weapons and explosives, an impressive array of weaponry has been stolen from military installations and National Guard armories. The losses include small arms, automatic weapons, recoilless rifles, anti-tank weapons, mortars, rocket launchers, and demolition charges.

A large number of commercially available publications provide detailed instructions on the home manufacture of explosives, incediaries, bombs, shaped charges, and various other destructive devices. All the required material can be bought at hardward stores, drug stores, and agricultural supply outlets. Many of the manuals also discuss tactics and techniques for sabotage operations. These types of books are readily available at libraries across the country, including the Library of Congress.

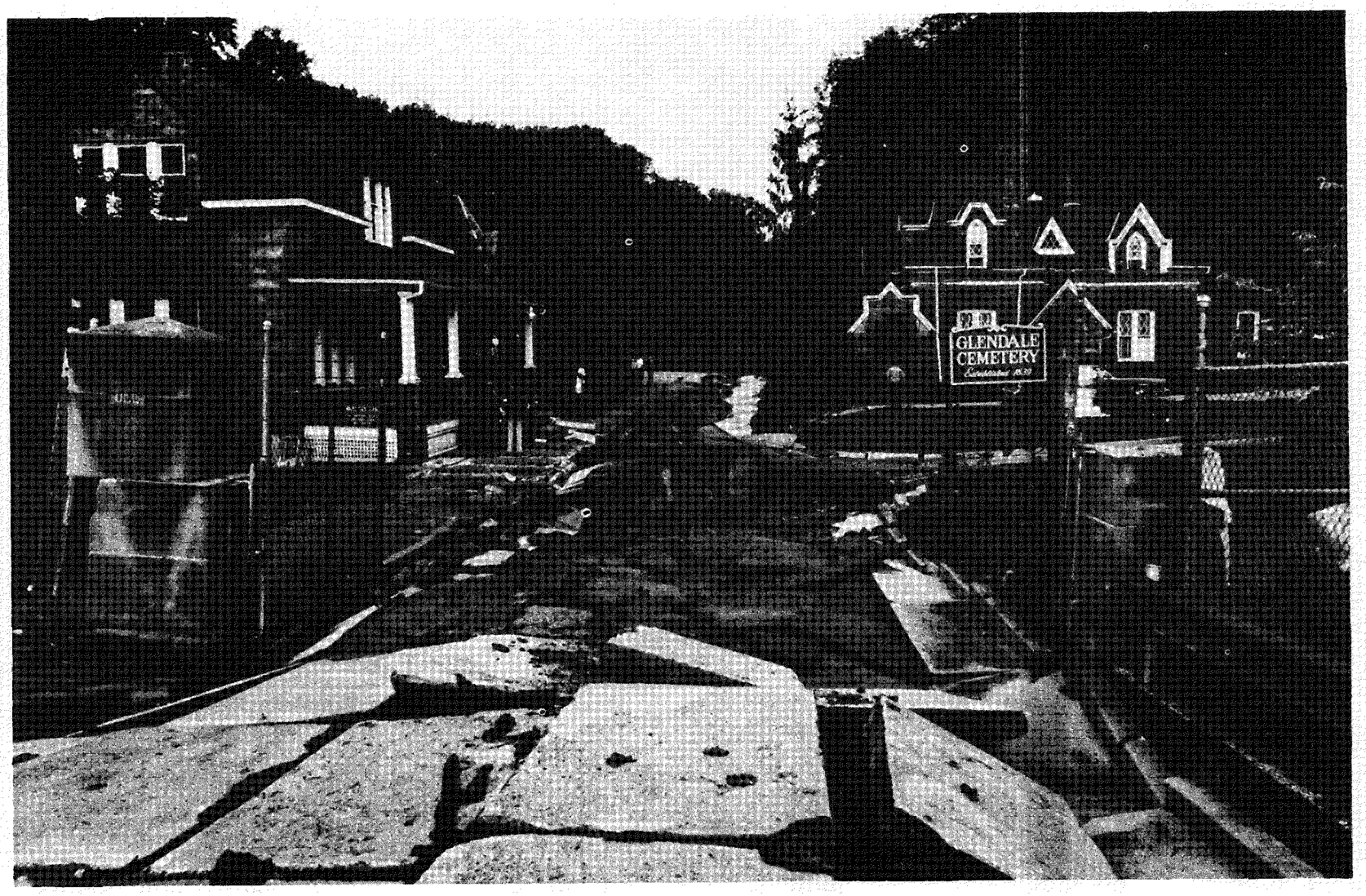
It is not unusual for international terrorist groups to be armed with the latest military versions of fully automatic firearms, anti-aircraft or anti-tank rockets, and sophisticated explosive devices.

The mobility of international terrorists and the ease with which they acquire and transport weapons is a matter of serious concern. Our inability to control the cross-border drug traffic, and the continuing large inflow of illegal aliens indicate that weapons and small terrorist units could also be infiltrated into the United States.

The Introduction of LEG or Naphtha into Underground Conduits

LEG could be used as an ignition material for fires. A hijacking of one or more tanker trucks would provide a significant, uncontrollable source of ignition and explosions. If LEG were released into a sewer system or subway, a disaster could result. Even naphtha, a much less dangerous material, can cause extensive damage, as a recent incident in Akron, Ohio showed.

Around 2:30 a.m. on June 23, 1977, a major sewer line running beneath Akron's Glendale Cemetary exploded. The street outside the entrance to the cemetary collapsed. (The photograph shows the resulting damage.) Water from a ruptured pipe enlarged the crater into a huge trench. As the blast rolled through nearly 7,000 feet of sewer main, other sections of pavement buckled and caved in. Cast-iron manhole covers were hurled into the air. Storm drains were cracked. Fortunately, much of the force of the explosion was vented through the manholes and storm drains or absorbed by the old-fashioned 13-inch brick walls of the sewer. Otherwise, the explosive mixture would have detonated, according to the City's investigators.[3] As it was, there was little damage to nearby homes except for some broken windows. If the explosion had occurred at a busier time, such as during rush hour traffic, damage would



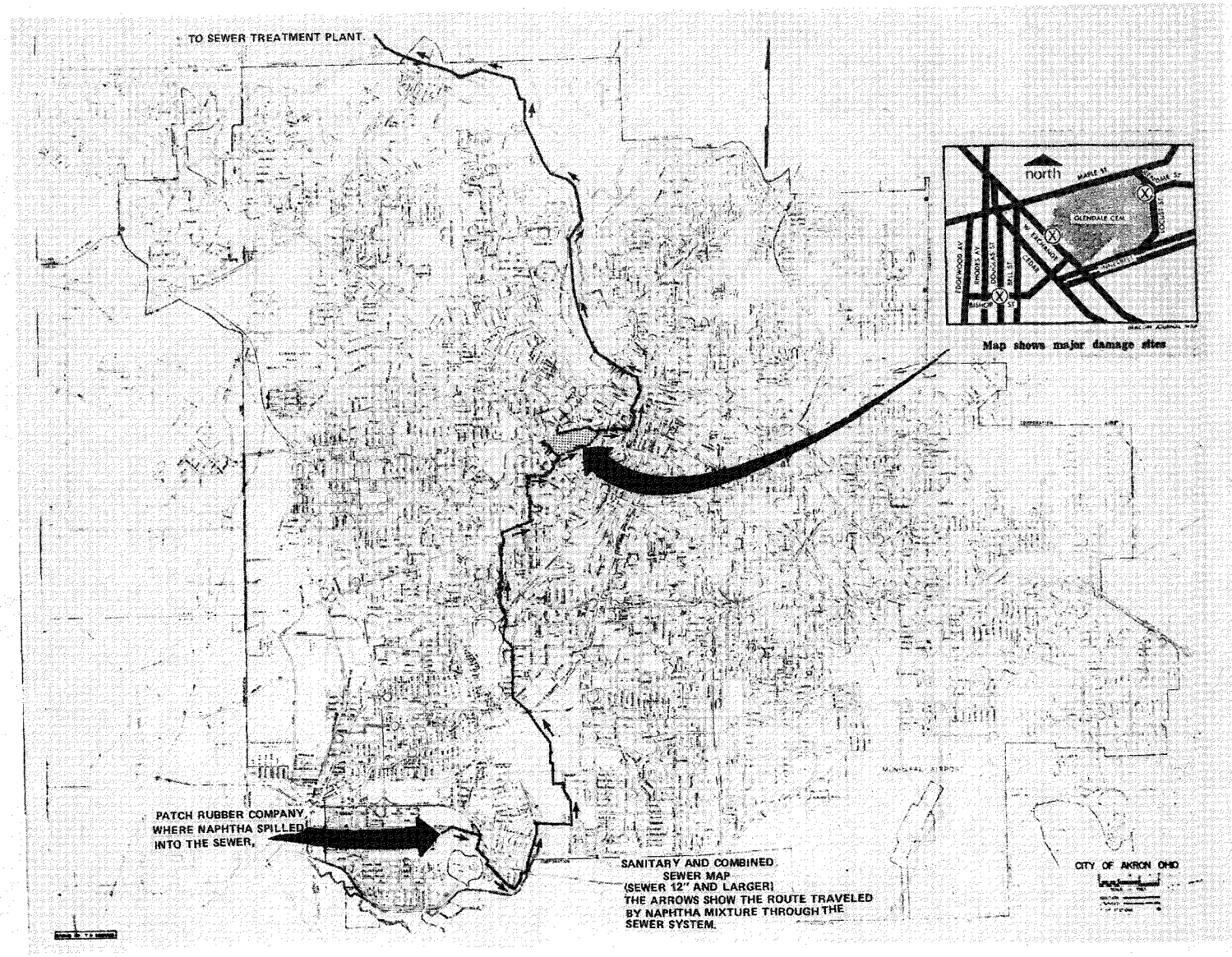
DAMAGE AT ENTRANCE TO GLENDALE CEMETARY AFTER THE NAPHTHA EXPLOSION IN THE SEWER SYSTEM JUNE 22, 1977.

have been greater, and injuries may have resulted. A sewer explosion in Cleveland in 1953 killed one person and hospitalized 58 others.[4]

The Akron blast was caused by naphtha. At approximately 8 o'clock the previous night, a disgruntled former employee broke into the Patch Rubber Company and opened several storage tanks. In all, 11 cubic meters (3,000 gallons) of naphtha and 3.5 cubic meters (900 gallons) of other volatile liquids spilled on the plant floor.

The naphtha poured down a drain in the floor and flowed into the sanitary sewer system at the rate of 64 liters (17 gallons) a minute. After about 3-1/2 miles, this line widens into the main bricklined storm and sanitary sewer. As the naphtha passed through this 10-foot diameter main line, there was enough air to dilute the rich vapor to the flammable range. The explosion came six hours after the naphtha was dumped, and eight miles from the point of entry. The route of the spill is shown on the map. The inset indicates the site of major damage.

Investigators suspect that the hot catalytic converter of a police car that had stopped close to a manhole opening set off the explosion. The engineers estimated that only 2.2 cubic meters of naphtha was required to fill the 6625 foot section of the main line involved in the explosion. Akron officials estimate that complete repairs of the streets and the sewer line will take at least a year and cost more than $10 million.


TO SEWER TREATMENT PLANT.
north
Map shows major damage sites
PATCH RUBBER COMPANY,
WHERE NAPHTHA SPILLED
INTO THE SEWER.
SANITARY AND COMBINED
SEWER MAP
(SEWER 12" AND LARGER)
THE ARROWS SHOW THE ROUTE TRAVELED
BY NAPHTHA MIXTURE THROUGH THE
SEWER SYSTEM.
CITY OF AKRON OHIO

An investigation of the 1953 Cleveland blast[4] concluded that the most probable cause was either industrial wastes, or gasoline leaking into the sewer, or a combination of these. The investigators found that the rate of vaporization of flammables and the length of time they remain in the sewer are critical factors in explosions of this kind. They also found that volatile flammable liquids in surprisingly small quantities may produce devastatingly destructive effects if the structures are not suitably drained or ventilated. They said that gasoline leakage of five gallons per day into the sewer for about a month, a total leakage of about one-half cubic meter, would have provided an explosive mixture sufficient to cause the disaster.

VULNERABILITY OF FACILITIES TO SABOTAGE

All our findings on the vulnerabilities of LEG and naphtha facilities to sabotage have been thoroughly corroborated by reference data, calculations on individual components, or actual test. The assessments are presented to provide a better understanding of the potential vulnerabilities of LEG system components. To avoid increasing the danger, none of the systems is identified with a specific site.

Our vulnerability assessment considers malicious acts by an individual or groups of individuals which could threaten offsite lives and property. The assessment was limited to the damage that might be caused by a sabotage group of no more than six outside individuals with the assistance of two insiders. The group's resources were limited to those known to be available, as discussed earlier. The actual threat could be considerably greater.

There are two basic types of LEG facilities: base load plants, including import terminals; and peakshaving plants. The storage and processing facilities of both types are similar in physical layout. The design of individual components (e.g., storage tanks, piping, processing equipment, dikes), however, varies with location and manufacturer, as shown in Appendix XVI-2. Peakshaving plants can be located in any area with access to transmission lines or truck transportation. Import terminals must have onshore pier facilities or offshore terminals with connecting pipeline trestles or tunnels.

Urban Area Facilities

Urban LEG facilities are usually located in heavy industrial developments predominantly occupied by petroleum product storage and processing. LEG storage facilities are often adjacent to other facilities which store very large quantities of LEG or other volatile liquids. Some are next to sewer plants which store large amounts of deadly chlorine gas. This proximity means that a single cause, such as an earthquake or an attack might simultaneously destroy many tanks, thus increasing the damage and casualties many times. A major incident at one facility might cause further failure at adjacent facilities and set off a chain reaction. For example, a detonation in a propane cloud might initiate a detonation in a natural gas cloud.

Urban area facilities are attractive targets for saboteurs, particularly terrorists, because of the immediate impact of any significant incident on large numbers of people. The normal workday congestion and confusion provide excellent cover for daytime infiltration,

observation, selection of targets and determination of access and escape routes. One possible form of sabotage involves selectively disabling critical components. Thus, it is important to carefully screen site personnel who have access to plant monitoring and control equipment. If insiders disable key components at the same time that outsiders breach a pipeline, a major spill could result. Certain tank designs and piping configurations we examined would facilitate causing a spill outside the containment area.

At one terminal we visited, police and Coast Guard security are routinely provided during LNG unloading operations, but this is not the practice at most LEG terminals.

We observed a salvage yard crane operating close to the pier-to-plant pipeline at this plant during the unloading of an LNG ship there. An error by the crane operator could have caused a large amount of metal scrap to drop on the pipeline. This could have released a significant quantity of LNG outside the diked area.

The extensive tank truck and rail car traffic between import terminals and other storage facilities provides a malicious group with three options. It can:

- Hijack one or more trucks and use the contents for malicious action.

- Conceal a time-delay device on a truck or rail car set to detonate at a critical time and location.

- Use a truck as a means of plant entry or possible extortion.

Storage Tanks and Dikes

The primary considerations in determining LEG container vulnerability are:

a. Tank design and materials.

b. The size and depth of penetration required to cause massive release of the contents.

The predominant materials used in tank construction are steel, aluminum and concrete. However, as shown in Appendix XVI-2, container designs and dimensions vary considerably between sites. Although none of the tanks we examined are impervious to sabotage, some designs do provide a greater degree of protection against explosive penetration than others. Stronger designs also complicate the sabotage operation by requiring specially designed charges, more explosive materials, and more onsite preparation time. Concrete tanks have much more resistance to penetration than single wall LPG tanks; double wall metallic tanks fall in between.

Concrete LNG Tanks

The depth of the concrete berm around a typical concrete tank provides fairly effective protection against explosive breaching of the tank walls. It would require close to 1,500 pounds of explosive placed in direct contact with the outside wall, to cause significant damage to a concrete tank of this size. If the walls were constructed

entirely of reinforced concrete, the explosive requirements would be increased by a factor of 1.5. The depth of the concrete berm also makes these tanks highly resistant to shaped charge penetration. There are currently no known weapons in the terrorist arsenal that are capable of one shot penetration of a concrete tank. The addition of a high contiguous sloped earthen berm around these tanks provides an almost impenetrable barrier against sabotage.

Double-Wall Metal Tanks

Because limited data are available on explosive effects against typical metal double-wall LNG tanks we conducted live firing tests against a full scale tank section with an inner tank of cryogenic aluminum. The tests confirmed that the double-wall structure of these tanks affords limited protection even against non-military small arms projectiles, and that devices used by terrorists could cause a catastrophic failure of the inner wall. The rapid release of LNG (at $-260^{\circ}F$) against the outer carbon steel wall could result in extensive crack propagation and possible collapse of that wall as well.

Double-wall tanks which permit access to the insulation space through near ground level manholes are particularly vulnerable to explosive damage. Interior placement of charges would more than double their effectiveness.

Single-Wall Metal Tanks

The single-wall metal tank is the most vulnerable to sabotage. The critical crack length (see Chapter 4) for typical large single-walled tanks is small enough so that

properly placed charges could cause their complete catastrophic collapse. This would cause a large amount of the contained fluid to escape the dike (see Chapter 5).

Tanks Built on Piles

Some large storage tanks are supported on pile foundations. We observed one design with about 1.5 feet of air space between the bottom of the tank and the ground surface. This design can reduce by 67 percent the amount of explosives required for extensive rupture of the tank floor. Ground wave reflection and the tamping effect of a partially enclosed space significantly increase the peak pressure of the blast wave. The partial confinement of the resulting gases sustains the pressure on the tank bottom, which can cause more damage than the initial blast wave.

There is also a danger of LEG and LEG vapor accumulating under the tank in the event of a spill. The gases, if ignited, might explode and cause an extensive rupture of the tank floor. No one has looked into this possibility.

Underground Storage

The pipes connected to mined caverns are vulnerable to both accidental and malicious actions, but redundant automatic safety devices provide an almost instantaneous water seal to control vapor release to the atmosphere. Liquid hydrocarbons can be released by overfilling, however, as has happened in Marcus Hook on January 28, 1978.

Close High Dikes

A typical thin high dike wall can be easily breached by a small amount of explosives and properly placed charges would blow out a very large section of the bottom of the wall.

Earthen dikes are much more resistant to sabotage than thin, high concrete dikes. Even the smaller earthen dikes are relatively difficult to breach unless boreholing techniques are used.

Piping

The liquid pipelines which fill and empty LEG tanks are extremely vulnerable, but there are few circumstances in which their rupture would result in offsite damage. To cause offsite damage would require careful planning, timing, and execution, and the assistance of at least one employee with a thorough knowledge of control panel operations and automatic safety valves. To avert such an incident, tank connections and pipeline routing should be examined to determine the possibility of:

- Inducing, from the head in the tank, a self-sustaining flow through the bottom draw-off lines to a point outside the diked area.

- Intentional pumping of LEG or naphtha to the same point.

In many facilities fluid can be sent beyond the dikes both ways. This is particularly critical in plants with concrete tanks and no containment area, or those with close high dikes.

SECURITY EVALUATION OF LEG TERMINALS

The most effective deterrent to sabotage is a well organized physical security program. In addition to a security plan which details responsibilities, procedures, and countermeasures, the need for the following factors should be determined for each facility:

- Physical barriers, guards, guard dogs, random roving patrols, and alarm systems.

- Area surveillance devices and intrusion detection systems; including terrestrial, in-water, and waterfront sensors.

- Specialized and redundant communications and lighting systems.

- Hardening of specific structures to reduce the ease of damage and control forceful entry.

- Security escorts for ships, trucks, and tank cars.

- Traffic control, air and underwater surveillance, unique security procedures and countermeasures for waterfront and shore facilities.

- Special damage control equipment and procedures.

- Personnel screening procedures.

- Visitor clearance and control.

- Special training requirements.

- Authority for guards to carry and use weapons.

- Training staff to avoid loose talk and to report suspicious persons.

Access to all of the facilities we visited would be easy, even for untrained personnel. At the LPG facilities, in particular, there was an apparent sense of complacency about security. The only special precaution we observed during our visits was the use of local police support for traffic control while the Descartes was offloading at the Everett LNG terminal. Only one site provided a detailed security plan in writing. The rules for LNG facilities under consideration by the Office of Pipeline Safety Operations, however, require that each LNG operator prepare and follow written security procedures.[5]

All of the 16 LEG storage facilities we visited are fenced and most of the plants have gate guards and routine visitor check-in procedures during daylight hours, but none of the guards are armed. Two sites use closed-circuit TV to monitor traffic at the main gate. There appears to be heavy reliance on the closed-circuit Low Light Level TV system on those sites where it is installed. Procedures for internal patrols seem to depend on the individual initiative of the crew foreman or night watch, particularly during plant "idle-time" periods. On one night neither we nor company personnel were able to establish phone contact

with anyone at an urban, operating LNG plant. There is no intrusion/detection alarm system at any of the installations.

The lack of redundancy of certain facility installations and equipment contributes to overall plant vulnerability. Emergency power supplies and communications are two critical areas. Because even untrained saboteurs recognize the importance of severing all communications and power supply lines, battery operated radios with a 24-hour emergency channel to police should be available at key locations throughout plant areas. Emergency generators should be located away from hazardous areas, with a fuel supply that is well protected from fire and explosions.

Security procedures for truck trailer and railcar operations are inadequate. Drivers are not identified nor are vehicles and railcars inspected, before loading or offloading. This is of particular concern because trucks are vulnerable to hijacking and unguarded railcars are attractive targets for terrorist groups.

VULNERABILITY OF LEG TRUCK TRAILERS AND RAIL TANK CARS TO SABOTAGE

Truck trailers are used to transport both LNG and LPG; rail tank cars are used only for LPG.

The extended exposure of these mobile LEG containers increases their vulnerability to sabotage. A truck or rail car which operates over an established route between fixed points is an easy target for a saboteur. A truck can be hijacked for extortion, or for malicious use of the cargo; a group of tank cars can be derailed at a predetermined

time and place. Both are very vulnerable to improvised explosive devices and other weapons commonly used by terrorists, including high-powered small arms. Truck trailers are particularly dangerous because they allow the easy capture, delivery, and discharge of a large amount of explosive substance to a point or points of the hijacker's choosing.

Container design is a critical factor in determining the vulnerability of a vehicle to destruction.

LPG Vehicle Tanks

The LPG containers used on tank cars and truck trailers are single wall, cylindrical, steel pressure vessels, mounted horizontally. The standard railroad tank cars hold 115 cubic meters, while the truck trailers hold 40 cubic meters. Tank car fittings and liquid lines are top mounted at the tank center, while trailers have bottom rear lines.

The same techniques can be used to penetrate or rupture LPG trailers or tank cars. The 5/8 inch steel wall can be easily cut with pocket size explosive devices, and many other weapons commonly used by terrorists would also be effective.

LPG vehicle tanks are especially hazardous because the LPG is stored under pressure, 255 psig at 115^{o}F for propane. Any tank penetration causes an LPG discharge and an associated fire hazard. LPG tanks frequently explode

when exposed to fire. The pressurized storage also causes LPG to discharge if any tank valve is opened, including the top mounted valves on tank cars.

LNG Trailer Trucks

LNG is currently carried overland only by trailer trucks. The tanks are slightly less vulnerable than LPG tanks because they are double-walled. The walls are relatively thin, however, and can be penetrated by a fairly small improvised shaped charge. Properly placed, such a charge would cause LNG to discharge into the insulation space, causing the outer jacket to fracture and disintegrate.

VULNERABILITY OF LEG AND NAPHTHA SHIPS TO SABOTAGE

External Attacks

There are very few alternatives available to a saboteur of an LEG ship if he is denied on-board access to vulnerable areas. The placement of explosive charges on a ship's hull requires diver training and specially designed devices or significant amounts of military type explosives to be effective. The sabotage operation would have to be conducted while the ship is anchored or alongside the pier. Improvised limpet mines can cause critical damage and flooding in single hull ships, including many LPG carriers. Several single hulled merchant ships were sunk in Vietnam with crude, home-made limpet devices. Improvised limpet mines could cause extensive, but not critical damage to a double hull LNG ship.

Effective port surveillance during LEG carrier operations can minimize the threat. The Coast Guard should also be prepared to take appropriate action in the event of a suspected attack. This includes a ship bottom and pier area search by qualified explosive ordnance disposal experts.

Boarding a ship in a roadstead or even at anchor is very difficult without crew assistance. However, saboteurs might use various ruses, such as feigning injury or distress, to gain this assistance. Unless pier access is restricted, a saboteur might be able to board a ship at the pier under some guise. Effective surveillance and awareness of the dangers by the ship's crew could prevent these unauthorized boardings.

Another potential sabotage threat comes from the crew. Only an expert would recognize some types of explosive material as explosives. One LNG ship crew member, trained in the use of explosives, could cause simultaneous tank and hull damage below the water line, with proper charge placement. In the absence of effective damage control, this might initiate an extremely hazardous sequence of events. A crew member of a single hull LPG tanker could do even more damage to the ship.

Vulnerability

The double hull of the LNG tanker provides a higher degree of resistance to external blast damage than the single hull of a LPG ship or a conventional tanker. It also provides reserve buoyancy and stability control in the event of extensive damage and flooding. We believe that an LNG tanker would survive a swimmer sapper attack by a

terrorist group without significant tank damage. The spherical tank configuration appears to be the least vulnerable to this type of attack because of the hull stand-off distance and skirt support structure.

All four tank designs allow for internal access below the storage containers. The pipeline tunnels or duct keels run the entire length of the cargo area with open trunks at both ends. (See Appendix VI-2.) These tunnels might become liquid distribution systems in the event of deliberate explosive rupture of a tank.

FINDINGS

THE THREAT

- Public utilities and petroleum companies have been often targeted by terrorist groups and individuals.

- A large range of firearms, ammunition, and explosives is available in this country to potential saboteurs. Instructions for the construction and use of appropriate explosives from easily available materials are widely available in open literature.

- The existence of highly trained, international terrorist groups armed with sophisticated weapons and explosive devices, combined with the openness of our borders, poses a serious threat to the safety of LEG and naphtha facilities.

- Recent and future technological advancements in weaponry will eventually increase the threat to LEG and naphtha facilities.

STORAGE FACILITIES AND DIKES

- Except during ship unloading at one site, the security procedures and physical barriers at LEG and naphtha facilities we visited are not adequate to deter even an untrained saboteur.

- Most LEG and naphtha storage tanks are highly vulnerable to sabotage. Metal tanks are the most vulnerable. Underground storage or concrete tanks with a sloped earthen berm from ground level to tank top provide the most protection against explosive penetration.

- Sabotage of single or double wall metal tanks could lead to complete catastrophic failure of the wall(s) and subsequent massive spilling of the contents. The level of sabotage needed is within the capabilities of terrorist groups.

- Properly placed charges would blow out a very large section of the bottom of a high, thin concrete dike. Properly designed earthen dikes are extremely difficult to breach.

- In many facilities, through manipulation of equipment, it is possible to spill a large amount of fluid outside the diked areas through the draw off lines.

ADJACENT ACTIVITIES

- Even a few cubic meters of LEG or naphtha in a sewer system can cause many casualties and do a great deal of damage.

- LEG storage facilities in cities are often adjacent to sites which store very large quantities of chlorine, LEG, or other volatile liquids. Thus, a single cause might simultaneously destroy many tanks, or an

incident at one facility might cause further failures at adjacent facilities.

LEG VEHICLES

- LEG trucks are highly vulnerable to sabotage and hijacking; tank cars are also highly vulnerable to sabotage.

- Small charges can penetrate the one or two walls of LEG vehicle tanks, as can other weapons.

- LEG can easily be discharged from vehicles, just by opening unlocked valves.

- LNG vehicle tanks are slightly less vulnerable to sabotage than LPG vehicle tanks.

LEG AND NAPHTHA SHIPS

- LNG ships are vulnerable to sabotage, but unless explosives are used on-board or the ship is hijacked, massive spillage into the water is unlikely.

- Improvised limpet mines placed on a single hull LPG ship, while it is anchored or alongside the pier, could result in a massive LPG release and the sinking of the ship. On-board explosives could sink the ship even more easily.

- No governmental body has made a comprehensive effort to determine critical shipboard vulnerabilities to malicious action.

GENERAL CONCLUSION

- The vulnerability to sabotage of LEG facilities and transportation in urban areas is a serious danger to offsite lives and property.

RECOMMENDATIONS

TO THE SECRETARY OF TRANSPORTATION

We recommend that the Secretary of Transportation:

- enforce the requirement, stated in 33 CFR Part 126.15(a), that guards provided by the owner or operator of an LEG facility be in such numbers and of such qualifications as to assure adequate surveillance and to prevent unlawful entrance. In particular we recommend that the Secretary make and enforce regulations requiring:

  1) - that every truck and train car is carefully checked for weapons and explosives before it enters the facility.

  2) - that every driver and passenger in a vehicle is positively identified before they enter the facility. Picture badges should be issued to all frequent visitors.

3) - surveillance of site boundaries and key components on a 24-hour basis.

4) - that devices be installed which can immediately detect unauthorized entry. These should include completely lighted fences, intrusion alarm systems which can detect if the fence is damaged or crossed, and low light television cameras which can see any area of the boundary.

5) - battery powered redundant communications through which security personnel at any point on the facility can communicate to each other and to local law enforcement officials.

6) - employee screening and training procedures. The training should include threat awareness, recognition of hazardous devices, special safety precautions, and preventive actions that can be taken.

7) - a written security plan which details appropriate procedures for all of the above and is routinely promulgated to all employees.

- require that loaded LEG trucks and loaded, stationary railroad cars not be left unattended outside the plant area.

- determine what security procedures are necessary to prevent LEG trucks from being sabotaged or hijacked and used for destruction. Particular attention should be paid to unavoidable movements of LEG through densely populated areas.

- identify all the specific design vulnerabilities to sabotage at each facility and determine the amount of hardening of key components that is needed to reduce facility vulnerability to sabotage and to control forceful entry.

- require that emergency generators be located away from hazardous areas, with a fuel supply that is well protected from fire and explosions.

- require that automatic shut-off or isolation valves be placed along pipelines which run from piers to storage tanks.

- prohibit the transmission of LEG through pipelines whose integrity is threatened by nearby offsite industrial activity.

- examine the total handling and storage system at each facility to see if an external pipeline breach in conjunction with the misuse or disabling of appropriate system components could cause a major spill outside the containment area. DOT should require whatever modifications are needed to make this impossible.

- examine all facilities near LEG storage sites to see the consequences of simultaneous failures at several sites from a single cause and whether failures at one facility could cause failures at others.

- determine whether LEG or LEG vapor accumulating under a tank elevated on piles could cause an explosion that could rupture the tank bottom.

- systematically determine the critical vulnerabilities to sabotage of ships carrying hazardous materials in U.S. ports and require appropriate preventive and mitigating measures.

- implement effective port surveillance during LEG carrier operations.

- be prepared to take appropriate action in the event of a suspected attack including a ship bottom and pier search by qualified explosive ordnance disposal experts.

- develop contingency plans and emergency procedures for individual ports in the event of a ship hijacking.

TO THE SECRETARY OF ENERGY

We recommend that the Secretary of Energy:

- establish a comprehensive program to determine the vulnerability of LEG tanks to sabotage. This program should include the effect of:

  o External explosives, including shaped charges.

  o Internal explosives.

  o Firearms and light anti-tank weapons.

  o Introduction of other chemicals.

TO THE CONGRESS

We recommend that the Congress:

- enact legislation requiring that facility guards carry weapons and be authorized to use them if necessary to prevent sabotage. This recommendation is similar to one that GAO made in 1977 for commercial nuclear fuel facilities.[6]

AGENCY COMMENTS AND OUR EVALUATION

The Departments of Transportation and Commerce question the need for much of the material in this chapter. They express concern that the chapter could provide material for potential saboteurs. Many industry comments reflected similar concerns.

Unfortunately, instances of sabotage and terrorism occur so frequently in today's world that the potential cannot be ignored in any serious treatment of the safety of highly dangerous substances such as liquefied energy gases. Nor would it be sufficient merely to say that LEG facilities are vulnerable to sabotage. In making a realistic assessment of this vulnerability, we have attempted to show that malicious groups could sabotage LEG facilities and that current safeguards should be upgraded substantially. We have been careful not to give any information which would significantly increase the ability of potential saboteurs.

Notwithstanding its overall concern, the Department of Transportation agrees with many of GAO's recommendations

and points to several comparable provisions for LNG facilities in an Advance Notice of Proposed Rulemaking (ANPR) published by OPSO on April 21, 1977.

In several instances the ANPR addresses generally, but not specifically, an issue dealt with in our recommendations. They would require, for example, a written security plan, employee screening and training procedures, locating emergency generators away from hazardous areas, and written procedures for dealing with possible damage effects. DOT agrees that more specific requirements can reasonably be included in its regulations. We believe the specific requirements we recommend are necessary.

One section of the ANPR partially satisfies our recommendation that DOT prohibit the transmission of LEG through pipelines whose integrity is threatened by nearby, offsite industrial activity. Only new LNG facilities connected to natural gas pipelines are covered, however. We believe that existing LNG facilities and new and existing LPG sites should also be covered.

ANPR provisions would also require 24-hour surveillance of site boundaries and key components, battery-powered redundant communications, and, at facilities storing 250,000 barrels (40,000 cubic meters) or more, intrusion devices. DOT's comment, however, notes that alternate provisions for small, remote sites may be needed or appropriate. We agree that it may be appropriate to consider special provisions for remote sites, but such provisions are not included in the ANPR.

Even though DOT agrees in general with a number of our recommendations and points to its ANPR as corrective action already underway, we should point out that the ANPR was issued over one year ago and is just that, an advance notice. No proposed rules have been issued, and DOT officials could not tell us when they may be.

DOT disagrees with our recommendation that it determine whether LEG or LEG vapor accumulating under a tank elevated on piles could cause an explosion that could rupture the tank bottom. DOT states that ". . .safety is more effectively and efficiently served by prohibiting such designs of new facilities, as provided in the ANPR."

Even if the building of new LNG tanks on piles is prohibited, it still is necessary, in our opinion, to determine the vulnerability of existing tanks built on piles. DOT states that such research would be "extremely costly". Experts we consulted indicate that the kind of structural analysis and explosion effect calculations needed to carry out our recommendations would not require a sizeable expenditure of money or time.

DOT objects to our recommendation that it require modifications in facilities to prevent a major spill from a combination of an external pipeline break and the misuse or disabling of appropriate system components. DOT states that: ". . .in the absence of any showing of an imminent hazard, we believe the intended retrofitting of existing facilities is unjustified, and short of shutting down a large number of facilities, implementation is not possible. Such action could have a dire impact on public welfare with

associated greater risk than continued operation of the facility. . ." They agree that such modifications should be made for new facilities, however.

We believe the existing facilities would need to be shut down only a short time, at most, in order to implement this recommendation. This could be done during a period of low demand. The grave danger which could be caused from a major spill generated in this manner is the same for existing and new facilities, and greatly outweighs any inconvenience involved.

DOT disagrees with our recommendation that it require every truck and train car to be carefully checked for weapons and explosives before entering a facility. DOT questioned whether such a check would be effective in light of the potential for concealment and resulting lost time and cost.

In some ways such checks would be similar to baggage and passenger checks at airports. Once LEG checks are standardized, they would require relatively little time and should prove to be very effective.

DOT states that some efficient steps can be taken to reduce the risks to LEG trucks of sabotage, hijacking, and destructive use. These include requiring vehicles to be attended, use of driver-initiated engine breakdown controls, manual reset wheel locks, locked valves, the installation of tire pressure release devices, gas tank water injectors, "on only" visual audible alarms, and automatic emergency signal transmitters. We agree that these measures should be required.

In a general comment on this chapter, DOT states: "The security measures proposed for LEG facilities, if imposed continually, are a classic example of an 'overkill' approach to protect one possible terrorist target while leaving other equally desirable targets unguarded. Furthermore, the recommended security measures would not deter the effective use of the mortar and rocket weapons which the report states are in the hands of potential saboteurs. Neither would these precautions at LEG facilities in any way affect the availability to saboteurs of gasoline or their access to drains for introducing many times the required 1/2 cubic meter into every sewer system in this country." Some industries made similar comments.

We do not agree for these reasons:

(1) Gasoline, because it is a liquid under normal conditions, is much less dangerous in sewers and elsewhere than LEG.

(2) Adequate security measures would offer great protection against the worst sort of sabotage---which requires entry to the site.

(3) Our work was directed to liquefied energy gases. The dangers are clear, and the measures needed are effective and appear to cost relatively little. If there are other equally grave dangers to public safety, corrective measures for them should also be considered.

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5. Department of Transportation (OPSO), Advance Notice of Proposed Rulemaking, "Liquefied Natural Gas Facilities (LNG); Federal Safety Standards", Development of New Standards. Federal Register, Vol. 42, No. 77, April 21, 1977.

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CHAPTER 10

THE CLEVELAND LNG ACCIDENT OF 1944

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INTRODUCTION

The accident in the liquefaction, storage, and regasification plant of the East Ohio Gas Company on October 20, 1944, was the first and only LNG accident in this country to cause off-site damage and injury. Several major investigations were therefore undertaken.

This chapter reviews the circumstances of the accident and the principal findings of the investigations. There are still lessons to be learned. LNG technology has changed since 1944, but it has not changed radically. The people who planned, built, and operated the Cleveland facility were trained, experienced, and reputable. They believed their plant was safe enough to be located in a populated area.

On October 23, the Mayor of Cleveland established a Board of Inquiry which produced the "REPORT OF THE TECHNICAL CONSULTANTS BOARD OF INQUIRY FOR THE MAYOR OF CLEVELAND ON THE EAST OHIO GAS COMPANY FIRE". This report, submitted in July 1945, addressed a broad range of questions relating to the design, construction, and operation of the plant. It included a narrative of the disaster that incorporated several eyewitness accounts of the early sequence of events.

In addition, the Federal Government's Bureau of Mines had a responsibility to obtain technical information on the causes of such disasters.[1] Its investigations produced "BUREAU OF MINES REPORT OF INVESTIGATIONS 3867".

The Coroner of Cuyahoga County also prepared a report whose recommendations and conclusions were included in the Mayor's Board Report.

The synopsis of the report of the Mayor's Board said: ". . .partly owing to the fact that there is no evidence of warning or irregularity in the behavior of the plant up to the moment of failure, the specific and direct cause of the failure may never be known exactly." It also noted that a number of possibilities were developed in the inquiry which, separately or in combination, could be the cause of the disaster.

BACKGROUND

The East Ohio Gas Company (EOG) supplied fuel to the growing Cleveland metropolitan area. The company examined ways to meet the increasing peak demand for gas, including the large requirements of war industries, and ultimately selected liquefied natural gas as the best solution. It built a new plant on the site of an older one that had been used for 50 years as a conventional gas plant with water-sealed compressed gas tanks. The new plant received natural gas from fields in West Virginia, liquefied it for storage, and regasified it for distribution through the regular gas distribution system when needed.

The commercial liquefaction process for natural gas they used was patented by a California inventor in 1937. The Hope Natural Gas Company initiated intensive laboratory study of the process and constructed a small pilot plant in the summer of 1939. Its operation led to the definition and solution of a number of technical problems. During six months of operation, the pilot plant produced about 22,600

cubic meters of LNG which was temporarily stored in a horizontal cylinder eight feet in diameter and 18 feet long holding about 26 cubic meters.[2] The EOG Cleveland plant was the first large operation anywhere.

The EOG plant, completed in January, 1941, had three spherical tanks. A fourth cylindrical tank was built two years later. The collapse of this cylindrical tank caused the disaster.

DESIGN, CONSTRUCTION, AND OPERATION

The people involved in planning, designing, constructing, and operating the EOG LNG plant were competent and reputable. Mr. H.C. Cooper, President of the Hope Natural Gas Company, testifying before the Mayor's Board, said that the extent to which engineering skill could prevent such disasters was an open question.

Site Selection

The site for the LNG plant was selected because it was already EOG property and was appropriately located on the gas distribution system. The storage tanks were placed on a small site in the middle of a densely populated and highly industrialized section. Mr. W.G. Hagan, Vice-President and General Manager of the EOG, told the Mayor's Board that the company felt it was building a safe plant that could be located anywhere. Ground tremors generated by activities within and outside the plant were not considered significant. Although the bearing capacity of the ground was low, the foundations of the tanks were built to compensate for this and remained stable throughout the disaster. No action was taken to prevent any material

spilled over the dikes from entering sewers.[3] During the October 20 incident, LNG was seen flowing in gutters, and several structures exploded or burned from the inside out. This suggests very strongly that sizeable amounts of LNG went into sewers and basements.

Tank Design

The original plant, with three 2,359 cubic meter spherical LNG tanks, produced its first LNG on February 7, 1941. By April 1942, EOG found it necessary to expand the storage capacity. Designs and bids for spherical and cylindrical storage vessels were called for. The Pittsburgh Des Moines Steel Company (PDM) told the gas company that a cylinder was as satisfactory as a sphere and cheaper. Mr. J.O. Jackson, Chief Engineer of PDM, later said that he had not recommended a cylinder over a sphere because of cost, but because a stress analysis of a cylinder could be made with greater certainty.[4] Appendix X contains a detailed discussion of the tank designs and testing.

The building permit for Tank 4, a cylinder of 70 foot diameter with a working depth of 43 feet and a capacity of 4,248 cubic meters, was issued in August 1942. It was put into service in the fall of 1943.

In both the spherical and cylindrical designs the inner tanks were made of a nickel alloy steel having at least 3.5% nickel and less than .09% carbon. Present day tanks are built of 9% nickel alloy steel. The spherical tanks were insulated with cork; the cylindrical tank, with rock wool. Present day tanks are insulated with perlite or polyurethane foam.

External Tank Frosting

Frost spots appeared on the bottom of Tank 4 several months before the failure. Mr. Jackson suggested ventilating the tank bottoms with heated air. This did away with the frost, but not, of course, with the cause of the frost. The spots returned when the air flow was stopped. Frost spots also appeared on the top of Tank 4, but disappeared when rock wool was added. Frost spots had previously appeared on the top of one of the spheres, but disappeared when granular cork was added.

Provisions for Spills

A failure of the metal during initial testing of Tank 4 (see Appendix X) led EOG to consider the possibility and effects of leaks or spills. It was decided to use an idle pit as a sump with drains running to it from all tanks.[5] Dike walls were also built around each tank, but their capacity was not adequate to contain and carry off to the sump a sudden large flow from one or more tanks. Little thought was given to massive spills because PDM said they were installing a tank that could not leak.[6] Thus, provisions were made only for relatively slow leaks. (Current LNG storage site dikes are also designed to contain only relatively slow leaks (see Chapter 5).

The spillage sump was covered by a steel top, grouted in around its circumference, and topped with a forty-foot stack. There was no burning taper, no flashback screen, and no provision for purging the sump with inert gas. The top collapsed inward in the disaster.

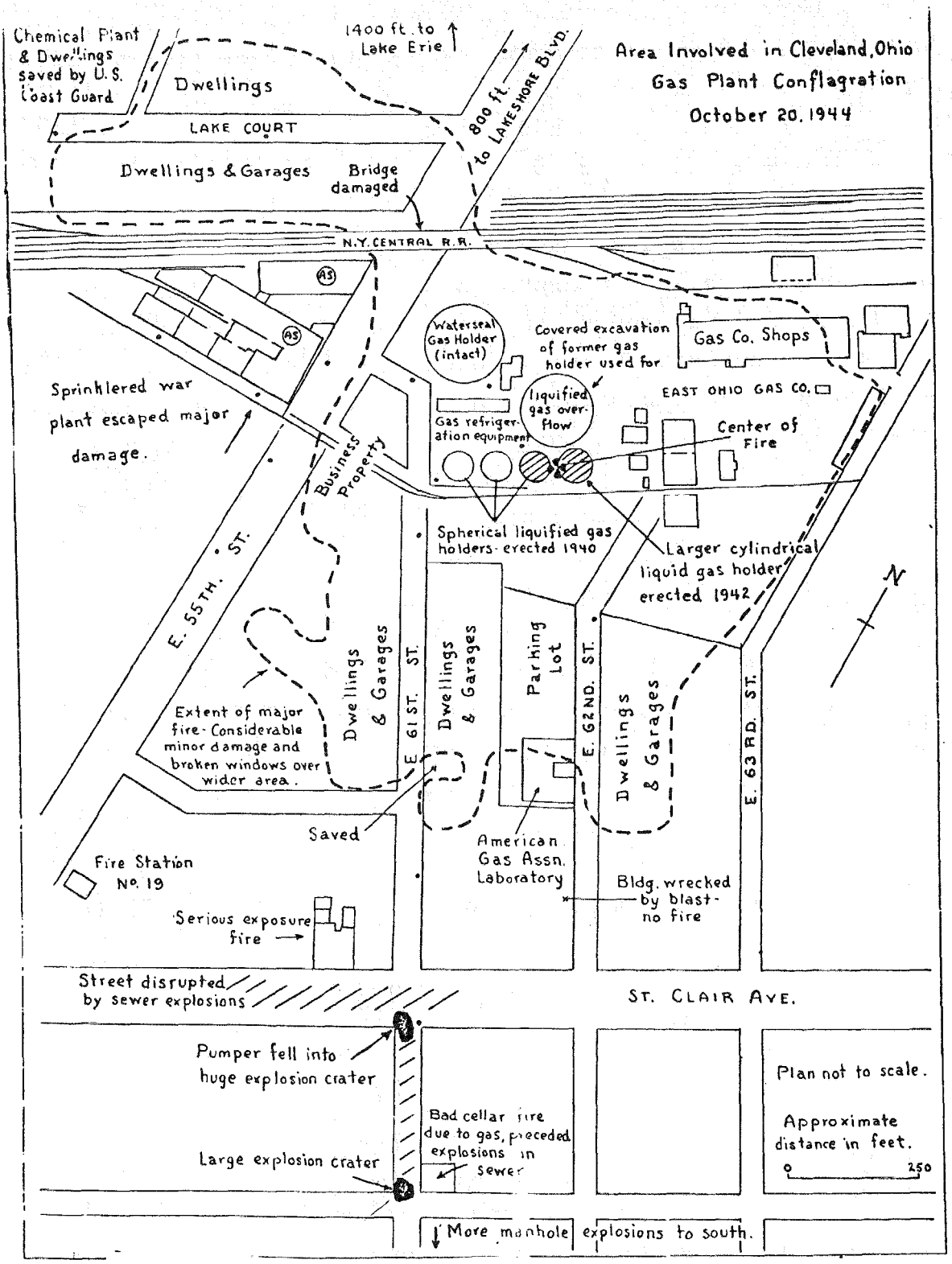
AN ACCOUNT OF THE SPILLS

In the afternoon of October 20, when Tank 4 failed, employees were performing their normal duties in shutting down the plant. They appear to have been well-trained and conscientious. No unusual conditions or causes for alarm came to their attention.

When the catastrophe began, the wind was from the north and northeast at 12 to 16 mph. The temperature was around 50°F.

First vapor and liquid came from the south side of the cylindrical tank.[7] Then it collapsed. There was a "whoosh," a dull red glow, and a slight earth shock. The vapor clouds spread in all directions, some hugging the ground while others rose above it. The clouds suddenly ignited with orange-yellow flashes. Then a great rush of flames generated waves of heat powerful enough to blister buildings half a mile away.

When Tank 4 failed, it released about 4,200 cubic meters of LNG at -260°F.[8] Vaporization began at once, but the lay of the land caused most of the liquid to flow south and southeast. The map shows the area involved in the accident. The plant was in a slight depression, but the general slope of the ground was downward from north to south with about a four-foot drop from the north side of the plant proper to a point 100 yards from the Gas Association Building. The liquid moved down East 62nd Street where some entered the storm sewer, vaporized, and exploded. The vapor moved along 62nd Street and ignited.



Source: NFPA Newsletter, November 1944.

About 20 minutes after Tank 4 failed, the legs holding Tank 3 collapsed from the heat, releasing another 2,100 cubic meters of LNG.[9] The subsequent explosion shot flames more than half a mile into the air. The temperature in some areas reached 3000°F.[10]

Some 10 minutes later another huge blast in the yard area began a series of explosions in sewers, underground conduits, and basements. Streets were blown up, manhole covers hurled into the air, water lines broken, and windows shattered. One explosion opened a crater 25 feet deep, 30 feet wide, and 60 feet long swallowing a fire department pumper and ripping a hole in one of the main intercept sewers. Smaller blasts continued for several hours.

FIRE BEHAVIOR AND FIREFIGHTING

The LNG spills produced explosions and rapid burning in gas clouds, large gas flames, and the burning of gas which evaporated as the liquid ran over the ground and found ignition points. There were fires and explosions in confined spaces, ignition of materials by radiant heat, and secondary fires started by LNG-soaked rock wool. Drops of liquid gas fell on roofs and ignited. Some buildings in the middle of areas of intense fire escaped almost undamaged while their immediate neighbors were almost totally destroyed. The photographs on the next two pages show the damage done.

The first fire alarm sounded almost immediately. The fire spread rapidly and eventually 8 alarms were struck. Before fire trucks arrived houses on both sides of East 61st and East 62nd Streets were burning. Those nearest the



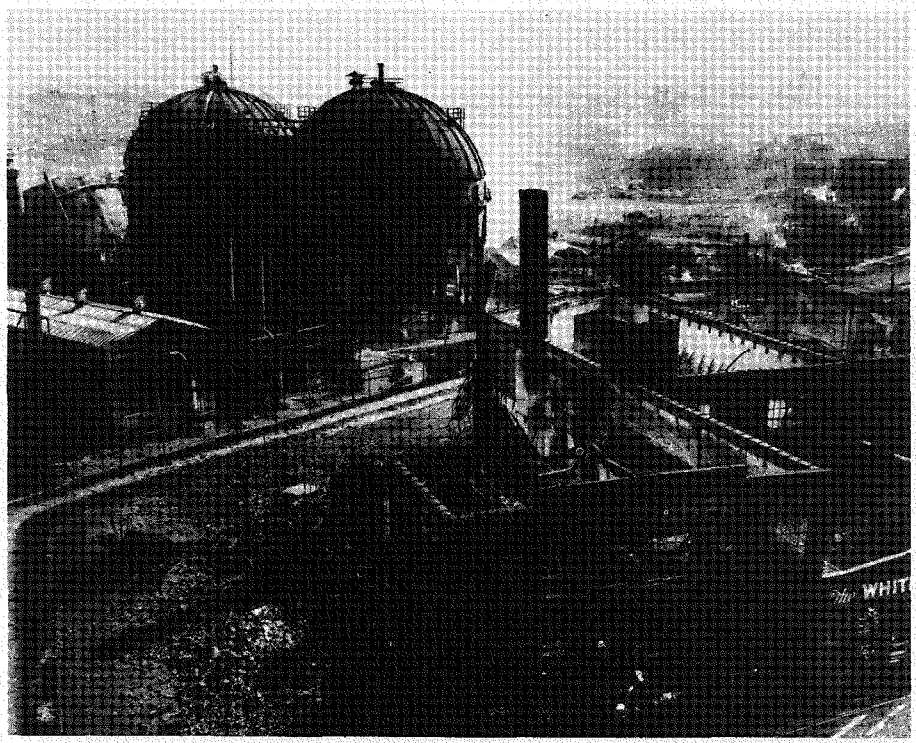
AERIAL VIEW OF DESTRUCTION CAUSED BY EXPLOSIONS AND FIRE AFTER LNG SPILL IN CLEVELAND, OHIO, OCTOBER, 20, 1944.

gas plant on 62nd Street were burning from the inside out. Flames ran along the curbing and disappeared into sewers.

A total of 35 firefighting companies, two rescue squads, a Coast Guard fireboat, and the arson squad were on the scene. Fire and explosions destroyed or damaged parts of the fire communication system, putting 230 boxes out of commission. Despite damage to some water mains, there was adequate supply. At some places fallen high-tension lines blocked streets and forced the fire department to lay very long lines for water.

CORONER'S REPORT[11]

Two factories, eight mercantile establishments, and the laboratories of the American Gas Association suffered



VIEW OF THE REMAINS OF THE PLANT AND LNG STORAGE TANKS.



REMAINS OF MAIN BUILDING OF EAST OHIO GAS COMPANY'S LNG FACILITY, AFTER 1944 DISASTER.

critical damage. The Cleveland Fire Chief gave these figures:[12]

Totally Destroyed	Partially Destroyed
79 houses	35 houses
2 factories	13 factories
217 automobiles	
7 trailers	
1 tractor	

The area directly involved was about one-half-mile square, of which about 30 acres were completely devastated; everything combustible burned. Some nearby dwellings suffered little damage while some farther away were destroyed.

At least 14 of 39 large industrial users of gas were temporarily shut down. Rail services passing through the area were rerouted. City transit services were halted by street damage and destruction of track. Electric cables serving the area were burned and poles destroyed. Some underground cables were damaged, and power was cut off as a safety measure. Telephone circuits were damaged and 878 telephones were put out of commission.

A thorough survey was made to locate and examine the parts and fittings from Tanks 3 and 4. The violence and speed with which Tank 4 collapsed was demonstrated by the fact that it broke up into hundreds of fragments, varying in size from 38' x 16' to pieces the size of a man's hand, which were distributed over thousands of square feet. One piece weighing several hundred pounds was thrown about 200 feet and smaller pieces traveled twice that distance.

Consultants to the Mayor's Board suggested that the initial failure of Tank 4 took place at the top center of the inner shell and that the possibilities of shock or stress in that part of the tank required particular examination.[13] The Bureau of Mines said that fragments from Tank 4 appeared to be of the type induced by embrittlement.[14]

According to early reports, 136 people were listed as dead and an additional 77 as missing.[15] The coroner's final tally was 130 deaths, and 225 injuries.[16]

The National Fire Protection Association (NFPA) Newsletter of November 1944 said that ". . .there might have been much more extensive loss of life had the explosion occurred an hour later". At the time of the fire most children were in school and most men were at work. The NFPA Newsletter also said: "The fact that the wind was blowing away from the congested part of the area is believed to have been a major factor in prevention of an even more devastating conflagration which could have destroyed a very large part of the East Side."

FINDINGS

- It is not certain what factor or combination of factors caused the collapse of Tank 4.

- Before the East Ohio Gas Company facility was constructed extensive research had been carried out and a pilot plant was built and operated.

- Before cylindrical Tank 4 was built, three spherical tanks had been operating without difficulty at the facility for more than two years.

- There is no reason to believe that the choice of a cylindrical shape for Tank 4 had any connection with the accident. All large LNG tanks today are cylinders.

- The staff and management of the East Ohio Gas Company who operated the facility, and the Pittsburgh Des Moines Steel Company (PDM) who built it were trained, experienced, and reputable.

- The East Ohio Gas Company took precautions to control small and moderate rates of LNG spillage. They assumed that a sudden massive spill was not credible. The same assumption is made today in designing dikes around LNG facilities. In fact, it is made in designing dikes around most facilities which store large amounts of all dangerous fluids.

- Both PDM and the East Ohio Gas Company assumed that a small leak would precede a catastrophic collapse. They also assumed that the small leak would be noticed and corrected before it became serious.

- Frost spots were noticed on the top and bottom of Tank 4 and had previously appeared at the top of one of the spherical tanks. The frost spots at the top of the tanks were caused by the settling of the insulation and disappeared when more insulation was added. Mr. J.O. Jackson, Chief Engineer of PDM, advised the East Ohio Gas Company to eliminate the frost spot at the bottom of Tank 4 by continuously ventilating it with warm air. It disappeared whenever this was done and reappeared when the ventilating was stopped.

- No thought was given to the nearby presence of other industrial facilities, residences, storm sewers, or other conduits. Little thought is given to similar neighbors in planning some facilities today.

- Less than 6,300 cubic meters of LNG spilled and a large part of that remained on Gas Company property. This is a very small amount compared to the capacity of today's facilities, which often store more than 100,000 cubic meters.

- The final death toll was 130. There were 225 injuries.

- The National Fire Protection Association (NFPA) said that casualties could have been much higher if the explosion had taken place at a different time of day. At the time of the fire most children were in school, and most men were at work.

- The NFPA also said that, if the wind had been blowing in the opposite direction, a very large part of the East Side of Cleveland could have been destroyed.

- Among the conclusions and recommendations of the Mayor's Board of Inquiry were the following:

  o "The obvious teaching of the. . .disaster is that insufficient attention was given by the public authorities and by the industry alike to the restrictions that were necessary for safety in the storage of this material; and that a false sense of security had been engendered. . ."

- An application for construction should include a full statement of the energy content and maximum possible rate of energy dissipation.

- The application should show proof that the design provides for the contingency of failure of each and every component, and for the consequences of failure.

- The owner should be required to prove that he offers no hazard to the surroundings and that firefighting and emergency provisions are adequate.

- Among the recommendations of the Bureau of Mines were the following:

  - Plants dealing with large quantities of liquefied inflammable gases should be isolated at considerable distance from inhabited areas.

  - Containers for the liquefied gas should be isolated from other parts of the plant and provided with dikes large enough to contain the entire contents of the tank.

  - Extreme caution should be taken to prevent spilled gas from entering storm sewers or other underground conduits.

- The Coroner's final conclusion was:

"In view of the destruction by this disaster, the Coroner must come to the conclusion that no plant or

structure of any kind which, by reason of its inherent nature may be explosive or inflammable, or which may present any hazard which would endanger life and property in its vicinity, should be permitted to be built in a residential, semi-residential, business or congested factory district."

AGENCY COMMENTS AND OUR EVALUATION

The Departments of Commerce and Transportation and the Federal Preparedness Agency of the General Services Administration comment that cryogenics technology, storage tank fabrication, and construction techniques have substantially improved since the Cleveland accident. DOT states: "The inclusion of an account of the 1944 Cleveland LNG incident in this report without stressing the fact that the apparent causes of this mishap do not exist at today's LNG facilities is misleading."

The actual cause of the Cleveland accident has never been determined. There is no reason to believe that cryogenics was the primary problem. LNG technology in use today is still relatively new. We are not sure what effect many years of exposure to very cold temperatures will have on modern LNG tanks. The industry did not discover the "rollover effect" of combining different LNG mixtures in a storage tank until after an August, 1971 incident in La Spezia, Italy in which about 220 cubic meters of LNG were released through safety valves. There is still much that needs to be learned about LEG properties and behavior. For example, much uncertainty still exists on the distance an LNG cloud may travel in a flammable state, as we discuss in Chapter 12.

Both Commerce and DOT emphasize the more recent LEG safety record. Commerce says that our analysis of an accident that took place 34 years ago points out the recent safety record of LEG facilities. Commerce also says that the serious oversights that contributed to the Cleveland accident could not happen with modern technology, strict construction safety codes, and sophisticated and redundant

monitoring equipment. They said, for example, that any facility would be immediately shut down if frost developed on the outer tank walls, and the defect corrected.

The LEG industry's safety record has not been perfect over the last 34 years. There is a long history of accidents in all aspects of LPG use. Although there have been no major LNG accidents since the one in Cleveland, there have been documented incidents in LNG production, storage, and distribution in the United States and abroad.

There is no evidence that present day technology, stricter construction safety codes, and sophisticated and redundant monitoring equipment can certainly prevent another major catastrophe. Present safety codes will not necessarily prevent flows over dikes, as we have shown in Chapter 5. Two major LEG storage facilities overseas have blown up as a result of accidents, including one in Qatar, in 1977.

In January, 1978, a 40,000 cubic meter butane storage cavern at the Sun Oil refinery in Marcus Hook, Pa., was overfilled despite three monitoring methods and a safety relief valve.

The cavern was excavated in granite more than 300 feet underground. The main device to measure the butane level in the cavern, a manometer, malfunctioned and indicated that the cavern contained only 10,000 cubic meters of butane. A vapor pressure gauge at the wellhead also malfunctioned, and company bookkeeping records, showing how much butane was pumped into and out of the cavern, were very inaccurate. The safety relief valve, set

at 175 pounds per square inch, never operated because the cavern pressure never reached that level.

The escaping butane caused fires that destroyed five houses only 100 feet from the outer wall of the cavern. Since 1956 there have been at least four other overspills from mined caverns.

The conclusions of those who investigated the Cleveland accident are still highly relevant: that plants dealing with large quantities of liquefied flammable gases should be isolated at considerable distance from inhabited areas, and that extreme caution should be taken to prevent spilled gas from entering storm sewers or other underground conduits.

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3. Mayor's Board, p. 94.

4. Bureau of Mines Report of Investigations 3867, May 30, 1945, (Hereafter BuMines) p. 13.

5. BuMines, p. 18-19.

6. Mayor's Board, pp. 43-44.

7. BuMines, p. 24.

8. BuMines, p. 24.

9. BuMines, p. 25.

10. Coroner's Report on East Ohio Gas Company Disaster, Cuyahoga County, Cleveland, Ohio, July 1945, p.8.

11. Coroner's Report, p. 11.

12. Mayor's Board, p. 31.

13. Mayor's Board, p. 7, 62, and 62-a.

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CHAPTER 11

LIABILITY AND COMPENSATION

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INTRODUCTION

A major LNG accident in a densely populated area could cause damage of such severity that injured parties could not be fully compensated under current insurance arrangements.

Claimants would face a complicated legal and financial situation. In some instances liability would be limited by statute. The long and complex litigation necessary would be burdensome and perhaps futile since neither the insurance nor the reachable assets of the corporation may cover the damages.

Companies that transport and store LNG are typically part of intricate corporate structures, which sharply limit the liability of the parent corporations for offsite damage. Most of the assets of the frontline company (the company actually owning or operating the facility or vessel) may be destroyed in a major accident. Moreover, the insurance policies the companies carry are inadequate to cover the claims that could result from a major accident in a densely populated area.

Although highly destructive materials are transported by ship or barge through city harbors and rivers, stored in tank complexes in or near densely populated cities, and carried by truck and train through large cities, the Federal Government has neglected the issue of offsite liability of hazardous enterprises. No Federal agency assumes responsibility for assuring adequate compensation of victims.

THE OWNERSHIP STRUCTURE AND FINANCING OF LNG COMPANIES

Import Facilities

LNG is imported and stored by wholly owned, separately capitalized subsidiaries of larger firms. The structure places "corporate veils" between parent firms and those subsidiaries most vulnerable to liability. The most thinly capitalized level in this structure is usually the subsidiary most directly involved in LNG operations, and most vulnerable to liability. To the extent that debt to equity ratios increase, claimants have fewer assets to proceed against, assuming the assets of corporate parents are out of reach.

Table 11-1 shows the ownership structure and financing of LNG import facilities. Figure 11-1 illustrates typical corporate structures. Meaningful financial figures are not available for some companies whose facilities are far from start-up.

If the insurance coverage and surviving assets of a company are inadequate, claimants would have to obtain any additional recovery from the assets of a parent firm. This would be difficult, because claimants would have to persuade a court to hold the parent company accountable for acts of its subsidiary. Courts do so only if they find: a) the primary firm has not been run as a separate entity, but is completely controlled and financed by the parent; b) it has been so thinly capitalized that it cannot withstand normal business risks; c) it has substantially no business except with the parent corporation, or no assets except those received from the parent.

TABLE 11-1 LNG TERMINAL COMPANY DATA RELEVANT TO LIABILITY AND COMPENSATION[1]

MARINE TERMINAL AND STATUS	CORPORATE STRUCTURE		CAPITALIZATION ($ MILLIONS) ASSETS	LONG TERM LIABILITY	EQUITY[2]	LIABILITY INSURANCE COVERAGE PER INCIDENT ($ MILLION)	CLEARLY AMENABLE SERVICE OF PROCESS[3]
Everett, MA (near Boston) currently operating	Primary Cos.:	Distrigas of Massachusetts Corp. (owner/operator)	33.1	14.9	18.3	*	Massachusetts, Delaware
		Distrigas Corp. (importer)	2.6	0	2.6	*	Massachusetts, Delaware
	Parent:	Eastern Energy Corp. owned by	19.6	13.4	6.9	*	Massachusetts, Delaware
		Cabot Corp.	477.3	129.2	240.4	*	Massachusetts, Delaware
Providence, RI	Primary Co.:	Algonquin LNG, Inc. (lessee,[4] operator)	+	+	+	+	Rhode Island
	Parent Cos.:	Algonquin Gas Transmission Co. owned	+	101.9	69.9	+	Delaware, Massachusetts
		by Algonquin Energy, Inc. owned by	+	+	+	+	Delaware
		Eastern Gas & Fuels Assoc. (36.8%)	675.0	202.9	283.9	+	Massachusetts
		New England Gas & Electric Assn. (34.5%)	160.8	29.4	128.1	+	Massachusetts
		Texas Eastern Transmission Corp. (28%)	2,725.7	1,019.1	900.9	(5)	Delaware
		Providence Gas Co. (0.7%)	65.1	23.5	18.2	+	Rhode Island
Staten Island, NY (Rossville) proposed	Primary Cos.:	Energy Terminal Services Corp. (owner/operator)	*	127.7(est)	46.7(est)	100.0	Delaware, New York
		EASCOGAS LNG, Inc. (importer)	N/A	N/A	N/A	*	*
	Parent:	Public Service Electric and Gas Co.	4,532.1	1,958.2	1,932.5	*	New Jersey
West Deptford, NJ (near Philadelphia) proposed	Primary Cos.:	Tenneco LNG Inc. (owner/operator)	N/A	N/A	N/A	*	New Jersey, Delaware
		Tennessee Gas Pipeline Co. (importer)	*	*	*	*	Tennessee
	Parent:	Tenneco Inc.	6,584.2	2,280.3	2,400.0	100.0 of excess liability coverage	Delaware, Texas
Cove Point, MD currently operating	Primary Co.:	Consolidated System LNG Co. (50%)	121.1[6]	54.0	65.1	140.0	Delaware, Maryland, Virginia
	Parent:	Consolidated Natural Gas Co.	1,798.4	639.3	755.7	*	Delaware
	Primary Co.:	Columbia LNG Corp. (50%)	220.5	94.0	95.6	50.4 Columbia Gas System and affiliates	Delaware, Maryland Virginia, Ohio
	Parent:	Columbia Gas System Inc.	3,202.6	1,352.1	1,062.8		Delaware
Elba Island, GA (near Savannah) operational in 1978	Primary Co.:	Southern Energy Co. (owner, operator, importer)	150.0	*	*	100.0 affiliates of Southern Energy Co.	Georgia, Delaware
	Parent:	Southern Natural Gas Co. owned by	787.8	278.4	293.6		Georgia, Delaware
		Southern Natural Resources, Inc.	1,189.6	428.1	419.7		Delaware
Lake Charles, LA application approved by FPC in mid-1977	Primary Co.:	Trunkline LNG Co.	190.0	145.0	50.0	"to the fullest extent possible"	Louisiana, Delaware

TABLE 11-1 LNG TERMINAL COMPANY DATA RELEVANT TO LIABILITY AND COMPENSATION (CONTINUED)

MARINE TERMINAL AND STATUS	CORPORATE STRUCTURE		CAPITALIZATION ($ MILLIONS) ASSETS	LONG TERM LIABILITY	EQUITY[2]	LIABILITY INSURANCE COVERAGE PER INCIDENT ($ MILLION)	CLEARLY AMENABLE SERVICE OF PROCESS[3]
	Parent:	Trunkline Gas Co. owned by	628.2	284.4	222.5	planned	Texas, Delaware[7]
		Panhandle Eastern Pipe Line Co.	1,694.6	798.7	490.7	*	Texas, Delaware[7]
Port O'Connor, TX	Primary Cos.:	El Paso LNG Terminal Co. (owner/operator)	Expects $457 million capital investment, 75% long term debt and 25% equity			*	Texas, Delaware
		El Paso Atlantic Co. (importer)	N/A	N/A	N/A	*	Delaware
	Parent:	El Paso LNG Co. owned by	*	*	*	*	*
		The El Paso Co.	2,410.1	1,201.8	529.5	*	Texas, Delaware
Ingleside, TX (near Corpus Christi) proposed	Primary Cos.:	NGP-LNG Inc. (owner/operator)	N/A	N/A	N/A	*	Texas, Delaware
		Natural Gas Pipeline Co. of America (proposed importer)	1,410.7	586.9	526.1	*	Illinois
	Parent:	Peoples Gas Company	2,198.8	973.2	1,368.1	*	Illinois
Southern California[8] Oxnard Los Angeles Point Conception proposed	Primary Co.:	Western LNG Terminal Associates (owner/operator)	379.4 (75% debt with project revenues as the chief security to lenders)	284.6	94.8	50 minimum for third party and property	California
	Parent Co.:	Western LNG Terminal Co.	16.2	-	-	*	California
		(50%) owned by Pacific Lighting Corp.	1,662.8	697.1	614.4	*	California
		Pacific Gas LNG Terminal Co.	+	+	+	+	California
		(50%) owned by Pacific Gas & Electric Co.	6,620.9	3,096.6	2,993.3	+	California

1. Sources: Company letters, FERC records, Moody's Public Utility and Industrial Manuals for 1976.
2. Common and preferred stock and retained earnings.
3. This column indicates states in which the company in column 2 is incorporated or doing business, or maintaining agents to receive service of summons and complaint.
4. The property is owned by Providence Gas Co.
5. Texas Eastern maintains $75 million property damage coverage and $100.5 million general liability coverage per incident.
6. Capitalization is expected to be $200 million when the facility begins operation.
7. Trunkline Gas is also subject to process service in Louisiana, Arkansas, Tennessee, Kentucky, Illinois, and Indiana. Panhandle Eastern is also subject to process service in Oklahoma, Wyoming, Kansas, Missouri, Illinois, Indiana, Ohio, and Michigan.
8. In September 1977, the State of California enacted a law authorizing only one LNG terminal site in the State.

* Company would not disclose this information.
\+ No letter was sent to the company.
N/A Not appropriate.

FIGURE 11-1 TYPICAL CORPORATE STRUCTURE FOR LNG IMPORT TERMINALS

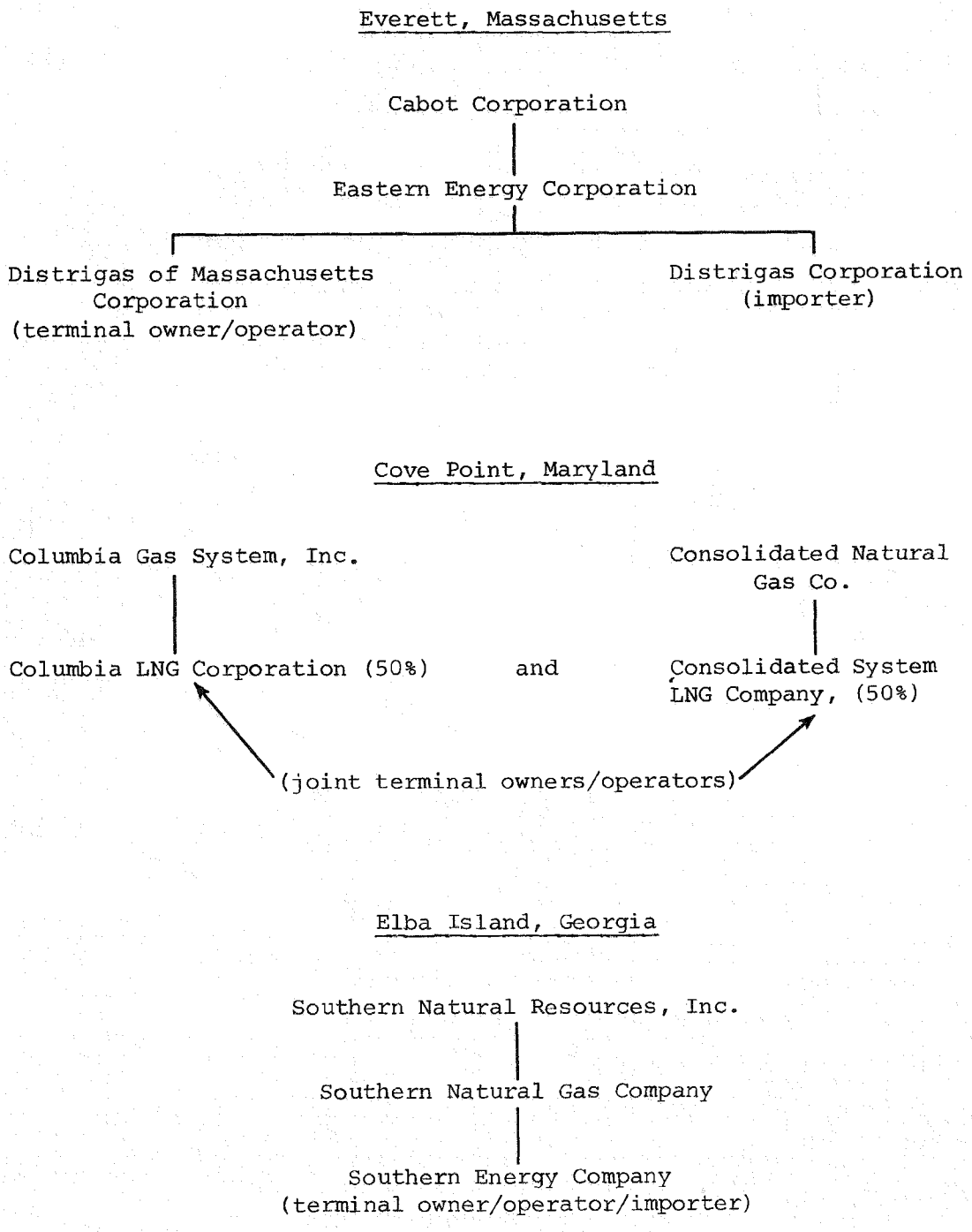
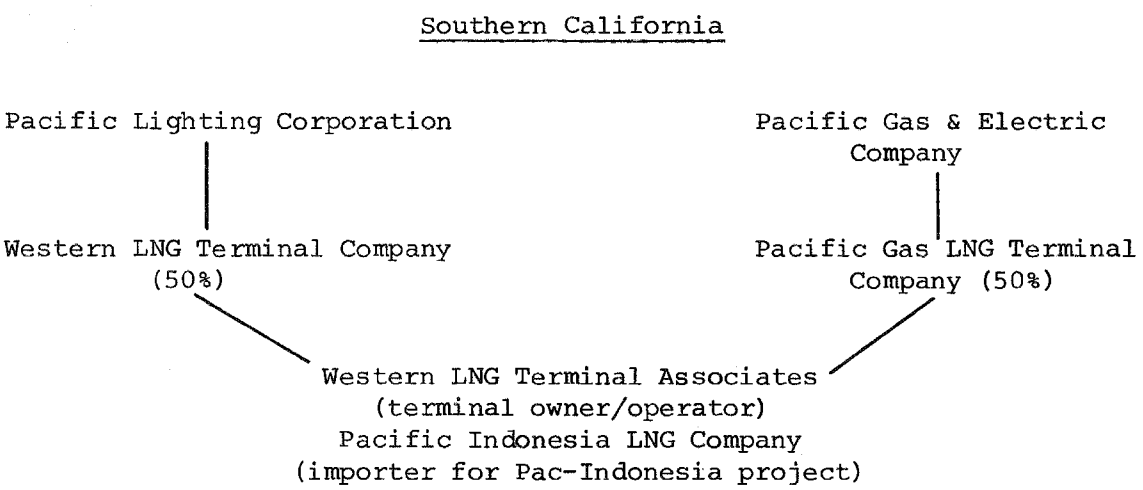


FIGURE 11-1 (continued)



If the defendant frontline firm has independent assets and/or insurance, even though these may be inadequate to satisfy the judgment, a court may not be convinced that it should pierce the corporate veil. In any case, the question may require extensive litigation.

Claimants who can convince a court to pierce the corporate veil still face stiff and extended litigation to prove the liability of the frontline and parent companies.

LNG Carriers

Each U.S. and foreign flag LNG vessel is ordinarily owned, leased, or chartered by a separate subsidiary company of a larger firm, as shown in Table 11-2. This structure is designed to limit liability exposure to the subsidiary company's assets. There is a statutory limitation (46 U.S.C. 183) on the liability that can be imposed on the owners and bareboat charterers* of ships and barges. The limitation, enacted in 1851, was intended to promote national fleets and international commerce. Many precedents date from a period when shipping was more simply organized than today's LNG trade, with its multi-layered, multi-national corporations.

Under the 1851 statute, the liability of both owners and bareboat charterers is limited to the salvage value of the vessel plus the amount owing for freight, if they can prove that they did not know about the causes of an accident. If injuries or deaths occur, however, the limit

*A bareboat charterer charters the hull, and mans and victuals the vessel. A time charterer hires the services of a vessel for a period of time, leaving its operation to others.

TABLE 11-2 LNG SHIPPING COMPANY DATA RELEVANT TO LIABILITY AND COMPENSATION[1]

MARINE TERMINAL & LNG SOURCE	SHIPPING ARRANGEMENTS	CORPORATE STRUCTURE	CAPITALIZATION ($ MILLION)	PROTECTION AND INDEMNITY INSURANCE COVERAGE[2]	CLEARLY AMENABLE SERVICE OF PROCESS[3]
Everett, MA from Algeria	Transportation in ships owned by	Gazocean USA, Inc. or Sonatrach (Algerian National company)	* *	*	Louisiana, Texas Texas
Staten Island, NY (Rossville) project being restructured[4]	Originally, 3 ships owned by EASCO, a subsidiary of Citicorp., the First Chicago Corporation and GATX, were to be	Bareboat chartered to separate subsidiaries of Energy Corp. They would time charter to subsidiaries of Burmah Oil Shipping Co.[5]	Nominal-required to maintain working capital by Maritime Administration	* $100 million	* Burmah, Delaware
Cove Point, MD and Elba Island, GA from Algeria, 1978	6 ships, each owned by a	Separate subsidiary of the	For each subsidiary, minimum working capital levels of $10.1 million up to aggregate of $42 million $168.1 aggregate net worth.[6]	in excess of $100 million	Delaware, Maryland Georgia
		El Paso LNG Co., which is owned by The El Paso Co.	* $2,410.1 assets	* *	* Texas, Delaware
	3 ships, each owned by a	Separate subsidiary of the	$314 aggregate capital. Net worth and working capital similar to above.	in excess of $100 million	*
		El Paso Maritime Co., a wholly-owned Liberian subsidiary of El Paso Natural Gas Co., which is owned by The El Paso Co.	The net worth and working capital maintained at a lower level than its subsidiaries $2,410.1 assets	* * *	Delaware Delaware Texas, Delaware
Lake Charles, LA from Algeria	2 ships to be furnished by	Lachmar, a 3-way partnership of subsidiaries of:	$332 estimated total capital costs[7]	*	*
		Panhandle Eastern Pipe Line Co. (40%)	$1,694.6 assets	*	Delaware, Texas
		General Dynamics Corp. (40%)	$1,338.1 assets	+	Delaware
		Moore McCormack Bulk Transport, Inc. (20%)	+	+	+
	3 ships to be chartered by the Algerian National Shipping Co. to	Sonatrach	*	*	*
Port O'Connor, TX from Algeria	6 ships to be furnished[8] by	El Paso Atlantic Co., owned by El Paso LNG Co.	N/A *	*	* * *
	6 ships to be furnished by	Sonatrach	*	*	*

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TABLE 11-2 LNG SHIPPING COMPANY DATA RELEVANT TO LIABILITY AND COMPENSATION (CONTINUED)

MARINE TERMINAL & LNG SOURCE	SHIPPING ARRANGEMENTS	CORPORATE STRUCTURE	CAPITALIZATION ($ MILLION)	PROTECTION AND INDEMNITY INSURANCE COVERAGE	CLEARLY AMENABLE SERVICE OF PROCESS[2]
Southern California from Indonesia	9 ships to be time-chartered by	Pacific Indonesia LNG Co.	0.6 assets	Value of vessel	California
		owned by Pacific Lighting	1,662.8 assets	*	California
		Corp. and by Pacific Gas and Electric Co.	6,620.9 assets	+	California
	3 ships from	Ogden Marine Indonesia, Inc., owned by	+	+	Delaware
		Ogden Marine, Inc.,	+	+	*
		owned by Ogden Corp.	926.0 assets	+	Delaware
	3 ships from	Zapata Western LNG, Inc.	+	+	Delaware
		owned by Zapata Corp.	796.6 assets	+	Delaware
	1 ship from	Zodiac Shipping Co., N.V.	+	+	Netherlands
		owned by N.V. Nederlandsthe Scheepvaart Unie.	+	+	Netherlands
	1 ship from	Gazocean S.A.	+	+	France
	1 ship from	Odessey Trading Co., Ltd.	+	+	Bermuda
		owned by Ocean Transport and Trading, Ltd.	+	+	United Kingdom
from South Alaska	2 ships built for	Pacific Marine Associates	*	*	*
		owned 50% by Pacific Lighting Marine Co. owned by	12.8 assets	*	California
		Pacific Lighting Corp. and	1662.8 assets	*	California
		50% by Pacific Gas Marine Co.	+	+	California
		owned by Pacific Gas and Electric Co.	6620.9 assets	+	California

1. Sources: Company letters, FERC records, Moody's Public Utilities and Industrial Manuals, 1976.
2. Insurance clubs place no fixed limit on the protection and indemnity coverage available to foreign flag ships, but until a recent change owners of U. S. flag LNG vessels could get this insurance only up to $200 million. British insurance clubs announced in February 1978 that they would offer unlimited protection and indemnity insurance to U. S. flag entries without regard to the value of the hull.
3. This column indicates states in which the company in Column 3 is incorporated or doing business, or maintains agents to receive service of summons and complaint.
4. In May 1977, EASCOGAS withdrew from its contract with Burmah Oil Shipping Company because its Gas Sales Contract with Sonatrach was terminated (the contract required EASCOGAS to obtain FPC approval by May 31, 1977).
5. A bareboat charterer not only charters the hull but also mans and victuals the vessel. Time-charterers hire the services of a vessel for a period of time, leaving its operation to others. Time charterers do not have to carry protection and indemnity insurance because they are not liable for faulty operations.
6. Each ship-owning subsidiary is required by MarAd to have these minimum levels of capitalization.
7. Anticipated sources of capital are: $50 million MarAd construction differential subsidy, $211.5 million from sale of long term debt, and $70.5 million from equity. The debt carries a MarAd guarantee.
8. The El Paso Atlantic Co. will either contract with affiliates or make arrangements with third parties.

* Company would not disclose this information
\+ No letter was sent to the company
N/A Not appropriate.

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is raised to $60 per ton of cargo. The 1851 limitation might not be applicable if LEG shipping were declared an abnormally hazardous activity, enabling recovery by injured parties on the basis of strict liability. For a large LEG ship this would be about $3,500,000.

Commerce's Assistant Secretary for Maritime Affairs, in an April 29, 1977, letter to us, described how the ownership structure of LNG vessels is utilized:

> ". . .In general, the ownership of LNG's {ships}, whether they be leased or owned, is by a trust or single-purpose corporation with only one vessel in each trust or corporation. If the vessels are subsequently bareboat or time chartered, they are likewise chartered to single purpose corporations. This structure is specifically utilized to attempt to limit third party liability to the value of the asset {vessel} with no recourse to any other assets. Usually, the obligations of these corporations are not guaranteed by any other party. Guarantees of charter hire or of freights payable under a transportation agreement may be guaranteed by a parent corporation to induce lenders. However, the limit of liability {of parent firms under these agreements} is only to the amount of hire or freights payable and would not in any way guarantee any third party as a result of a casualty. In theory, an injured third party would only have recourse to the value of the vessel and insurance carried by the owner or bareboat charterer. . ."

An LNG ship corporation's major asset is the ship itself. Most of these corporations are not required to carry specified amounts of net worth and working capital. Such requirements are, however, among the conditions imposed under Title XI of the Merchant Marine Act of 1936, as amended, under which a qualified candidate may have the U.S. Government guarantee loans up to 87½ percent of a ship's costs for construction, reconstruction, or reconditioning. The program is administered by the

Maritime Administration in the Department of Commerce. Sixteen U.S. flag LNG carriers are being constructed under this program.

Under this program, the El Paso Company (parent of the El Paso LNG Company) has committed itself to cause each of its LNG ship-owning subsidiaries to have a specified net worth on the delivery date of its tanker, and, if called upon, to make additional specified contributions of capital to each subsidiary for working capital purposes. The aggregate amount of the first of these commitments for all six subsidiaries is approximately $168.1 million, including minimum working capital requirements of $16.1 million. The aggregate maximum amount of the second of these commitments for all six subsidiaries is $42.1 million.

The mortgages on these six tankers will be in favor of the United States, as collateral for the government guarantees. Similar arrangements are required for ships being built for other companies.

When shipowners are required to have substantial net worth, as they are under the Title XI program, injured parties enjoy better prospects of finding assets from which claims might be paid. However, if claims exceed the level of assets required by the Maritime Administration, a court might be less likely to assert jurisdiction over the parent company than it would if no government regulation was involved. A court might seriously consider and defer to that agency's judgment on the adequacy of capitalization of the subsidiary.

Recovery can be difficult if the defendant is a foreign corporation. Foreign nations or nationals own, or expect to own, LNG ships for use in conjunction with terminals in Everett, Staten Island, Cove Point, Elba Island, Lake Charles, and Southern California. Unless a liable corporation has other assets in this country, the ability to recover will depend on whether a U.S. court decree is honored in a foreign court. This may be less likely if the liable corporation is owned by a foreign government.

In order to recover damages, a plaintiff must first locate assets here or abroad. Such a wide-ranging search for proof of assets might be beyond the resources of many plaintiffs.

Findings

- LNG is imported on ships, each owned or leased by a separate subsidiary corporation, and stored in terminals owned by subsidiaries. Parent firms are, in many cases, wholly-owned subsidiaries of still larger firms, which may themselves be wholly-owned or under another firm's corporate control.

- The level most vulnerable to liability is usually the most thinly capitalized. LEG terminal companies generally have no limit on their ratio of debt to equity, and only those ship-owning subsidiaries whose ships are being built under the Title XI program are required to carry specified minimum amounts of net worth and working capital.

- In many cases the major assets may be the ship or terminal itself, which may not survive an accident which does extensive offsite harm.

- Most of the assets in the system are protected by the corporate layers. It would be difficult for claimants to litigate the liability of parent firms for damage caused by an LNG accident. If they did, the litigation would be a long and expensive process, which many litigants could not afford.

- The ownership structure of LNG carriers is designed to protect the assets of owners and bareboat charterers. The statutory limitation on liability further benefits these single-ship corporations or trusts. Even if personal liability is established, available assets may not be sufficient to satisfy claims.

- Claimants attempting to recover damages through foreign assets of foreign corporations will encounter special difficulties, particularly if the foreign corporations are government owned.

LNG LIABILITY COVERAGE

Import Terminal Coverage

Table 11-1 includes data on insurance coverage provided by companies at our request. Among those which responded fully, present or planned terminal coverage ranges from $50 million per incident for Pacific Lighting Corporation's proposed Western LNG Company terminal, to $190.4 million total coverage per incident carried by the

co-owners of the Cove Point, Maryland terminal. The $100 million insurance coverage for the Elba Island, Georgia terminal is carried by affiliates of Southern Energy Company, the terminal owner. Southern plans to obtain additional liability coverage before operations begin in 1978.

We could not obtain detailed insurance information for the Everett, Massachusetts terminal, which has been operating since 1971. The terminal is owned and operated by Distrigas Corporation of Massachusetts. The president of Eastern Energy Corporation, Distrigas' corporate parent, replied to our letter to Eastern's corporate parent, Cabot Corporation.

> "The insurance coverage carried by the Cabot LNG companies is in layers, and different policies would respond, depending on the specific circumstances of any particular claim. It is not corporate policy to disclose details or limits of insurance coverage, but we do carry amounts of insurance representing what we believe reasonably prudent management requires."

None of the 50 states requires proof of public liability insurance as a prerequisite to obtaining a permit for dealing, storing, or handling LNG. Ten states do require such proof from LPG companies, but the amount required may be as low as $10,000 per incident; the maximum required anywhere is only $100,000 for any one incident.

LNG Carrier Coverage

Insurance clubs place no fixed limit on the protection and indemnity (liability) coverage available to foreign flag vessels, but until a recent change owners of U.S. flag LNG vessels could get this insurance only up to

$200 million. British insurance clubs announced in February 1978 that they would offer unlimited protection and indemnity insurance to U.S. flag entries without regard to the value of the hull. The insurance data in Table 11-2 were provided in 1977. El Paso LNG informed us that all of its ships are insured against accidents to the maximum extent available in the market, and that in every case this is "in excess of $100 million." Pacific Lighting plans carrier coverage "at least equal to the value of the vessel."

In states which have "direct action" statutes, injured parties can sue the insurers directly, prior to the rendering of a judgment against the owner or charterer. In Independent Towing Company, 242 F. Supp. 950 (E.D. La. 1965), the court held that liability limitation proceedings do not exclude direct action against an insurance company as permitted by Louisiana state law. It held further that insurers, unlike vessel owners and bareboat charterers, cannot claim the protection of the limited liability statute. In states without a direct action statute (for example, Maryland, Massachusetts, and New York) injured parties do not have this recourse.

Shipbuilding Insurance

Prior to navigation, shipyard risks are imposed upon builders, subject to normal contract exoneration terms. Ship-building contractors give a six-month to one-year warranty that does not cover design defects. Design defect liability might be imposed upon marine architects, who are insured independently.

Liability Coverage of LNG Trucking Companies

Under Interstate Commerce Commission (ICC) regulations, LNG trucking companies are required to carry only minimal amounts of liability insurance, but they ordinarily carry much more than the required amount. The ICC regulations call for policies of $100,000 (maximum liability for any one person), $300,000 (maximum liability for one incident), and $50,000 (property damage for one incident). This subject is discussed in more detail in Chapter 7.

Findings

- Present and planned liability coverage for LNG import terminals ranges from $50 million to $190 million per incident. Ten states require proof of liability insurance for LPG facilities, but the maximum required is $100,000 per incident.

- Where there have been no injuries or deaths, the liability of shipowners and bareboat charterers may be limited to the post-accident value of the vessel plus the freight then pending, if they can prove that they did not know of the factors that caused the accident. If there are injuries or deaths the limit is raised to $60 per ton of cargo. For a large LEG ship this would be about $3,500,000.

- The amount of liability insurance coverage the ICC requires trucks under its jurisdiction to carry (up to a total of $350,000 for one incident) is much lower than the amount some gas companies require LNG trucking firms to carry ($10-30 million). A trucker

may also be covered under the gas company's liability policies, but if a liable trucker is not acting as the agent of the gas company, claimants may not have access to this coverage.

- A major accident could cause damage of such severity that injured parties could not be fully compensated under existing insurance policies.

SUPPLEMENTAL LIABILITY COVERAGE FOR HAZARDOUS OPERATIONS

The Nuclear Power Experience

The question of how to handle the potentially large but unpredictable liability from public utility installations using new technology confronted Congress in the 1950's with the advent of commercial nuclear power. Congress found that the size of the liability which could result from a nuclear accident and the lack of available, adequate commercial liability insurance were major obstacles to the commercial development of nuclear power.

The Price-Anderson Act, Section 170 of the Atomic Energy Act of 1954, as amended (42 U.S.C. 2210), was enacted in 1957 to solve this problem. It established a combination of private financial protection and government indemnity amounting to a maximum $560 million to cover liability claims that might arise from a nuclear accident at a commercial nuclear facility.

The objectives were (1) to assure the availability of funds to satisfy liability claims in the event of a catastrophic nuclear accident and (2) to remove the

deterrent to private investment of possibly enormous liability claims.

The 1957 Price-Anderson Act was regarded as temporary legislation and was written for only a 10-year term. In 1965 the Act was extended an additional 10 years by P.L. 89-210. A second 10-year extension, until August 1, 1987, was enacted by P.L. 94-197.

P.L. 94-197 continues to limit the amount of liability protection (and the liability that may be imposed) to $560 million, even though estimates of economic losses alone range as high as $14 billion.[1] The new amendments spell out for the first time, however, that in the event of a nuclear incident involving damages in excess of $560 million, "the Congress will thoroughly review the particular incident and will take whatever action is deemed necessary and appropriate to protect the public from the consequences of a disaster of such magnitude."

Nuclear power plants must be licensed by the Nuclear Regulatory Commission (NRC). Owners of power reactors are required (10 CFR 140) to have and maintain financial protection in the amount of $125 million for each nuclear reactor with a rated capacity of 100 electrical megawatts or more. Liability insurance is available from two insurance pools: the Nuclear Energy Liability-Property Insurance Association and the Mutual Atomic Energy Liability Underwriters. The amount of financial protection required of reactors of less than 100 megawatts is established with a formula that takes into account the population near the reactor. The amount cannot be less than $4.5 million nor more than $74 million.

The first $140 million of damages from a nuclear incident would be paid out of insurance pool funds. To cover additional damages, the pools could collect up to $5 million for each licensed reactor. With 65 reactors presently operating, these "retrospective premiums" could total $325 million.[2] The Act requires owners to maintain proof of their ability to pay these retrospective premiums.

The Price-Anderson Act requires that the reactor owners must execute and maintain an indemnity agreement with NRC, under which NRC will indemnify the owner for all public liability claims exceeding these two levels of financial protection, up to $560 million per nuclear accident. The Act authorizes the NRC to collect indemnity fees of $30 per year per thousand kilowatts of thermal energy authorized in the reactor's license, with a minimum fee of $100 per year. The annual fee for a 1,000 megawatt (electric) power plant would be about $104,000.

The Supreme Court, in a June 26, 1978 decision, upheld the constitutionality of the Price-Anderson ceiling on nuclear liability. The court reversed a district court ruling that the limitation violates due process.[3]

Hazardous Materials Compensation Fund

We believe that a more adequate liability insurance system is needed for non-nuclear hazardous operations, and that the arrangements should be considered from the viewpoints of both accident prevention and equity. Accident prevention requires that the system provide maximum incentives for safe operations. Equity requires that those harmed are fairly and promptly compensated.

We propose a system somewhat similar to that created by the Price-Anderson Act for nuclear power. Corporations transporting, storing, or using significant quantities of flammable hazardous materials would be required to: (1) carry the maximum liability insurance available from the private sector, and (2) contribute a fixed sum per BTU to a Federal Hazardous Materials Compensation Fund (HMCF). The Fund would pay claims (beyond those paid by private liability insurance) up to a fixed ceiling for any one incident. Non-energy hazardous materials corporations could contribute to the Fund on a different basis.

All the consumers of the gas that goes through a particular facility would bear the costs of private insurance for that facility. All those receiving service from an operation would pay to cover the risks incurred by those near the operation.

All LEG users (and eventually, perhaps, all users of other hazardous materials) would share the cost of building and maintaining the Fund. This is not completely equitable, since customers of safer facilities would be subsidizing customers of less safe facilities. We feel, however, that only through such a Fund will those harmed in an accident, particularly those without large intact resources, be able to get prompt, fair compensation for claims against very large corporations and insurance companies. The Fund's only task after an accident is to assure that all monies paid out are warranted by the damage done.

In order to make the implicit subsidy involved in the Fund more equitable, we propose that the United States be subrogated to the rights of injured persons compensated by

the Fund so that the Attorney General of the United States can sue the companies or persons responsible for the accident for whatever monies the Fund has paid out. The Attorney General will have many more resources available to him for such a suit than will a shopkeeper or homeowner.

The problem with the Price-Anderson Act is that, if an incident causes more than $560 million dollars of damage, there is no assurance that all legitimate claimants will be fully compensated. This is clearly inequitable, and since the costs of their liability insurance and their contributions to the Fund will be passed on to their customers, this provides no incentive for public utilities to improve the safety of their operations.

In order to remedy this concern, we propose that Congress consider legislation which would allow injured parties in a hazardous materials accident to sue individually, or as a class, when permitted by the jurisdiction's rules of civil procedure, for damages beyond those covered by insurance and the Fund, all the companies in the corporate chain back to the beneficial corporate owners (but not including individuals who are stockholders).

In a typical LEG corporate chain the "benefited corporation" at the top controls the lower companies and receives all the profits. An LEG disaster in which the claims exceed the limit that the Fund can pay, would probably destroy most or all of the assets of the frontline company. Thus the benefited corporation, which receives all the profits, may have little more to lose from a disaster that does enormous damage to the general public than from one that only destroys the facilities of the

frontline company. This gives it little extra incentive to prevent such a disaster. We think this shows up in the fact that facility components such as dikes are built under standards which are adequate to control small accidents, but are not adequate to stop offsite damage from very large ones.

No expense or administrative burden will be placed on anyone by this provision unless a disaster involving very large damage to the general public occurs. Every company we have talked to considers the possibility of such a disaster to be extremely small. Thus they should have little objection to a requirement that the assets of a benefited corporation be on the line in the event one does occur. Such a provision would improve the equity of the situation and give benefited corporations a strong incentive to prevent such disasters. It would help to remove the burden of possible uncompensated risk from segments of the general public. Some of the risk would be placed directly on the benefited corporations, whose officials could lower the risk by ordering their frontline subsidiaries to build and locate facilities prudently.

Findings

- A more adequate liability insurance system is needed for non-nuclear hazardous operations. The system should include incentives for safe operation and prompt, fair compensation for anyone injured.

LIABILITY LITIGATION

Most of the problems we have discussed have been those that claimants might face once a company's liability

had been established in court and a judgment awarded. Claimants' problems in reaching that point are often much greater. It is often difficult to establish the primary cause of a major accident because critical evidence is destroyed. This type of litigation is usually long, complex, and expensive; plaintiffs may encounter jurisdictional problems and hostile legal precedents.

Securing Jurisdiction

The process begins with securing a court's jurisdiction. If the defendant is incorporated or doing business in the state in which a suit is brought, this can be done by serving a summons and complaint. Owners/operators of LNG terminals, for example, must maintain agents to receive such documents in the state where their terminals are located (see Table 11-1), and U.S. flag LNG tanker subsidiaries must also maintain such agents. El Paso LNG Company noted that its various LNG tanker subsidiaries could be sued as a matter of course in Delaware, Maryland, and Georgia, and that, if such companies commit a tort in any other coastal state, they could be sued in that state also. It may not be possible to serve legal documents on some foreign flag vessel owners. Sonatrach, Algeria's national company, does maintain agents in Texas. As noted earlier, foreign assets of foreign corporations are difficult to reach, especially if the foreign corporation is government owned.

If a defendant is not doing business within the state in which a suit is brought, the service necessary to secure jurisdiction must be made under state "long-arm" statutes. To legally extend such an arm, the defendant must be deemed

under state law to have "sufficient" contact with the state in which suit is brought.

If the defendant is reached by serving documents on his legal agent, the resulting judgment can be enforced so as to reach all the defendant's assets to satisfy claims. When jurisdiction is secured by attaching an object such as a ship, however, the court is only empowered to dispose of the ship to satisfy claims.

Plaintiffs could face a spectrum of state, and maritime and other Federal laws. Jurisdiction would be complicated if an incident affected persons and property in more than one state: New York and New Jersey, for example, or Maryland and Virginia. Separate trials in both states might be necessary. Some claimants might be able to sue in Federal court, while others could not.

When an administrative agency—for instance, the Federal Energy Regulatory Commission—has jurisdiction over some aspects of a facility at which an accident has occurred, a court may defer judicial proceedings pending the outcome of administrative proceedings. This deferral arises from employment of the doctrine of "primary jurisdiction," so called because the agency originally certified the facility as necessary and reasonable. The doctrine is used because the administrative agency may have the capacity to provide expert insights to the court. However, the delay of judicial proceedings and the need to participate in agency proceedings may work great hardship on a plaintiff because it delays his ultimate recovery and forces him to retain additional counsel, fund additional litigation, and assume additional burdens of proof. If a plaintiff's case is to benefit from a showing that

defendant failed to adhere to regulatory requirements, it must also be shown that those requirements were intended to protect persons in the plaintiff's position.

Legal Theories of Recovery

A plaintiff must establish a legal theory permitting recovery which is recognized by the court in which the suit is filed. These include: (1) the attribution of negligence on the part of an LNG operator and (2) strict liability—the assertion that the risk factor in LNG operations is so great that liability for any accident that may occur, regardless of fault, must be accepted by the operator. The availability of non-negligence causes of action (theories of recovery) varies among the states.

A plaintiff may assert that a defendant is liable irrespective of fault because an LNG operation is an ultra-hazardous undertaking, as in McLane v. Northwest Natural Gas Co., 467 P. 2d 635 (Or., 1970), a case arising from the death of a workman at an LNG site. In this case the court held that the storage of natural gas in a populated area is abnormally dangerous because of the inherent risk and not the frequency of harm. The fact that the defendant held a certificate or franchise for the activity was not allowed to bar liability. Similarly, in Yommer v. McKenzie, 257 A. 2d 138 (Md., 1969) the court imposed strict liability in consequence of damages resulting from the leakage of a gasoline tank located near a residential well.

The decision in Doundoulakis v. Town of Hempstead, 381 N.Y.S. 2d 287 (App. Div., 1976) supports imposition of strict liability upon those who engage in an activity which

poses a great danger of invasion of the land of others. The court held that it matters little whether the force used is dynamite, gunpowder, or pressure created by accumulating, massing, and diverting large amounts of water, or whether the invasion is by objects projected by explosion. It was noted that a deliberate manipulation of natural forces or resources—frequently on a massive scale—often underlies these invasion-causing activities.

The State of New York has recently enacted legislation which applies strict liability to LNG and LPG operations. The Liquefied Natural and Petroleum Gas Act, 1976 Laws, Chapter 892, determines the storage, transportation, and conversion of LNG and LPG within the state to be hazardous, entailing strict liability on the part of any person who undertakes such activities. Neither regulatory compliance nor the exercise of due care can prevent recovery for personal or property damage caused by the accidental release of LNG or LPG. In addition, Maine imposes strict liability for damages resulting from natural gas operations generally, without specifying any applicability to LNG.

A variant of the theory of inherent risk is the theory of enterprise liability in which a defendant is found to have created, in the course of a profit-seeking undertaking, an unavoidable risk to a plaintiff, and thus to be responsible for the cost of damages that result when that risk materializes.

According to the Restatement of Torts (Second), risks requiring the imposition of strict liability due to abnormally dangerous activity on the site, arise from a meld of factors (Sec. 520): high degree of risk of harm,

gravity of potential harm, risk not eliminated by reasonable care, activity not a matter of common usage, activity inappropriate to its location and its value to the community is outweighed by its dangerous attributes.

The 1851 statutory limitation on the liability of shipowners and bareboat charterers might not apply if LEG shipping were declared an abnormally hazardous activity, enabling recovery by injured parties on the basis of strict liability.

The doctrine of res ipsa loquitur (the thing speaks for itself) may be available to help a plaintiff establish liability for negligence. Under this theory, liability for negligence is imputed in the event of an occurrence which would not have happened under normal circumstances without negligence on the part of defendant, to which plaintiff did not contribute, and concerning which defendants are likely to have more information or access to information than is available to the plaintiff. If there are multiple defendants, application of this doctrine requires that defendants jointly control the instrumentality which caused the accident.

For purposes of determining negligence, it may be stated that:

- A shipowner is not liable for the negligence of a harbour pilot if the use of such a pilot is mandatory, but the ship is liable in rem. 2 Benedict on Admiralty §11 (7th Ed. revised).

- Should an accident result from negligence by a ship's master, claims for damage may be brought against him,

against the vessel involved, or against the ship's owner personally. (Supra.)

Liability for Damages Caused by Sabotage

Damages resulting from sabotage of an LNG operation constitute a special category. Assignment of liability in such cases would have to be premised on the existence of a duty of care owed to the injured plaintiff. A duty to maintain adequate security is owed to employees and invitees on the premises of a facility or vessel, and may be owed to others offsite. Of course, in the absence of other evidence, a duty of reasonable care would not necessarily be breached by an incident. Even where security measures were less than "adequate," an owner might not be held liable if it appeared that "adequate" security would not have afforded protection. This line of reasoning assumes, of course, that the defendant is not liable under the enterprise theory simply because he caused the dangerous facility to be placed in the community.

Neither the Congress nor the courts have viewed the risk of harm being inflicted intentionally upon a facility or vessel as properly assignable to the owner or operator, unless one or the other is negligent.

Liability for "Acts of God"

Companies are not liable for damages resulting solely from lightning, earthquakes, and other "acts of God." Injured parties would not be compensated.

Findings

- There is no simple procedure for claimants to recover damages from a major LNG accident. Instead, claimants face long, complex, and expensive litigation involving potential complications at every step in the legal process.

- If the defendant corporation is foreign-owned, the corporation may be out of reach.

- Even when it is possible to summon defendants, claimants may encounter a spectrum of state, and maritime and other Federal laws.

- In some states claimants may be able to establish a non-negligence legal theory such as that the operation was an ultra-hazardous undertaking, or created an unavoidable risk to the plaintiff. In other states where such theories are not available, plaintiffs will have to prove that the accident was due to want of care on the part of defendants.

- If damages result from an act of sabotage, liability will be difficult to prove.

- Companies are not liable for damage caused by lightning, earthquakes, or other "acts of God." Injured parties would not be compensated.

- It is not always possible to prove the primary cause of a major accident. Critical evidence may be destroyed in the accident itself.

FAILURE OF AGENCIES TO EXERT FEDERAL JURISDICTION OVER LNG OFFSITE LIABILITY

No Federal agency considers the issue of offsite liability in dealing with LNG operations.

The Federal Power Commission, which had jurisdiction over LNG imports and import facilities, informed us: "No studies have been done by this commission on legal liability of owners and operators. We believe the Courts have the responsibility to decide the liability issue."

We do not agree. Under Section 7 of the Natural Gas Act, projects approved for certification by the Commission must comport with "the public convenience and necessity". We believe the availability of adequate compensation for offsite damage is as much a matter of public convenience and necessity as other safety and environmental issues which the courts and the Federal Power Commission have recognized as the Commission's responsibility.

The courts have construed Section 7 broadly. Among the issues raised in relevant decisions:

1. The Commission may consider the impact a proposed project would have on air quality. See FPC v. Transcontinental Gas Pipeline, 365 U.S. 1 (1961). With the passage of the National Environmental Policy Act, a project's impact on the human environment has become an even clearer element of public convenience and necessity.

2. The Commission is authorized to require that a proposed project be financially feasible and

reliable, and that the applicant be sufficiently financially responsible to support the undertaking. See Kansas Pipeline and Gas Co., 2 FPC 29(1939). The existence or absence of liability can materially affect all of these factors, although the Commission has not yet so viewed it. A liable company with inadequate insurance or resources could be forced into bankruptcy or reorganization, to the detriment of its level of service.

The Commission itself has recognized that it has an obligation to consider the safety of projects coming before it. See, for example, recent decisions in Trunkline LNG Company, Docket No. CP 74-138 (February 18, 1977) and in the Initial Decision in El Paso Alaska Co., et al., Docket No. CP 75-96, et al., (February 1, 1977).

The possibility of public exposure to uncompensated risk is a matter affecting the safety practices and plans of an applicant. It appears that the Commission has not so much rejected, as overlooked, the relevance of compensation for offsite damage. The subject was raised in one interrogatory to the Commission, from the Honorable John Murphy, Member of Congress, regarding LNG imports into New York and Boston. See Distrigas Corporation et al., FPC Docket No. 73-78 et al., and Eascogas LNG, Inc., FPC Docket No. CP 73-47 et al., interrogatory filed June 16, 1976. Representative Murphy asked detailed questions about the kinds of issues examined in our analysis. We believe that such questions should be answered in testimony before the Commission under oath for every LNG facility and terminal. In addition the Commission could require that: (1) a project's Environmental Impact Statement include information about the applicant's ability to compensate for

offsite damage; (2) LNG applicants post liability bonds as a condition of certification.

The Commission also has jurisdiction over the LNG importer, who may be a separate entity from the terminal owner or operator. Under Section 3 of the Natural Gas Act, persons wishing to import natural gas must obtain the Commission's permission on such conditions as it finds consistent with the public interest. The Commission has not asserted jurisdiction over the parent corporations of importers. This means that the Commission might require an importer to maintain an agent for receipt of service in a state, but not the importer's parent company.

We believe the Commission could require that LNG applications include all of the real parties at interest (including owners of tankers) and that it should condition the permits upon all parties assuming liability for damages resulting from accidents they cause. This would not be unreasonable; banks which finance ships and terminals require parent corporations up the line to co-sign notes.

{FPC's Section 3 authority over imports was transferred to DOE. The Secretary may assign these functions to either the Federal Energy Regulatory Commission or to the Economic Regulatory Administration. The final distribution of responsibilities within DOE has not been completed. The substance of the discussion above remains valid.}

Findings

- No Federal agency considers the question of offsite liability of LNG operations. This includes the

Federal Energy Regulatory Commission which is responsible for granting Certificates of Public Convenience and Necessity or licenses for LNG facilities. The Commission's position is that the liability issue is solely for the courts to decide.

- The courts have not precluded the Federal Power Commission from considering environmental and safety issues under Section 7 of the Natural Gas Act. We believe the availability of adequate compensation for offsite LNG damage falls within this range.

- The DOE agency with Section 3 responsibilities could require importers to maintain agents for the receipt of legal documents in all states in which they operate. We believe Section 3 also confers sufficient authority on the agency to assert jurisdiction over LNG tanker companies transporting imported natural gas.

RECOMMENDATIONS

TO THE SECRETARY OF ENERGY AND THE FEDERAL ENERGY REGULATORY COMMISSION

We recommend that the Secretary of Energy and the Federal Energy Regulatory Commission take steps to:

- ensure that adequate compensation for offsite damage is available before permitting LNG projects to proceed.

- use their authority to require that importers and LNG tanker companies maintain agents for the receipt of legal documents in all states in which they operate.

- consider their possible authority to require the parent corporations of LNG tanker companies, which apply to transport imported natural gas, to assume joint liability with the applicant for damages resulting from accidents they cause.

TO THE CONGRESS

We recommend that the Congress:

- enact legislation which requires that strict liability be applied in all accidents involving LNG and LPG.

- amend the 1851 Act (46 U.S.C. 183) which limits the liability of owners and bareboat charterers of ships

and barges by substantially raising the statutory limit for vessels carrying hazardous materials.

- enact legislation creating a more adequate liability insurance system for non-nuclear hazardous material operations that would:

  1) - Require corporations transporting, storing, or using significant quantities of flammable hazardous materials to

     -carry the maximum liability insurance available from the private sector.

     -contribute a fixed sum per BTU to a Federal Hazardous Materials Compensation Fund (HMCF).

  2) - Provide that the United States be subrogated to the rights of injured persons compensated by the Fund, to allow the Attorney General of the United States to sue the companies or persons responsible for an LEG accident to recover whatever monies the Fund has paid out.

  3) - Allow injured parties in a hazardous materials accident to sue individually, or as a class when permitted by the jurisdiction's rules of civil procedure, for all damages beyond those covered by insurance and the Fund, all of the companies in the corporate chain.

AGENCY COMMENTS AND OUR EVALUATION

The Department of Commerce states:

". . .The conclusions and recommendations with respect to statements requiring that the companies involved in supplying LNG and LPG be liable to the full extent of the assets of their parent corporations would be totally unacceptable to any corporate board of directors. If the liability conditions suggested by the GAO were to be imposed on the industry, the effect would surely be the total withdrawal and disinvolvement of private enterprise with LEG projects or any project that has unlimited risk. No private corporation could assume that type of exposure in any one element of its overall business activities. Such a requirement would have the same effect on the industry as the Cleveland disaster in 1944, which as the report indicates virtually halted the use of LNG for 20-years. . ."

Commerce also states:

". . .it is illogical to believe that government officials from the many agencies that are involved in regulating liquefied energy gases would permit participating companies to engage in unsafe operating procedures that would prove ultimately inadequate and unsafe to the public. . ."

If the risk of an accident involving extensive offsite damage and injury is negligible, it is difficult to see why extending liability to the corporations which get all the profits would make a profitable venture "totally unacceptable to any corporate board of directors". Corporate boards frequently take very substantial risks for profit. It is at the heart of the free enterprise system. If, on the other hand, the risk of extensive offsite damage and injury is not negligible, it seems unfair that those who happen to live or work near a facility and get no

profits should have to risk their lives and property, while the corporations which receive guaranteed profits do not even have to assume the financial risk of liability for the damage.

The Federal Preparedness Agency states:

"We agree with GAO that there is insufficient liability protection on LNG facilities. The recommendations appear well founded with an urgent requirement that they be acted on to assure adequate protection for this public. . ."

The Department of Transportation states:

". . .A number of statements concerning liability are inaccurate or overly broad. However, it is likely that there is a need for a new liability and compensation system. Such a system should be established by a comprehensive Federal statute addressing preemption, liability, liability limits, creation of a compensation fund, and other necessary legal issues. . ."

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CHAPTER 12

SAFETY RESEARCH AND DISPERSION MODELS

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INTRODUCTION

This chapter gives a methodology for LEG safety research, discusses important past Federal and private studies, and evaluates current Federal programs and proposals. The next chapter reviews past work in two related critical areas: detonation and flame propagation in LEG clouds. The highly technical parts of both chapters are printed in italics. Non-technical readers may omit them.

Because we are critical of the direction, level, and duration of Federal research plans, and because the time when the result will be most useful is short, we make detailed suggestions in this and the following chapter for a program that would cost much less, take less time, and get more useful results. This research needs to be undertaken as soon as possible.

BRIEF OUTLINE OF RESEARCH ACTIVITIES

A number of civilian government agencies have been involved with LEG safety research. These include the Federal Power Commission (FPC), the National Bureau of Standards (NBS), the Energy Research and Development Administration (ERDA), the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), and several offices of the Department of Transportation (DOT), including the Office of Pipeline Safety Operations (OPSO) and the U.S. Coast Guard. See Appendix XII.

NBS has been primarily concerned with properties of materials, literature surveys, and data retrieval. NASA

has maintained a bibliography of relevant published material. OPSO has sponsored state of the art studies and analyses of incidents. Studies of vehicle accidents have been made elsewhere in DOT. The Coast Guard has sponsored a considerable body of LEG research as part of its responsibilities for marine transportation. For some time they have been funding studies of dispersion, flame propagation, and detonation, at the U.S. Naval Weapons Center at China Lake, California. NSF has sponsored research, and the Department of Energy (DOE) is currently planning a program of LNG research evaluated below.

In addition, a large amount of research has been carried out under private sponsorship, and in the preparation of Environmental Impact Statements by FPC.

AIMS

In order to assess the worth of past and projected research activities, it is necessary to consider the purposes they are intended to serve.

The primary goals of Federal research in this area should be:

- To clarify the hazards, risks, and consequences of LEG operations so that appropriate regulations can protect the public, i.e., as an aid in formulating or modifying regulations.

- To aid in assuring that the plans and practices of operating facilities are adequate to satisfy the regulations.

NATURE OF THE PROBLEM

It is convenient to divide safety research problems into three categories: hazard assessment, risk assessment, and damage assessment. These respectively address the questions:

1. What hazards could lead to a disaster?

2. a) In what ways can each disaster occur?
   b) What is the chance of each of these ways occurring?

3. What damage can be expected from various levels of disaster?

In addition to these questions, research can directly address such questions as:

4. Will current or planned safety systems provide the safety expected of them?

5. Do current regulations and procedures adequately ensure safety in specific areas?

6. What steps can be taken to reduce risks and what are the relative costs of such steps?

Comments on the status of each of these areas follow.

HAZARD ASSESSMENT

If an evaporating LNG spill does not catch fire, the resulting cloud of vapor will eventually dissipate. Four

key questions are:

1. How long will it take for an LNG spill to disperse harmlessly?

2. How far can a cloud of vapor travel before it becomes harmless?

3. Under what circumstances can such a cloud detonate?

4. What sort of combustion takes place if the cloud ignites at various stages?

There has been some research effort and controversy over these questions. In particular, there is considerable disagreement over the distance a cloud might move and still be flammable,[1-12] and uncertainty as to the behavior of very large clouds. Detonation is discussed in detail in Chapter 13.

Flame Propagation Models

Most discussions of hazards from LNG-air clouds assume that a flame ignited on the downwind edge of the cloud will burn back to the source. A flame propagates in a natural gas-air cloud at 6-12 miles per hour. High wind speeds increase air turbulence and thus flame propagation speeds. But it is not possible from present knowledge to tell whether a flame front ignited on the downwind edge of a cloud in a high wind would burn back to the source or be carried forward by the wind. In a recent test at China Lake, the cloud from a small spill on the pond spread onto the land in a light wind. After ignition on the land, the flame front burned back to the shoreline and then stayed

burning there until almost all the vapor was consumed. It then burned back to the source. This totally unexpected effect has not yet been explained. In another test, a spill on the pond was ignited at its center and the flame remained there without spreading. The explanation for this is also unknown. The appearance of these unexpected phenomena during relatively few, quite small tests further illustrates how little is understood about flame propagation in such clouds.

Much less research has been done on dispersion and flame propagation in LPG clouds than in LNG clouds. Thus, these phenomena are even less understood for LPG than for LNG.

Finding

- Very little reliance should be placed on present models of flame propagation in LEG-air clouds in evaluating the dangers of possible spills during operations.

Large Pool Fires

Most discussions of the consequences of an LEG ship tank rupture assume that a large pool fire will result. It is not presently known, however, whether a very large pool of burning LNG on the water could produce a large fireball in the air. A large cloud of LPG might produce a fireball or detonate. A fireball or a detonation would be much more dangerous than a pool fire.

Finding

- It is not prudent to assume that a very large pool fire cannot form a fireball.

Land Spill Hazards

While there has been some research done on cloud dispersion and flame propagation from water spills, there are hazards associated with land spills from storage tanks, railcars, or trucks on which almost no research has been done. For example:

1. Spillage of LEG into sewers, subway tunnels, or other conduits. In the previously discussed 1944 Cleveland incident, much of the destruction was caused by LNG and cold natural gas entering sewers and basements where it produced explosions and fires. Among the questions associated with LEG hazards of this kind are:

   a) Assuming a spill into a sewer system, how far can LEG flow before vaporizing?

   b) Under what circumstances will the gas enter buildings and explode?

   c) What are the consequences of a spill into a subway, railroad, or highway tunnel? In particular, how wide an area would be affected? What would the effects be?

   d) What are the effects of LEG or gas in the basement of a modern multi-story structure?

e) What configurations or environments are particularly vulnerable to spills of this kind?

f) What is the credible damage from an accident in each of several possible environments?

2. Secondary fires and explosions. Under what circumstances will secondary effects amplify the hazards from a fire caused by a spill? Will the secondary effects feed back and enhance the direct destructive effect of the spill?

   Questions of this kind depend on the site involved. The danger of secondary fires and explosions is greater if the surrounding area contains flammable materials and structures. Junk yards, for example, present this kind of hazard. An important question is whether or not LEG poses a significantly higher danger than gasoline or petrochemicals in generating secondary effects.

3. Neighboring facilities containing hazardous materials. LEG facilities are sometimes located near other tank storage sites, sewer plants, or other places that store hazardous materials. An earthquake, sabotage, or some other cause could result in a combined spill and conflagration involving several facilities. Also, fire or a shock wave from one facility could spread to another, producing a higher level of hazard than from any one alone. The existence and nature of

the augmented hazard from different types of neighboring sites should be investigated.

4. Sabotage. An individual or group intent on causing public damage may be able to create hazards at LEG facilities that might otherwise be so unlikely as to be ignored. It is important to explore such potential hazards.

Finding

- There has been no effort in recent years by the Federal Government to answer questions of the kind described in 1-4 above, nor is any contemplated as far as we can tell.

Federal Plans for Hazard Assessment

DOE is presently planning a $50 million program of research over the next 5 years which will be focused primarily on LNG hazard assessment.[13] The major expenditure ($35 million) is for building storage tanks and facilities at a testing ground in order to produce and analyze very large (1,000 cubic meter) spills.

Investigations of vapor dispersion and flame propagation characteristics, and of potential control techniques are also planned. There have already been a number of conflicting studies of vapor dispersion, and specific recommendations for future research have been published. Vapor dispersion and flame propagation problems are important, and clearly deserve further study. Unfortunately, however, large scale experimentation is not

scheduled until FY-1982. By the time the results are available, the questions may be moot since most facilities will have already been approved. Further, it is not clear how the experiments will produce useful information. (Will large-scale releases be sudden? Will they be allowed to drift? Will they be over land or water? What wind conditions will be tested?)

Current fluid dynamical modeling of LNG spills has little sophistication. The magnitude of the potential hazard requires much better effort than various current estimates of downstream methane concentration, which differ by more than a thousand percent. The credibility of predictions from future models will depend on successful scaling tests comparing numerical experiments with laboratory and field experiments. To establish the validity of the scale dependence and hypotheses contained in the models, extensive small scale studies of all parameters are needed, followed by a few critical larger scale (350 cubic meter) tests.

DOE's program uses an unnecessarily long time to develop credible models for spills, vapor dispersion, and flame propagation. We believe that all needed small scale experiments could be finished by mid-1979, leading to a highly plausible prediction scheme for the few large scale field tests in late 1979.

The differences in the predictions of the vaporization rate of spills are perhaps the easiest factor in previous calculations to improve upon, with a more complete parameterization of convective heat flux from ocean and air into the spreading LNG layer.

Finding

- DOE's research plans will take too long to carry out to have much impact on the siting or design of most facilities. Its research program aims to subsidize the general development of LNG use and increase basic scientific knowledge rather than quickly attack specific safety issues. The necessary development of accurate spill models could be completed by late 1979.

RISK ASSESSMENT

Research on the risk of LNG spillage from tankers has been carried out under Coast Guard sponsorship. Studies of the risks of LNG shipping and storage tanks at proposed terminals at Los Angeles, Point Conception, and Oxnard, all in California, were done by Science Applications, Inc. (SAI) under sponsorship of the proposers of the projects. The FPC has studied the risk at several facilities. These and similar studies are summarized in Reference 1.

Risk assessment first lists all possible sequences of events that can produce disaster, and then attempts to assign probabilities to each element of these sequences and thus to entire sequences.

The validity of risk assessment depends on the following factors:

- Have all significant disaster paths been identified?

- Have the probabilities of all the sequence elements been accurately assigned?

- Have the couplings and interactions among these sequence elements been correctly analyzed?

Typically, a poor risk assessment study underestimates risks because it overlooks disaster paths and underestimates couplings among elements.

SAI Risk Studies

The most comprehensive risk studies to appear so far are the SAI studies of Los Angeles, Oxnard, and Point Conception.

The SAI study of the proposed Los Angeles LNG facility finds that the probability of a tank rupture on a ship is rather high, approximately one in ten over the twenty year lifetime of the facility.[3] SAI, however, uses a model in which vapor typically spreads 1.2 miles in a flammable state. Thus, they find the onshore risk from such spills to be small since they claim the likely collision region is 2 to 7 miles offshore.

J. Havens assessed SAI's estimate of flammable cloud dispersion distance and comparable estimates made by other investigators: .75 miles (Federal Power Commission); 5.2 miles (American Petroleum Institute); 11.5 miles (Cabot Corporation); 16.3 miles (U.S. Coast Guard CHRIS); 17.4 miles (Professor James Fay); and 25.2-50.3 miles (U.S. Bureau of Mines).[2] According to Havens: "The FPC estimate, in the author's opinion, is not justified. . .In the author's opinion, the predicted maximum distances of about 5 miles by Feldbauer and about 1 mile by SAI. . .cannot be rationalized on the basis of any argument thus far advanced except that of gravity spread/air

entrainment effects and experimental verification of those effects has not been adequately demonstrated."

SAI's Dispersion Model

A spill from a ship tank rupture has three phases.

1. The spilling out of liquid over the water, and its spread and evaporation.

2. Propagation of the vapor when the liquid has all evaporated, but the resulting cloud of vapor is still heavier than air.

3. The subsequent spreading and dispersion of the vapor when, through increase in temperature, it has become no more dense than air.

There is not much controversy about the first phase; the liquid would be heated very rapidly by the water and would evaporate at a rate of roughly an inch per minute, according to most experts. The FPC model, however, uses a much lower evaporation rate which causes its very small distance to nonflammability.

The third phase represents a phenomenon that is less understood, but there are vapor dispersion models that apply to similar phenomena. Models such as SAI's can be checked and calibrated for behavior in this phase.

Models of the second phase, however, are controversial. There is a cloud or fog of heavy vapor above the water, undergoing rapid heating from the 32°F

water below and gravitational slumping. The vapor mixes with the atmosphere, which is cooled and stratified by it.

In describing the second and third phases, SAI uses numerical computations based upon conservation laws and empirical eddy transport equations in the average concentration of vapor. SAI's calculations involve average quantities only.

The crucial assumption in SAI's approach which results in a short distance to the lower flammable limit is probably wrong. *In their model the rate of vertical mixing of concentration is related by a "vertical eddy diffusivity" to the rate of change of concentration with height. A similar model is used for momentum diffusion. As defined, these diffusivities are complicated functions of the entire system. SAI models the momentum diffusivity at a point as a function of height above the ground and the computed temperature gradient. The diffusivity for momentum is chosen to match normal atmospheric experiments. The normal atmosphere value is also chosen to calibrate the concentration diffusivity.* The consequence of these assumptions is that there is no clear boundary between the vapor cloud and the air, and enormous mixing is predicted at the edge of the vapor cloud.

This phenomenon is not suggested by any experiment. It stems, rather, from the use of a mathematically simple model for diffusivity in a range where it has not been tested. One would, on the basis of physical intuition, rather assume that the local wind shear at the top of the dense vapor cloud determines the magnitude of vertical mixing.

California's Energy Resources Conservation and Development Commission, in its August, 1977 draft report, "LNG Siting: An Assessment of Risks", also was skeptical of the manner in which entrainment and mixing are modeled in SAI's code.

There are alternate simple diffusivity models. An opposite extreme from SAI's would be a model in which the diffusivity is related to the distance from the top of the cloud rather than from the sea. Such a model for phase two would have very different consequences than SAI's.

As a result of the large amount of mixing predicted by SAI's diffusivity model, vapor concentration falls rapidly from vertical mixing and there is comparatively little spreading before it is diluted.

Data from small scale confined spills suggests that the diffusivity assumptions in the SAI model could be modified empirically to deal adequately with large scale spills. However, careful scaling from a series of different size spills is needed. It should be possible to determine the validity of these assumptions instead of guessing about them.

Estimates made by our consultants indicate that SAI's results for distance to flammability (1.2 miles) are likely to be five to ten times too low, i.e., the distance to flammability is probably 6 to 12 miles.

Finding

- SAI's dispersion distance computations are based on models chosen for mathematical simplicity and have no

experimental basis. Because of their models' short distance to the lower flammability limit, SAI may have seriously underestimated the onshore risk of tank rupture at sea. Testing of models and suitable improvements to them can be made by small scale experiments along with larger size tests of scaling. Results should be obtainable in one to two years.

At Oxnard and Point Conception, SAI's calculation of risk does not take into account possible collisions in the shipping channels. Ignoring this risk may be unjustified in light of the previous discussion. On the basis of its computations, SAI finds that no more than 97,000 fatalities would occur in an incident and this number has a probability of only 5×10^{-50} per year. (Apparently SAI considers the probability that its dispersion computations are wrong and one of the others right to be less than 10^{-40}.) On the other hand, T. Needels[2] of FPC agrees that FPC dispersion calculations may be wrong, but suggests that the chance of a major tank rupture is very small. In reference to Havens' report he writes, "Your otherwise fine report may therefore permit misleading information because it analyzes essentially impossible events."

Finding

- The short SAI dispersion distance is crucial to the low risk reported by SAI. A substitution of 6 or 12 miles for the 1.2 miles used would dramatically increase estimates of LNG risks at Los Angeles.

Storage Tank Rupture

SAI essentially rules out storage tank rupture from normal use by the following reasoning. Since critical

crack length greatly exceeds tank thickness, cracks will leak long before they pose a danger of rupture. There is a one in a thousand chance per year of a leaking crack, but only a one in a million chance that the leak will fail to be detected and the crack repaired before rupture. Earthquakes are assumed to reduce critical crack length, but could, according to SAI, shatter a tank only if the quake reduced critical crack length to tank thickness. This would require an extraordinary earthquake. However, this reasoning does not apply to outer tanks which do not leak if cracked, and which have the potential to damage or crack the inner tank if they collapse. SAI does not consider this possibility. What is more, as is shown in Chapter 3, if a tank fails in an earthquake, the most likely mode of failure is for the tank walls to lift off and separate from the tank bottom, spilling the contents. SAI also ignores the possibility that a crack of critical length might be induced by sabotage, as discussed in Chapter 9.

Another difficulty in SAI's risk analysis is that it was made before the proposed facilities were fully designed. Thus, flaws in design, construction, or operation that would lead to safety problems were ignored.

The SAI studies conclude, therefore, that the primary means by which a land facility can fail and cause a disaster is by being hit by an airplane. Such an event could rupture inner and outer tanks and dikes as well. Many other possible disasters are considered, but all are calculated to have very much smaller chances of occurring than a plane hitting a facility (which is estimated to occur once in a million years).

In part, the small probability calculated for most disaster sequences in LNG risk analyses stems from the fact that at least two simultaneous unlikely events are required for them to occur.

Unfortunately, it is possible for a single initiating event to produce simultaneous failures. Indeed, it is typical that failure of one component or system produces failures of others, and one cause may produce several failures. SAI's assumption that a disaster requires a number of independent occurrences is questionable, because several systems can fail from one source.

For example, in the 1944 Cleveland incident (see Chapter 10), shocks of some sort apparently produced a small crack in one inner tank. It may be that leakage through this crack over a relatively long time eventually led to exposure of the outer tank and a massive spill. Fire from this spill then produced rupture of another inner and outer tank. Thus four tanks, two inner and two outer, probably ruptured from a sequence started by one cause.

If 1944 data and the SAI study methods were used to compute the probabilities of a tank rupture, the probability associated with four tanks rupturing at roughly the same time (even including the "common mode" computations used) would be less than one in ten million. Yet four tanks did rupture at roughly the same time probably as a result of a perfectly natural and not unlikely sequence of events, starting from not very improbable small cracks. Even though for a long time there was substantial evidence of á small leak, which was investigated by the gas company and the tank builders, the leak was not repaired. In the light of what happened in

Cleveland, it is hard to justify SAI's probability of one in a million for leaks not being detected and repaired before rupture.

The low dikes used in many facilities will not hold all the LEG that would emerge in a sudden massive tank rupture. As shown in Chapter 5, a high percentage of the fluid could surge over the dike. All the risk assessments so far have assumed that such spills would be confined to the enclosed diked area, unless the dike also failed.

None of the probabilities calculated in any of the LNG risk assessments consider sabotage. Thus, the chance of failure from malicious action has to be added to the calculation. We do not think that this can be done with present knowledge, but without sabotage probabilities, any total risk calculation lacks much usefulness.

DAMAGE ASSESSMENT

Damage assessment has been examined under contract to the Coast Guard and as part of several risk assessment studies.

Among the major problems not adequately addressed in these assessments are the following:

- Secondary fires.
- Dike overflows.
- Presence of other hazardous materials nearby.
- Problems associated with sewers and other underground structures.
- Effects of sabotage.

EFFECTIVENESS OF SAFETY SYSTEMS

In the past, OPSO and the Coast Guard have studied the effectiveness of proposed procedures, equipment, and safety devices, but their research budgets are no longer adequate for them to pursue such research effectively. It is important that these studies be done by the agencies involved in regulating the areas. Only they have the direct hands-on knowledge that makes such research to the point.

ADEQUACY OF SAFETY REGULATIONS

Provisions in OPSO's Advance Notice of Proposed Rulemaking would strengthen the previous LNG safety standards in many respects and may be controversial. Neither OPSO nor the Coast Guard have enough research funds to evaluate the adequacy of the existing industry codes or the proposed standards.

LONGEVITY OF LNG OPERATIONS

Large-scale LNG operations will probably be over by the end of this century. Most large LNG facilities have already been planned, licensed, or built. Five years from now there will be few, if any, left to build. A very expensive research plan such as DOE's, which aims at increasing basic knowledge over a five year period (to start sometime in the future) instead of concentrating on answers in the next two years, is a misuse of resources. DOE has already spent one critical year planning such a program. It is unlikely to publish substantial results much before 1980. Most results will probably come after that. These will have little effect on what is actually built.

In several chapters of this report we have suggested other specific research items and programs. Most of these can be carried out in the next two years.

CONCLUSIONS

- The present plan to channel the bulk of LNG safety research through DOE is faulty and will not produce timely or useful safety results. DOE plans to support LNG research in a manner analogous to its support of research in other areas. This is entirely inappropriate in relation to the safety of facilities now under development, under construction, or in use. The research needed for current, temporary technology is different from that which is needed for long-term and not yet perfected technologies. At the same time, the organizations directly responsible for safety have inadequate budgets and personnel to make informed technical judgments on safety.

- Good quality hazard analysis has been carried on primarily by the Coast Guard. Its emphasis, however, has been on the effects of a spill on water. There is a need for much more thorough hazard analysis of the interaction of LEG spills with man-made structures such as buildings, subways, sewers, and ships.

- Building expensive, new facilities for very large (1,000 cubic meter) experimental spills is not a sensible way to spend LNG safety research funds. It is unlikely that any results can be obtained in this manner soon enough to affect the design of most facilities.

- LEG risk assessment studies have not reached a stage where they give confidence in their conclusions. Therefore, safety decisions cannot logically be based on them. Regulatory agencies will have to make

timely, prudent decisions with the realization that many important questions cannot presently be answered with confidence.

RECOMMENDATIONS

TO THE CONGRESS

We recommend that the Congress provide to the organizations directly responsible for LEG safety (OPSO, FERC, ERA, NHTSA, OHMO, Coast Guard, etc.) adequate budgets and personnel to make informed technical judgments and do research on safety procedures and equipment to be used under their jurisdiction. Adequate funding should eliminate the need for agencies to share costs of hazard studies with private industry.

TO THE SECRETARY OF ENERGY AND THE SECRETARY OF TRANSPORTATION

We recommend to the Secretary of Energy and the Secretary of Transportation that:

- The primary goals of Federal research on hazardous materials be to: (1) clarify the hazards, risks, and consequences of their use, so that appropriate regulations can protect the public; (2) aid in assuring that the plans and practices of operating facilities are adequate to satisfy the regulations; and (3) investigate techniques to reduce the risk of their storage and transportation.

- An immediate, significant research program be focused on the interaction of spills of hazardous substances with man-made structures such as buildings, subways, sewers, and ships.

- An immediate program be started to investigate the possibility of preventing or mitigating the effects of sabotage on the storage and transportation of hazardous materials in populated areas.

TO THE SECRETARY OF ENERGY

We recommend that the Secretary of Energy replace immediately the department's present LEG safety research plans with a less costly, two-year effort focused on the sort of studies of detonation, fire characteristics, flame propagation, vapor dispersion, crack propagation, and interaction with man-made structures that we have outlined in this and other chapters. The research program should also seek to determine the best remedial measures for dealing with fires from LEG spills.

NOTE: Agency comments on LEG research and our evaluation of the comments follow the recommendations in Chapter 13.

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CHAPTER 13

DETONATION AND FLAME PROPAGATION RESEARCH

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INTRODUCTION

The purpose of this chapter is to review the most pertinent experimental research that has been performed on the detonatability of LNG and LPG vapor-air mixtures, to suggest the critical unanswered questions, and to recommend research which would answer these questions within the next 1 to 2 years. Certain recent theoretical models are also briefly reviewed. In the closing section we analyze the possibility of a flame propagating upwind through an LEG vapor-air cloud. The highly technical parts are italicized. Non-technical readers may omit them.

A detonation is a combustion (burning) wave moving supersonically. The combustion is so rapid that a high temperature is reached before the mixture has much chance to expand, thus producing a high pressure that is essentially independent of the presence of confining walls. (The maximum detonation pressure is 250 pounds per square inch (psi).) In contrast, a deflagration is a flame front which moves at subsonic speed, generally building up little pressure unless the mixture is confined in a closed or nearly-closed structure. The more general term explosion usually denotes any sudden gaseous expansion which produces a loud noise. Explosions include detonations as well as milder events such as the bursting of buildings due to deflagrations inside, or pressurized gas bottles blowing up.

The planned rapid increase in the domestic shipment and storage of LEG makes urgent the question of whether destructive detonations are possible. Very large amounts, 150,000 cubic meters or more, will be shipped or stored in one place. If even a small part of this amount were

spilled and the ensuing vapor-air cloud detonated, the resulting blast wave could injure people and damage structures miles from the cloud center.

LNG is primarily methane (65 to 99% by volume), with smaller amounts of the heavier hydrocarbons ethane and propane.[1] Methane burns when mixed with air within the flammability limits (5.3 to 15.0% methane[2]), but methane-air mixtures are very difficult to detonate. This is supported by laboratory and field experiments[3,4,5] and by the fact that no accidental detonations are known to have occurred over decades of commercial and residential usage of natural gas. However, experiments have shown that methane-air mixtures in large pipes can be made to detonate.[3,6] And very recently it has been shown that even unconfined homogeneous mixtures will detonate, if they are large enough in volume and initiated with several kilograms of high explosive.[5,7] Moreover, in contrast to natural gas at room temperature, the cold vapor from an LNG spill is denser than air. Thus, a large cloud may be formed near the ground. A large cloud may be detonatable. Finally, boil-off of spilled LNG may result in fractional distillation,[8] so that the last part of the vapor cloud to be formed contains principally ethane and propane, which are considerably easier to detonate than methane.[9]

LPG is composed primarily of propane and butane, in relative proportions that may vary widely.[10] These gases have similar detonation properties, when concentrations are measured relative to the stoichiometric* value for each mixture,[9,11] and both are significantly easier to detonate

*A stoichiometric mixture is one that has exactly the amount of oxygen needed for complete burning.

than methane.[9] There has been at least one well-investigated accidental detonation of an unconfined propane-air cloud, which was released by a break in a pressurized propane pipe. The detonation was apparently initiated by the explosion of a concrete warehouse.[12] There is no doubt that for comparable amounts LPG presents a greater detonation hazard than LNG.

STATEMENT OF THE PROBLEM

The general problem addressed in this chapter is whether large releases of LNG or LPG can lead to detonations, initiated by sources that might be present in the vicinity of LEG storage facilities or transportation routes, and if so, what fraction of the total fuel spilled would contribute to the detonation. This general problem can be subdivided into the following technical questions:

1. If LNG is spilled on water or land, is there significant separation of the hydrocarbon components during the boiloff?

2. What are the spatial and temporal variations of the fuel vapor concentration in the vapor-air cloud formed when LNG or LPG is spilled and the variations in the hydrocarbon composition for LNG if differential boil-off occurs?

3. What types of sources could initiate detonation in the vapor-air cloud formed by an LNG or LPG spill, or in the aerosol cloud of liquid droplets formed by the violent disruption of an LNG or LPG container? For experimental

convenience in preliminary investigations, this question may be replaced by the question: Will any of these sources detonate homogeneous vapor-air or uniform liquid droplet-air mixtures? Such homogeneous situations represent "worst cases", and the large vapor clouds from actual releases may contain nearly uniform regions, at least part of the time. Two other important questions are:

a. Since it is well established that explosive gases can be detonated more readily in large tubes than in unconfined regions, is it possible that in an LEG release a detonation might be started in a storm drain, tunnel, or similar structure and propagate from there to the unconfined cloud?

b. Since mixtures of air with LEG vapor are much easier to ignite than to detonate, and since many explosive mixtures are known to make a transition from a deflagration to a detonation if a long enough burning path is available, can such a transition also occur after a large LNG or LPG release, either in the unconfined cloud or in a storm drain or tunnel?

4. If a detonation occurs, what fraction of the vapor cloud (or aerosol cloud) actually detonates and contributes to the explosive yield? This depends on the spatial and temporal

variations of the fuel concentration in the cloud and on the characteristics of a detonation in an inhomogenous mixture (the answer to Question 2). Clearly, there will always be a cloud "fringe region" where the fuel is too diluted to detonate, and, if detonation initiation occurs before considerable mixing with air has taken place, there will be an inner region too rich to detonate. In the intermediate region, where the fuel concentration may vary back and forth across the nominal detonation limits due to incomplete mixing, the situation is more complex.

PAST INVESTIGATIONS RELEVANT TO LEG CLOUD DETONATIONS

Detonation of Essentially Unconfined Mixtures of LEG Vapor with Air

The experiments most relevant to the present problem are those on completely unconfined (and therefore inhomogeneous) hydrocarbon-air clouds released in the open, but very few such experiments have been carried out. Benedick et al.[11] produced propane-air clouds by releasing gaseous propane on calm days. They successfully detonated the clouds using 0.8 kilograms (kg) of sheet explosive as initiator, but they made no quantitative measurements. Also, propane aerosol clouds produced by explosive disruption of a liquid propane container have been detonated by an explosive charge, but again no measurements were made.[13]

Another relevant observation comes from an accident that occurred in 1970 near Port Hudson, Missouri.[12] A

pipeline carrying liquid propane under pressure broke and about 90 cubic meters escaped into the open in the next 24 minutes. A large detonation then occurred, probably initiated by pressure build-up after ignition in a concrete warehouse about 300 meters downwind and downhill from the pipe break. An analysis of the blast damage indicated that the explosive yield corresponded to detonation of about 7.5% of the total propane which had escaped.[12] Similar analyses of the accidental detonation of other large vapor clouds (most of them not LEG) give explosive yields less than 10% of the total fuel energy.[14] All these clouds were very small compared to the contents of modern storage tanks or ships. Much larger clouds might give substantially greater percentage explosive yields if initiated near the time when the maximum volume of the cloud lies within the explosive limits.

A pertinent "negative" observation is that a number of small test spills of LNG on land and water have been deliberately ignited and none of them detonated.

In the majority of "unconfined" detonation experiments, the fuel-air mixture was contained in a thin rubber or plastic balloon or bag. Usually the mixture was initiated by high-explosive charges of varying sizes. In such an arrangement, theory and observations show that if the bag is large enough the detonation will either propagate or die out before any disturbance reaches the container walls. Accordingly, the results are the same as for a completely unconfined fuel-air mixture, except that the mixture is more uniform than one resulting from an LEG release in the open.

Early investigations of essentially unconfined fuel-air detonations were carried out in the USSR by

Kogarko, Adushkin and Lyamin[4] on stoichiometric mixtures of methane, propane, and acetylene with air, in spherical rubber balloons up to 3 meters (m) in diameter. As initiators, they used TNT charges of various sizes placed in the balloon center, and they determined the progress of the detonation by means of photographs and pressure sensors at various distances from the center. They concluded that propane-air mixtures could be detonated by a 155 gram (gm) TNT charge, but methane-air mixtures required a 1 kg charge (the largest they tried). Their result for propane appears to be reasonably accurate, but their result for methane is questionable. The 1 kg initiator needed to detonate the methane-air mixture contained 8% as much energy as that in the entire balloon, and this energy may have been enough to detonate the gas locally without producing a self-propagating detonation.

During the years since Kogarko's work there have been a number of investigations of gas detonations in spherical geometry using as initiators high explosives of only a few grams, or electric sparks of even less energy. Most involved hydrogen-oxygen or hydrocarbon-oxygen mixtures, although in some cases increasing amounts of nitrogen diluent were added. With these small initiators some investigators obtained detonations in propane-oxygen mixtures, but, as expected from Kogarko's results, detonations were no longer obtained after addition of only a moderate amount of nitrogen (much less than that in a propane-air mixture).

The next relevant investigation was carried out by TRW under sponsorship of the American Gas Association.[15] In 6.1 m diameter balloons filled with a stoichiometric mixture of air and natural gas (88.4% methane, 8.2% ethane

and 1.2% propane), they were unable to produce propagating detonations with a 0.48 kg charge of C-4 explosive placed either in the balloon center or 15 centimeters (cm) above the ground. Since in the latter geometry reflections from the ground should roughly double the effective initiator energy, and since C-4 has about 30% more energy than the same mass of TNT, the TRW results tend to confirm the conclusion that Kogarko did not actually obtain a propagating detonation in his methane-air mixture with 1 kg of TNT.

Results of large-scale experiments on propane and butane, conducted at Albuquerque, New Mexico, were published in 1970 by Benedick, Kennedy and Morosin.[11] *Using long rectangular plastic bags (1.8 m x 1.8 m x 7.6 m or 1.2 m x 1.2 m x 6.1 m) and an initiator of up to 0.8 kg of Dupont EL 506-A.5 sheet explosive at one end, they were able to detonate propane-air mixtures with fuel concentrations between 3% and 7%, and butane-air mixtures with fuel concentrations between 2.5% and 5.2%.*

A few years later similar tests were made at Eglin AFB, Florida by Vanta, Foster and Parsons[15] *on natural gas-air mixtures in bags 1.2 m x 1.2 m x 6 m and 2.4 m x 2.4 m x 2.4 m. They observed "erratic" detonations for near-stoichiometric mixtures initiated by sheet explosives of about 1 kg. It is not necessary to discuss the validity of their conclusions, since their work has been superseded by very recent unpublished experiments by Benedick and colleagues,*[7] *who definitely observed a propagating detonation in a stoichiometric methane-air mixture contained in a 2.4 m x 2.4 m x 12 m bag and initiated by 4 kg of sheet explosive backed by a large plywood sheet and placed over one end. This is the first known propagation*

of a sustained detonation in an "unconfined" (bagged) cloud of methane/air. While active instrumentation was limited to high-speed photography, we believe the quality of the data to be excellent. Benedick also produced a detonation over about three-fourths the length of a 1.7 m x 1.7 m x 9.5 m bag containing a slightly richer mixture using 2 to 4 kg of sheet explosive; however, it appeared that the 1.7 m dimension was marginal to support a sustained detonation.

A more extensive investigation, using compact rather than sheet explosive charges, has recently been carried out by Bull et al. in Great Britain.[5] *They exposed stoichiometric hydrocarbon-oxygen-nitrogen mixtures in thin plastic bags 1 m diameter x 3 m long to shock waves from square cylinders of high explosive (Tetryl) of several sizes ranging up to 0.52 kg. By interpolation or extrapolation against the nitrogen concentration, the minimum charges necessary to detonate stoichiometric mixtures of air with methane, ethane, propane and butane were determined to be 22, 0.04, 0.08 and 0.08 kg, respectively. The minimum charge for mixtures of methane and ethane fell between the values of the two pure gases; for 65% methane and 35% ethane (within the possible LNG range, if the differences between ethane and the heavier hydrocarbons are neglected) the minimum charge was about 0.3 kg. Deviations from a stoichiometric mixture by 20% toward the lean side or 50% toward the rich side increased the minimum charge by about a factor of 3. These experiments were well instrumented and carefully performed. The results appear to be quite reliable.*

Very recently, Lind has investigated detonation initiation in hemispherical balloons of 10 m diameter at China Lake, California.[16] *Using a hemispheric Composition*

B charge placed in the center on top of a steel plate (which should approximately double its effective energy), with 1.4 and 2 kilogram charges he did not obtain detonation in stoichiometric mixtures of air with natural gas (96% methane, 3% ethane, 1% propane), or with 86% methane/3% ethane/11% propane (1.4 kg charge). He did obtain detonation with an 81% methane/3% ethane/16% propane mixture (1.4 kg charge). His results, though less complete, are consistent with those of Bull et al.[5,9]

Lind also ignited methane-air and propane-air mixtures in the center of the hemisphere with a spark, but he did not observe any transition from deflagration to detonation in 5 m or 10 m paths. In such slow flame experiments the plastic container may have a significant influence by temporarily holding in the pressures built up by the flame, but this can only assist in the transition to detonation. Lind's work appears to be of high quality and reliable.

Some recent theoretical papers pertinent to unconfined vapor-air explosions are worth mentioning. Kuhl, Kamel, and Oppenheim[17] analyzed the pressure waves that would be produced by a steadily expanding spherical deflagration front. Their results show that for the usual flame speed the pressure waves would be quite weak, but if the flame speed could be considerably increased (by turbulence, for example), destructive pressure waves would be produced even without a true detonation. The immediate usefulness of this work is limited by our lack of knowledge of what flame velocities might be attained in realistic situations.

Williams,[18] Strehlow,[19] Oppenheim et al.,[20] and others have developed simplified models which also show a

strong dependence of the overpressure produced by a non-ideal explosion on flame speed and combustible cloud shape. These models indicate that if flame speeds of about 35 m/sec or more are present, damaging overpressures can be produced even though such speeds are far below those associated with a detonation.

Very recently Boni et al.[21] calculated the tendency of flames in unconfined methane-air mixtures to accelerate and make a transition to detonation. They used a simplified chemical kinetics scheme and assumed various values of the turbulent eddy diffusivity. These numerical calculations indicate that such a transition will occur only if unreasonably high levels of turbulence are initially present or are generated by the flame. Similar calculations with a more complete chemical kinetics scheme might suggest whether ethane-air or propane-air mixtures would make the deflagration to detonation transition. However, because of the simplified and parametric treatment of turbulence, the results could not be relied upon without experimental confirmation.

In a recent theoretical analysis, Sichel[22] has expressed the minimum energy required for the blast initiation of detonation in planar, cylindrical and spherical geometry in terms of a parameter which can be evaluated for any fuel/air ratio of a given hydrocarbon if the minimum initiation energy is known for any one geometry and fuel/air ratio of the same hydrocarbon. Most of the results pertinent to LEG detonations that his theory could give have already been obtained experimentally by Bull et al.[5,9] However, Sichel's equations, with the parameter evaluated from the data of Bull et al., can be used to show that lightning bolts must have energy densities of 4×10^7

and 4 x 10^5 Joules/m in order to detonate stoichiometric methane-air and ethane-air mixtures, respectively. The ethane-air value falls within the upper range of typical lightning bolts[23], but the methane-air value is almost as large as that for lightning "superbolts", which occur about once in every two million strokes.[24]

Detonation of Confined Mixtures of LEG and Air

Essentially all quantitative investigations of detonations in confined hydrocarbon-air mixtures have dealt with the mixtures in pipes and tubes. These investigations are pertinent to LEG cloud detonations because the heavy vapor may seep into storm drains, sewers, tunnels, or similar structures, and a detonation started there may propagate out into the free cloud.

In early work, Henderson[25] determined that in a 10 cm diameter pipe 75 m long, closed at both ends and filled with a stoichiometric mixture of air and natural gas (91% methane, 8.5% ethane), deflagrations made transitions to detonations in a distance of 100 to 200 pipe diameters, but only when the fuel-air mixture was initially flowing at over 1.3 m/sec (apparently creating the required turbulence). Later, Gerstein, Carlson and Hill[6] observed that a similar mixture (90% methane, 8% ethane) in a 61 cm diameter closed pipe 93 m long made such a transition in 50 to 150 pipe diameters when the mixture was initially stationary, but the detonation velocity oscillated about the theoretical value, a "galloping" detonation. This work was actually carried out at initial pressures of 0.2 to 0.4 atmosphere, but the results were rather insensitive to pressure variations.

Kogarko[3] determined that a stoichiometric methane-air mixture in a 30.5 cm diameter pipe could be initiated by a 0.05 kg high-explosive charge inside the closed end, while a 0.07 kg charge detonated considerably leaner and richer mixtures (almost to the flammability limits). No detonations could be obtained in a pipe of only 2 cm diameter. Similar experiments with propane-oxygen-nitrogen mixtures by Manson et al.[26] in tubes up to 5.2 cm diameter gave detonations only for mixtures with slightly less nitrogen than in propane-air mixtures, but a short extrapolation indicated that propane-air detonations could be produced in tubes of 6 cm diameter or larger.

Benedick obtained detonation of stoichiometric methane-air mixtures over the entire length of open-ended wooden boxes about 0.6 m x 0.6 m x 9.8 m by detonating 250 gm of sheet explosive inside the fuel-air mixture, but about 0.5 m outside of one end of the box.[7] He did not, however, get a detonation in similar tests with the mixture ignited by either 32 gm of explosive or by a glowing filament placed at the end of the box.

Observations on an accidental explosion that occurred near Port Huron, Michigan are also pertinent. Methane gas seeped into a 4.9 m diameter water tunnel that was under construction. Apparently the gas was accidentally ignited near the closed end. This produced a "galloping" detonation with regions of high pressure occurring about every 60 tunnel diameters (along a 5 km length of tunnel), where it blew holes in the 30 cm thick concrete tunnel liner.[27]

Apparently no studies of the deflagration to detonation transition for ethane-air and propane-air

mixtures in tubes have been published. However, numerous laboratory experiments, using more easily detonated gases in small tubes, have shown that such transitions generally occur if the tube is wide enough to allow a detonation, long enough to permit a complete transition, and if the gases are ignited either near a closed end or a long distance from both ends.[28] *Ignition with a weak source near an open end does not yield a detonation.*

Distribution of Detonatable Mixtures in an LEG Vapor Cloud

An important consideration for estimating the effects of an unconfined LEG vapor cloud fire or explosion is the mass fraction and location of that portion of the cloud between the flammable or detonatable concentration limits (the detonatable limits are presumably close to the flammable limits when a sufficiently large initiator is involved). Although a number of methane concentration measurements were made during a series of small LNG test spills in earthen dikes,[29] and also in wind tunnel vapor dispersion simulation studies,[30,31] the data are not extensive enough to provide good estimates of vapor cloud concentration contours.

If it is assumed, as many of the available vapor cloud dispersion models do[32]*, that the concentration structure of these vapor clouds can be described as a gaussian distribution in space, one can easily demonstrate that, regardless of the form of the gaussian dispersion coefficients, the maximum mass fraction of the methane cloud between the 5 and 15 percent concentration contours is approximately 45%,*[14] *whereas for propane a maximum of approximately 65% of the cloud mass can lie between the 2 and 10% flammability limits. The maximum flammable*

mass fraction occurs approximately when the maximum concentration in the cloud reaches the upper flammability limit. Thus, the maximum mass fraction occurs at only one instant in time; at both earlier and later times, the flammable mass fraction is less. We emphasize, however, the the gaussian assumption ignores smaller-scale concentration variations due to irregular turbulent mixing, and, even as an approximation to the mean concentration profile, it has not been verified by adequate measurements on a large, negatively-buoyant vapor cloud.

FLAME PROPAGATION

It has often been stated that if an LEG vapor cloud is ignited at its edge, the flame will burn back to the site of the spill. This may not be true if the cloud is ignited on the downwind edge in a strong wind.

Relevant observations have recently been made by Lind, who spilled 5.7 cubic meters of LNG in 1-1/2 minutes on a 50 m x 50 m pond, and ignited the vapor a short distance outside and downwind of the pond, in winds of 2.5 to 5 m/s (5.5-11 mph). The fire burned back to the edge of the pond (a 2-1/2 foot drop), paused, and then burned more slowly back across the water. Most of the LNG had been consumed before the flame left the edge of the pond. LPG spills gave similar results, but the pause was shorter.

Laboratory measurements give laminar flame speeds for these mixtures of only 0.5 m/s (1 mph) or less, but in turbulent flows the flame speeds often reach 5 to 10 m/s (11 to 22 mph) and occasionally faster. On a windy day the atmosphere is quite turbulent, so flame propagation in a combustible mixture against a moderate wind may be

possible. However, the flame plume formed initially near the ignition point produces an updraft which draws in air from the sides, giving a velocity which adds to the wind velocity and makes upwind flame propagation more difficult. Near the water or land, friction prevents the gases from moving with the full wind speed, so upwind propagation may occur. However, when ignition occurs before the bulk of the vapor has mixed much with air (which is generally true while the liquid is still boiling off, as in these test spills), the vapor near the ground is too rich to burn. An exception is the fringe region where the edge of the cloud touches the ground.

For a considerably larger spill, the flame plume formed near the ignition point may be so large that it will create its own strong inward winds, pulling almost all of the flammable vapor to it without the plume moving much.

If ignition is delayed until most of the vapor is diluted into the flammability region (which has not been attempted in any of the test spill ignitions that we know of), upwind propagation should be easier. There is also a chance of a propagating detonation as discussed earlier. It is also possible that a sufficiently strong wind will carry the flame front away from the spill.

Finding

- Current knowledge of flame propagation in an LEG vapor/air cloud is insufficient to determine whether the flame will burn back to its source if a large cloud is ignited on its downwind edge in a strong

wind. It is possible that the flame will stay at the ignition point, or that it will be carried downwind. In a recent test in a low wind at China Lake, LEG vapor/air clouds generated on the water were ignited on land and burned back to the water's edge. They stopped and burned there for some time before continuing across the water. This unexpected result shows again how little is understood about such problems.

GENERAL CONCLUSIONS

Flame Propagation

- Little reliance should be placed on statements that if an LEG vapor/air cloud is ignited on its perimeter the flame front will burn back to the source, regardless of the wind conditions.

LEG Vapor-Air Detonations

- In a large release of LEG, it is possible that the resulting vapor-air cloud will detonate and produce a blast wave that could injure people and damage structures out to a large distance. Experiments have demonstrated that essentially unconfined mixtures of air with the LNG and LPG hydrocarbons will detonate if initiated by a large enough charge of high explosive. Moreover, at least one carefully analyzed accident involved the detonation of a medium-sized cloud of propane (a major LPG and minor LNG constituent). What has not yet been determined is what sources are sufficient to cause detonation of an LEG vapor cloud (either directly or indirectly by a multiple-stage process, such as starting a detonation in a confined region, or in a region enriched with the more easily detonatable hydrocarbons from the spill, and then propagating through the main cloud). In addition, the maximum fraction of the cloud which is properly mixed and detonatable at one time is not well established. In accidental detonations this fraction is not believed to have exceeded about 10%, but dispersion theory suggests that it could reach 45% or more.

- The critical questions concerning LEG detonation can be answered in 1 to 2 years if a vigorous research program is undertaken. The emphasis of the program must be on experimental studies, since the physical problems involve the interaction of turbulent fluid mechanics with complex chemical kinetics. These problems cannot, with high confidence, be solved theoretically at any time in the near future. Moreover, most of the experiments must be done on a size scale of meters to tens of meters because they must be much larger than the detonation induction length, which is relatively long for hydrocarbon-air mixtures (especially for methane).

SPECIFIC TECHNICAL CONCLUSIONS

LEG Vapor-Air Detonations

- Theory suggests and preliminary laboratory experiments support the idea that considerable fractionation occurs when spilled LNG boils off, with methane primarily boiling off first, then ethane, then propane. This result is important because the latter two hydrocarbons are considerably easier to detonate than methane; accordingly, it needs confirmation by further laboratory and field tests. If it is confirmed, wind tunnel and field tests are needed to determine if the components remain separate during cloud dispersion and mixing with air.

- An explosive source too weak to start a detonation in an unconfined hydrocarbon-air mixture might initiate detonation in a large pipe or tunnel, and the detonation then might propagate from the pipe to the unconfined cloud. Such a process has been observed in small-scale experiments using fuel-oxygen mixtures, but not in fuel-air mixtures. Experiments on the latter are needed.

- Information is not readily available on the presence near possible LEG release areas of stored high explosives, acetylene or other compressed gas bottles, sewers, subways, storm drains, subsurface conduits, vulnerable high voltage lines, tall structures where lightning is likely to strike, and other objects that might contribute to detonation initiation. Such information is critical for safety evaluations and Federal agencies should require it

before they make any determination of the safety of a proposed facility.

- Very few experiments have been carried out on the detonation of mixtures of air with methane, ethane, and propane, either unconfined or in large pipes, by the weaker sources mentioned above (sparks, exploding bottles, etc.). A more complete matrix of measurements is needed.

- Practically nothing is known about the propagation of detonations through inhomogeneous regions, where either the fuel/air ratio, or the proportions of the different fuels, vary. Relevant experiments are badly needed, especially on mixtures containing small regions where the concentrations lie outside the detonation limits.

- No information is available on the ease of detonation of LEG aerosols; a quick experimental survey is needed.

- Information on the spatial and temporal variation of the fuel/air ratio in a large LNG or LPG vapor cloud is inadequate to predict with confidence what fraction of the cloud is detonatable. Wind tunnel and field tests are required to answer this question.

RECOMMENDATIONS

LEG DETONATION RESEARCH

TO THE SECRETARY OF ENERGY

We recommend to the Secretary of Energy that his department focus its LEG detonation research to answer critical questions on LNG cloud detonation as quickly as possible and to provide important information on the initiation of detonation in LPG clouds. The physics associated with these questions is so complex that to obtain a complete, quantitative understanding of the phenomena both detailed theoretical modeling and extensive laboratory and field experiments are necessary. But complete, quantitative understanding is not needed for the policy decisions about LEG use that have to be made. For near-term results on detonatability (obtainable over the next 1 to 2 years), we recommend that emphasis be placed on relatively large-scale (350 cubic meters) field experiments supplemented by wind tunnel investigations. Continuation of some of the laboratory experiments and approximate theoretical modeling currently being pursued, however, can be useful to help plan the field experiments and interpret their results.

We believe that such a program could be conducted within two years and would involve less than a fifth of the $50 million DOE is planning to spend on LNG research. A suggested program devised by us is presented below, including rough cost estimates. DOE has questioned whether the program can be carried out at these cost levels. We have reviewed our estimates carefully and believe that, with prudent use of public funds, the estimates are valid.

See the section on Agency Comments below.

The ultimate scope and extent of the experiments described will depend upon what is learned as each part of the work is completed. If, for example, it is found from early experiments that differential boiloff of the liquid does not occur under field conditions with LNG spills, then detonation experiments might be limited to three fuels: methane, methane with 35% ethane, and pure propane (for LPG applications). Should the converse prove to be the case, then testing of a larger range of fuel mixtures with various initiation sources might be necessary, substantially expanding the test matrix.

The first four research tasks described and the preliminary two-phase cloud experiments would provide answers to critical questions on LEG vapor cloud detonation within about one year, provided the work is well coordinated and conducted in parallel where possible. The estimated cost for these tasks is $1.5 million.

In one additional year, at an estimated cost of $3 million, 350 cubic meter field tests could provide increased confidence in the answers obtained during the first year. They would also provide information on downwind combustible vapor cloud travel and possibly fireball radiation. (If an initial set of explosively dispersed LEG experiments were conducted, add roughly $800,000 to the second year's cost.)

Differential Boiloff of LNG Constituents

Perform field experiments spilling LNG on unconfined areas of salt water and measuring spatial and

temporal concentrations of methane, ethane, and propane in the vapor above the evaporating liquid. Perform similar experiments for spills on soil.

This work, some of which has begun at the Naval Weapons Center, China Lake, California, with 6 cubic meter spills, will provide a check of MIT laboratory work to determine if a strong fractionation process also occurs under field conditions. Tests should be run in the size range of 1 to 35 cubic meters (1 truckload) to provide as wide a range as can be obtained relatively rapidly and inexpensively. If enrichment in ethane or propane is found, the large vapor cloud field tests should also be instrumented to give measurements of differential boiloff over an experimental range of 3 orders of magnitude.

We estimate that these differential boiloff tests would require about $300,000 and eight months time. Conducted early, the output could have a substantial influence on the type and scope of further detonation experiments.

Detonation Initiation Sources

Survey, compile, and physically describe all current and foreseeable sources of rapid energy release which might be located up to about 5 km from LEG marine terminals and major storage areas. Determine through analysis and screening experiments which of these energy sources are potentially capable of detonating methane-, propane-, and perhaps ethane-air mixtures. Select those potential initiation sources believed most likely to produce a detonation in LEG vapor clouds for use in cloud detonation experiments.

These potential initiation sources should include electrical discharge sources (including lightning), high pressure gas containers, highly flammable stored gases and stored oxygen, machinery capable of exploding, condensed explosives, etc. The study should evaluate the effects of confining structures such as large metal and concrete pipes open to the atmosphere (storm drains), and underground conduits and shafts into which gas might flow. Whether ethane is considered should depend on the findings of this work and that of the preceding experiment.

About six months and $100,000 are required for this effort.

Wind Tunnel Vapor Plume Tests

Conduct vapor dispersion experiments in a meteorological wind tunnel to define the existence and distribution of detonatable hydrocarbon concentrations in the dispersing LEG vapor cloud.

If the LNG boiloff tests show that little fractional distillation occurs, these experiments need to simulate only methane and propane clouds. If fractional distillation does occur, the tests should also include releases that simulate the fractional distillation found in the experiment on boiloff, using downstream sensors that can distinguish the different gases. The results would determine whether high concentrations of the heavier hydrocarbons persist in sizeable regions of the cloud as it disperses downwind, in time to provide inputs to the field detonation experiments discussed below. They would also provide a measure of the possibly detonatable fraction of the cloud as a function of time after spill, whether or not strong species separation persists. Finally, the results

would be useful for planning and evaluating the large-scale field tests discussed below.

We estimate that the wind tunnel experiments can be conducted in eight months for $200,000, with useful data produced as early as four months from the beginning of testing.

Detonation Initiation and Propagation Experiments Using Plastic Bags

> *Perform experiments to determine if the sources selected in the ignition source study produce detonations in a range of methane/ethane mixtures contained in large plastic bags, and in mixtures of air with methane, 65% methane/35% ethane, and propane.*

These experiments should include a range of ethane-air mixtures only if the boiloff and wind tunnel investigations show that LNG boiloff produced hydrocarbon fractionation that persisted while the fractions were mixed with air to detonatable concentrations. Although some of these bag experiments, using high explosive initiators, have already been carried out by investigators at China Lake, Albuquerque, and in Great Britain, more are required using other types of initiators that might be present near LEG releases, including multiple stage processes such as propagation from a pipe to a bag, and from a bag of ethane to one of methane. Both stoichiometric and off-stoichiometric mixtures should be included in the investigation. If carried out in rectilinear bags, the experiment will provide a measure of the lateral dimensions required to propagate a detonation in a geometry similar to

that of the cloud from a spill. Bags of dimensions up to 3 or more meters on a side and 30 meters long should be used. The experiments should also investigate propagation in inhomogeneous fuel/air mixtures by use of partitioned or multiple bags, with adjacent compartments filled with mixtures having different fuel/air ratios.

In addition to direct-initiation experiments, a number of tests should be conducted to determine if transition from deflagration to detonation (or to a near-detonation that produces destructive overpressures) can occur when the mixture is ignited with a weak source. The effects of turbulence, dust, and partial confinement should be included. The linear dimensions of the bags required for the tests might be three or more times greater than those for the direct-initiation experiments.

The cost of these "bag" experiments is difficult to estimate accurately because of uncertainties in the number and sizes of tests ultimately required. However, if 100 separate tests are assumed, about $750,000 and 8 to 12 months would be required.

These bag experiments, together with the wind tunnel tests, will be the culmination of the first year's effort and should provide initial answers to the basic detonation questions. An assessment should be made of the results at this juncture and a decision made as to whether large spill detonation tests are essential to provide answers with higher confidence. If deemed so, the following experimental program should be undertaken (for which planning would have been completed during the first year).

Large Vapor Cloud Field Experiments

Conduct a set of experiments in which about 350 cubic meters of LNG and about 150 cubic meters of propane are spilled on water and soil, and attempt to detonate them with appropriately chosen initiators.

These experiments would integrate all the phenomena tested separately in the earlier experiments. Detonation would not be attempted in the first tests for water or for soil spills, but measurements would be made to describe the spatial and temporal concentrations and hydrocarbon composition. These first tests would serve to check the differential boiloff and wind-tunnel experiments, thereby increasing confidence in the description of dispersing vapor clouds. They would also help determine the maximum distance at which a non-detonated cloud could initiate fires.

Attempts would be made to detonate the cloud in subsequent tests using initiators selected from the first year's work. Since the tests would be expensive and since a large number of detonation attempts are needed for high confidence, perhaps 10 to 20 initiators would be activated simultaneously in each test cloud. With careful initiator spacing and monitoring, one could establish which initiators produced detonation and whether a given detonation propagated through several pockets of the combustible mixture. Repeat tests would be performed to provide an adequate statistical base.

The results of these experiments should provide high-confidence answers to the question of LNG and LPG vapor cloud detonatability as well as a measure of the

extent and pattern of possible blast damage should detonation occur. In addition, such tests could provide valuable data on fireball and flame radiation.

Since the cost of these tests will be substantial, careful planning will be required to establish the minimum acceptable spill sizes; results should be analyzed after each test to minimize the number of tests required. We estimate that a program of twelve tests would cost about $3 million. If detailed test planning is accomplished during the first-year effort described above, most if not all of the twelve-test program could be completed in the second year.

Two-Phase Cloud Detonation

Perform experiments in plastic bags to determine whether a cloud formed by a spray of LNG or LPG droplets in air is more or less easily detonated than gas/air mixtures of the same fuels at ambient temperature.

These experiments would be conducted in a manner similar to those on detonations using plastic bags, so that a direct comparison could be made with those results. They would serve to establish whether the cloud produced by an exploding container of the cryogenic liquids has the potential for posing a special explosive hazard. Performed as part of the plastic bag experiments discussed above, a few tests should cost an additional $100,000 and take about one or two additional months. Should these tests indicate that a special hazard might exist, tests with the fuel explosively dispersed should be considered. An initial set of 10 such tests, using the techniques applied to the

Fuel-Air-Explosive (FAE) weapon development and about one to two cubic meters of liquid fuel, would cost about $800,000 and take about nine months to one year to perform.

AGENCY COMMENTS AND OUR EVALUATION

The Departments of Energy, Transportation, and Commerce all comment that GAO's research suggestions are well-founded, but that they are inadequate to provide a thorough understanding of LEG hazards and that they will cost more and require more time than is projected.

We agree that our research program would not answer all questions of LEG behavior. However, we believe that this relatively brief and inexpensive effort could provide more useful information for the decisions to be made in the next few years than DOE's longer, more expensive program.

The major source of the difference between DOE's and GAO's estimates of the time and money needed to carry out an adequate research program is DOE's proposal to build a new facility for intermediate and large-scale test spills. This facility would cost $18 million and require two years to build. We do not believe that a new, permanent facility is needed to proceed with our program. A natural body of water could be used for water spills; surplus liquid hydrogen tanks (currently available for $0.2 million) could be used for test site storage; mobile instrumentation vans (of which DOE has several) and temporary sensors could replace permanent sensor networks and instrumentation buildings.

DOE currently plans spills of up to 1,000 cubic meters, an arbitrarily chosen number. Our calculations indicate that spills of 350 cubic meters are sufficient.

DOE plans a large number of experimental tests; we believe that multiple sampling and careful analysis would

drastically reduce the number needed. DOE believes that 240 detonation and initiation tests would be necessary; we expect that 100 tests would provide sufficient information, and that each test would cost only half of DOE's estimate. DOE recommends 100 large-scale tests; we believe that twelve tests, each testing 10 to 20 detonation initiators, would be adequate.

DOE and DOT comment that a major obstacle to accurate experiments is the lack of a rapid response particle detector. We agree that such an instrument is needed. The Coast Guard says that they will have developed a detector for total hydrocarbon vapor concentration by the first quarter of 1979. We believe that using existing technology a suitable particle-separator and detector could be developed by then.

In addition to this general research plan, we also recommend that Congress provide adequate research budgets to the Federal agencies with regulatory responsibility. DOT comments that "LEG research to date has been fragmented and often duplicative because of the interrelated needs of the responsible agencies." We agree. The research program we suggest would provide information valuable to all agencies. However, problems peculiar to each segment of the LEG industry (e.g., ships, trains) can best be investigated by the agency with specific jurisdiction. This research could investigate specific technological problems, evaluate existing codes, and develop adequate new standards.

DOE comments that this "supports the notion that regulatory agencies should perform research (on a cost sharing basis with industry)." We oppose such

cost-sharing. It is for this reason that we stress that Congress should provide adequate research budgets for the appropriate agencies.

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CHAPTER 14

THE CAPABILITY OF NON-URBAN SITES TO MEET TOTAL U.S. IMPORT REQUIREMENTS FOR LPG

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INTRODUCTION

Liquefied petroleum gas (LPG) is the nation's fourth largest source of energy, supplying some 13 million customers. Most of these customers are in rural areas, including approximately 1.4 million farms. Farmers use LPG, principally in the form of propane, for agricultural purposes and home heating.

In addition, LPG can be used to supplement or substitute for natural gas. Recent curtailment of natural gas supplies to industrial users has led many independent energy consultants and governmental agencies to predict a new, high level of demand for LPG. (See Appendix XIV-1 for a breakdown of LPG demand.) At the same time, domestic production of LPG is declining along with that of the two basic products from which it is derived—natural gas and refined oil.

As a result, the United States has begun to import LPG through marine terminals in large quantities, and analysts forecast a sharp rise in LPG imports over the next decade. The import terminals have been built as near as possible to LPG customers in order to reduce transportation costs. Most are on urban sites.

As analyzed in earlier chapters, LPG ships and storage tanks pose hazards to the areas near the terminals. Increased LPG imports at urban terminals will increase those hazards. Presently, there is only one non-urban LPG terminal; however, four new import projects using non-urban terminals have been proposed. By 1985, non-urban terminals will have the capacity to receive all of the projected LPG imports. Whether the LPG could then be distributed to the

final consumers through the existing distribution system, or what additions would be necessary to make this possible, is unclear.

Part of the demand for LPG as a supplement to natural gas can be met by linking natural gas pipelines to non-urban LPG import terminals on the Gulf Coast and injecting liquid or vaporized LPG into the passing gas stream.

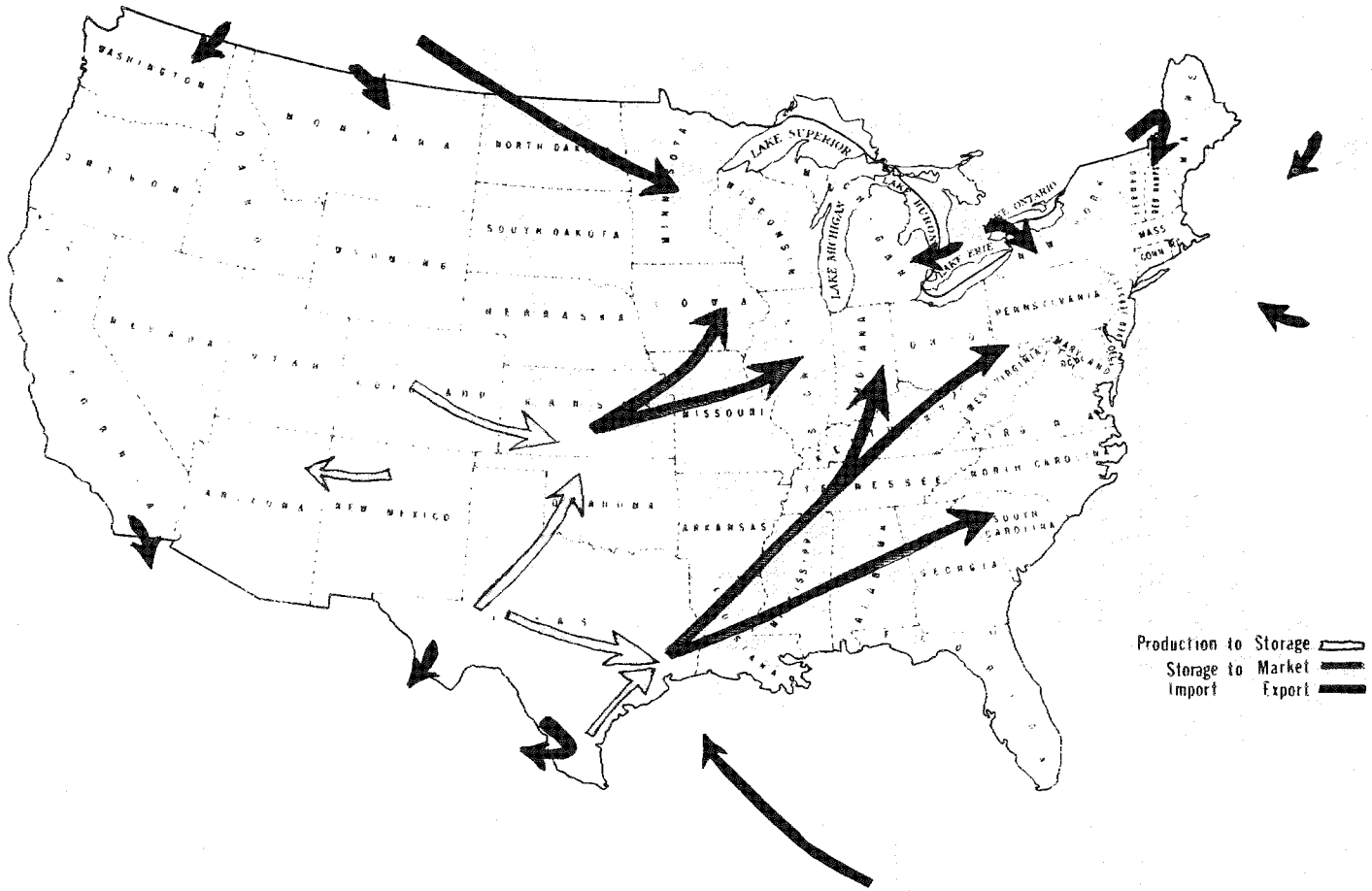
DISTRIBUTION

LPG products travel from production sources and major storage centers through a complex distribution system. Domestically produced LPG moves from a production site by pipeline, truck, or rail into a storage complex or an interstate pipeline and then to a local storage terminal. From there the LPG is shipped by truck or rail to the final consumer. The sequence for imported LPG is the same, with an import terminal substituted for the production site.

The domestic LPG logistical system consists of 16 existing import terminals, 56 million cubic meters of primary storage space, 70,000 miles of cross country pipelines, 16,300 rail tank cars, 25,000 transport and delivery trucks and more than 8,000 bulk storage and final distribution points. (Figs. 14-1 and 14-2, Table 14-1.)

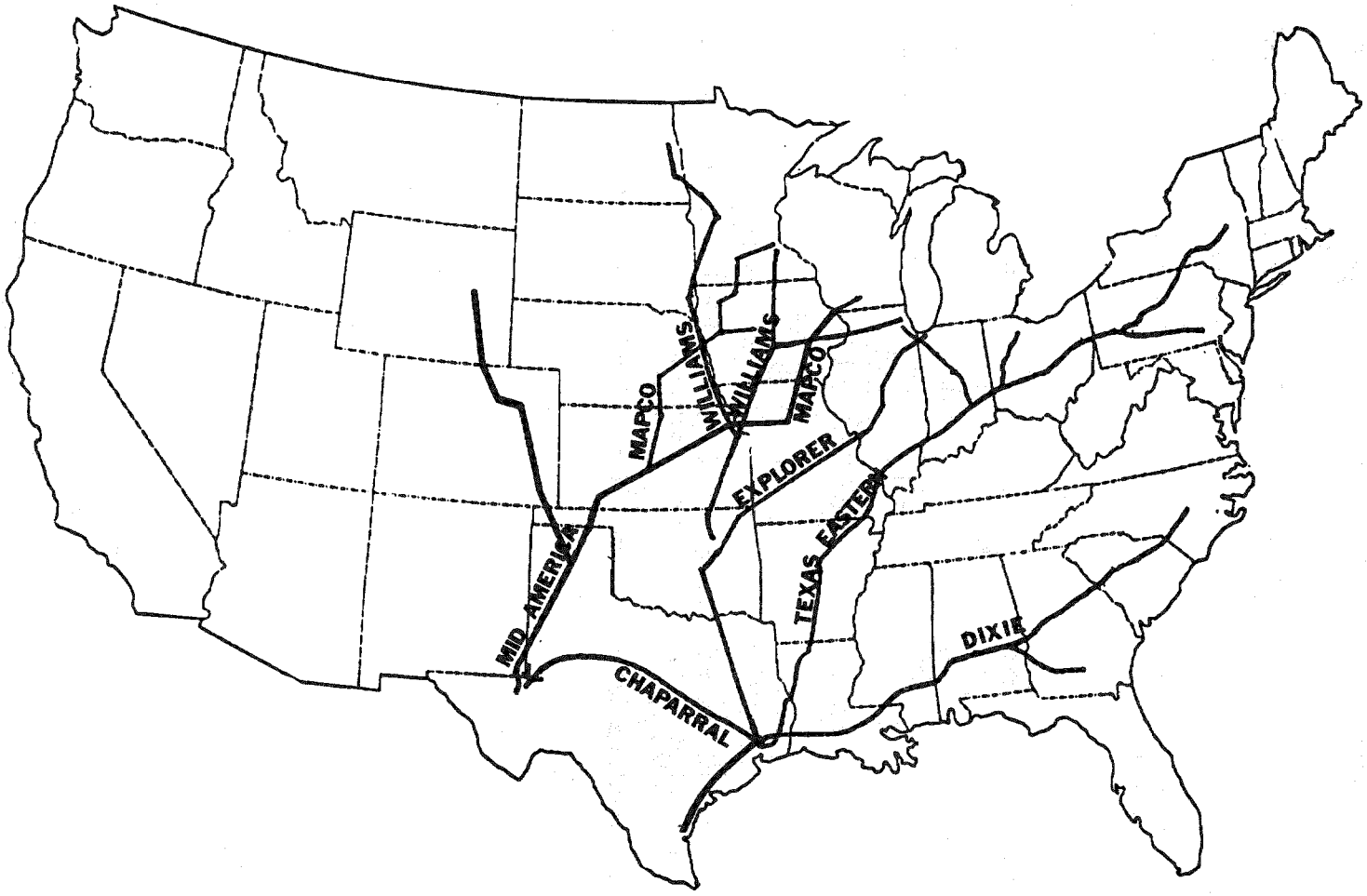
The system is flexible because of the location of the import terminals and major pipelines and the availability of railcars and truck-trailers. During the winter of 1976-77, however, LPG demand in the Northeast exceeded the

FIG. 14-1 LPG PRODUCTION FLOW



DERIVED FROM INTERVIEWS WITH LPG INDUSTRY PRODUCER/MARKETING GROUP.

FIGURE 14-2 – MAJOR PIPELINES WITH CURRENT OR POTENTIAL LPG CAPACITY



DERIVED FROM COMPANY PIPELINE MAPS AND INTERVIEWS.

TABLE 14-1 DOMESTIC BULK TRANSPORTATION OF LPG, 1975 AND 1976
(In units of 1,000 cubic meters)

	1976	Percent of Total	1975	Percent of Total
Truck	2,565	3.4	2,823	3.8
Rail	683	0.9	1,095	1.5
Pipeline-Truck	67,679	90.6	68,925	91.9
Pipeline-Rail	3,404	4.6	1,975	2.6
Tanker or Barge*	406	0.5	168	.2
Total	74,737	100%	74,986	100%

*Approximately 90% of the volume in this category is transported by pipelines prior to tanker or barge movement.

Source: National LP-Gas Association, "1976 LP-Gas Market Facts"

system's ability to move LPG from storage centers to markets. The situation could have been alleviated if more storage had been available in the Northeast.

AGRICULTURE

The regional consumption of LPG according to end use is shown in Fig. 14-3. Agriculture is a major user of LPG (see the tables in Appendix XIV-1). Fifty-one percent (1.4 million) of all farms in the United States use LPG for a variety of purposes including crop drying and powering poultry brooders, stock heaters, tractors, and irrigation pumps.

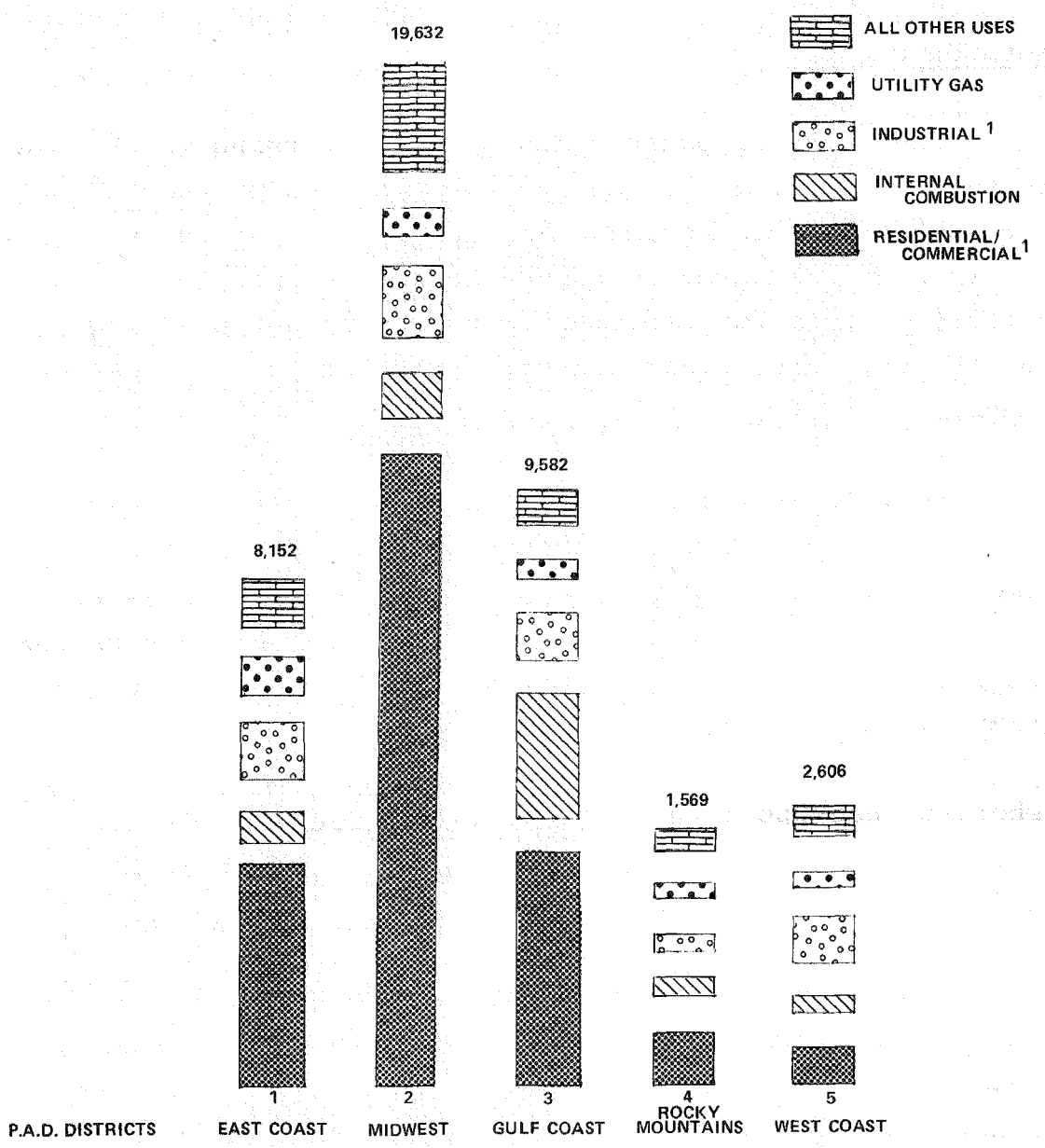
Agricultural consumers along the eastern seaboard will be the most severely affected by the decline in domestically produced LPG unless additional supplies are imported into the area. Historically, LPG for this region has been transported from the major producing and storage areas in the Midwest and Gulf Coast.

It would be cheaper to satisfy any excess Eastern demand by importing LPG through East Coast, rather than Gulf Coast, marine terminals.

Because existing LPG pipelines are full much of the year, import terminals and adequate storage in consuming areas are important. Certain underutilized natural gas transmission lines, however, could be converted to carry LPG. This would lessen the need for import terminals and local storage.

FIG. 14-3-

SALE OF LPG BY PRINCIPAL USES: 1975**
(IN UNITS OF 1,000 CUBIC METERS)



**EXCLUDING CHEMICAL & SYNTHETIC RUBBER, AND REFINERY FUELS AND FEEDSTOCKS.

1 AGRICULTURAL USE IS USUALLY AGGREGATED INTO THE INDUSTRIAL OR COMMERCIAL TOTALS.

DERIVED FROM NATIONAL LP—GAS ASSOCIATION (NLPGA) DATA IN "1975 LP—GAS MARKET FACTS "NLPGA SOURCE: BUREAU OF MINES.

USE AS A SUPPLEMENT TO NATURAL GAS

An increase in demand for LPG may come from industrial consumers whose supply of natural gas has been curtailed. LPG can be furnished to these consumers through the existing natural gas pipeline system by injecting it into the pipelines at or reasonably close to import terminals. The LPG can be introduced into the gas flow by one of three methods: (1) by first mixing it with air, (2) by breaking it down into methane and thus creating a synthetic natural gas (SNG), or (3) by injecting it in its liquid form. The first two methods are currently in use at many utility sites (see Appendix XIV-1).

LPG-Air

LPG is consumed as a gas although it is produced, stored, and transported as a liquid. The gas has 2.5 to 3 times greater energy density (energy per unit volume) than methane, the largest component of natural gas. The vaporization of the liquid and injection of air by natural aspiration or mechanical compression dilutes LPG to an energy density equal to that of natural gas. Several hundred domestic gas-air plants exist for standby and full-time use at industrial and utility sites.

Synthetic Natural Gas

SNG is currently being produced to augment declining natural gas supplies by changing LPG or other petroleum based fuels to methane. Thirteen SNG plants ranging in size from 16 MMcf/d (million cubic feet per day) to 250

MMcf/d are currently operating. Five of these use LPG as a feedstock component and one uses propane to raise the energy density of the output gas.

LPG Liquid Injection

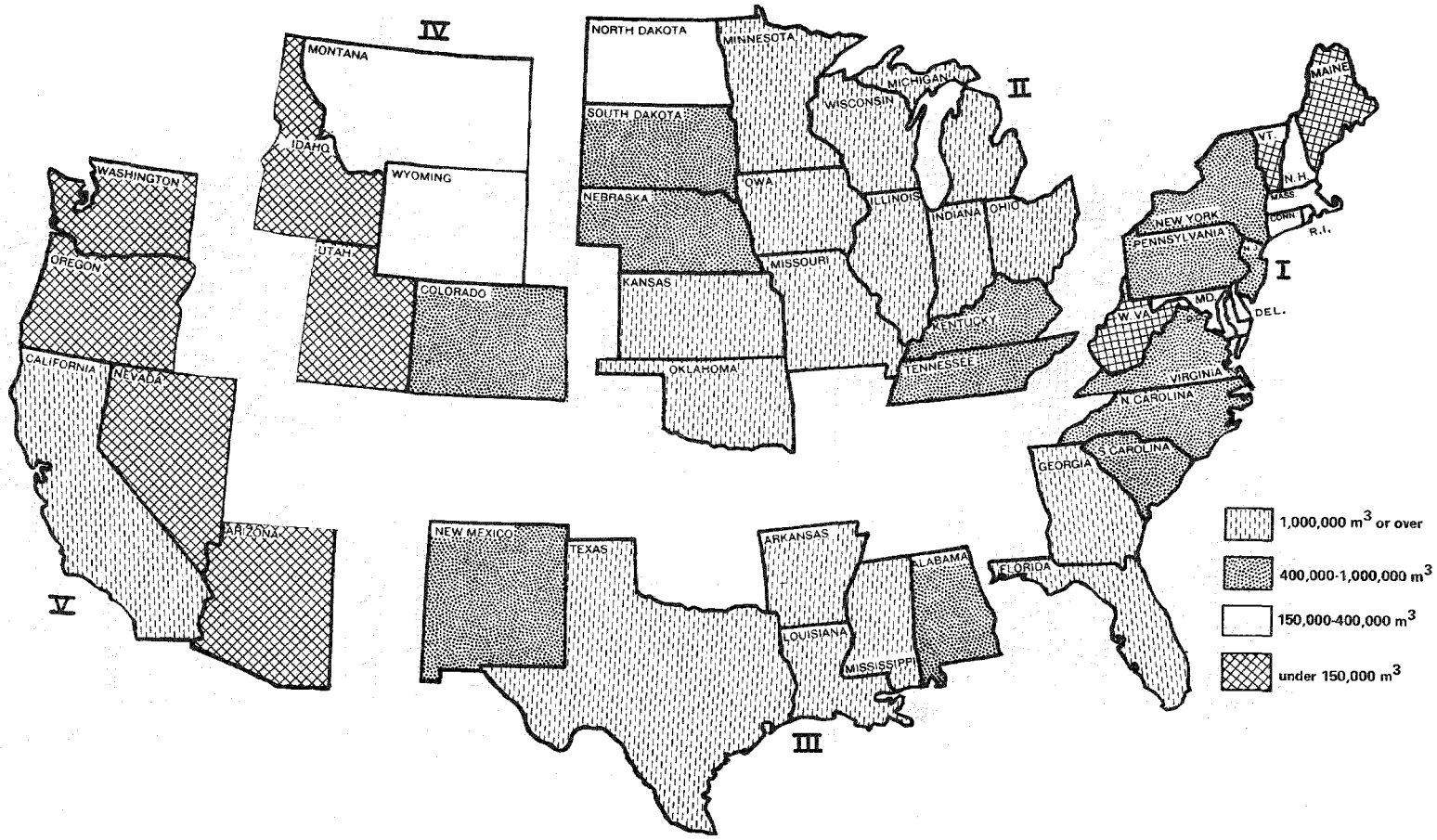
A new method injects liquid LPG directly into a natural gas pipeline. The injection must be into a substantial flow of natural gas, such as the main transmission lines in the Gulf Coast region. The liquid propane is heated to help it vaporize and blend completely into the passing gas stream. A transmission line with 1.5 MMMcf/d (billion cubic feet per day) can receive up to 8,000 cubic meters per day of propane, or smaller amounts of butane. The need for high volume gas lines and large LPG storage currently limits this method to the Gulf Coast where imports can be stored in large salt domes.

SUPPLY AND DEMAND

The demand for LPG in the United States varies by region. (Figs. 14-4 and 14-5.) Demand is high in rural areas because supplying natural gas to these areas by pipelines would be too expensive. The demand may be met by locally produced supplies or by bringing it in from other sources. Particularly remote locations are limited to locally produced LPG supplies because of the high cost of moving LPG from distant sources. (See Fig. 14-6.)

In the northern states, the principal demand for LPG is in winter. The interstate pipeline system cannot fully meet this peak demand. Consequently, inventories are built up during the summer to help meet winter requirements.

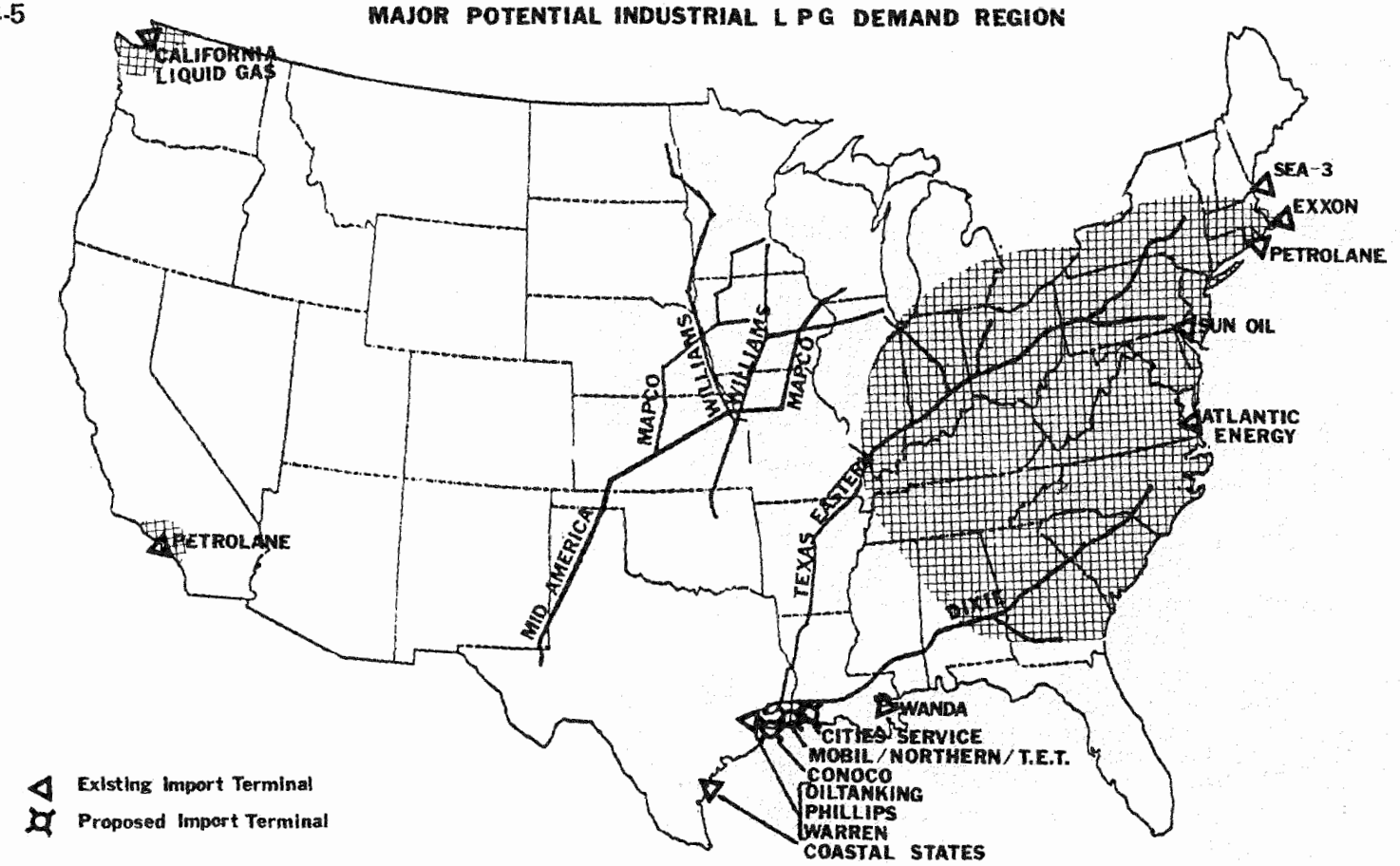
FIG. 14-4- LPG SALES WITHIN P.A.D. DISTRICTS



NATIONAL LP-GAS ASSOCIATION, "GAS FACTS—1975," AND BUREAU OF MINES

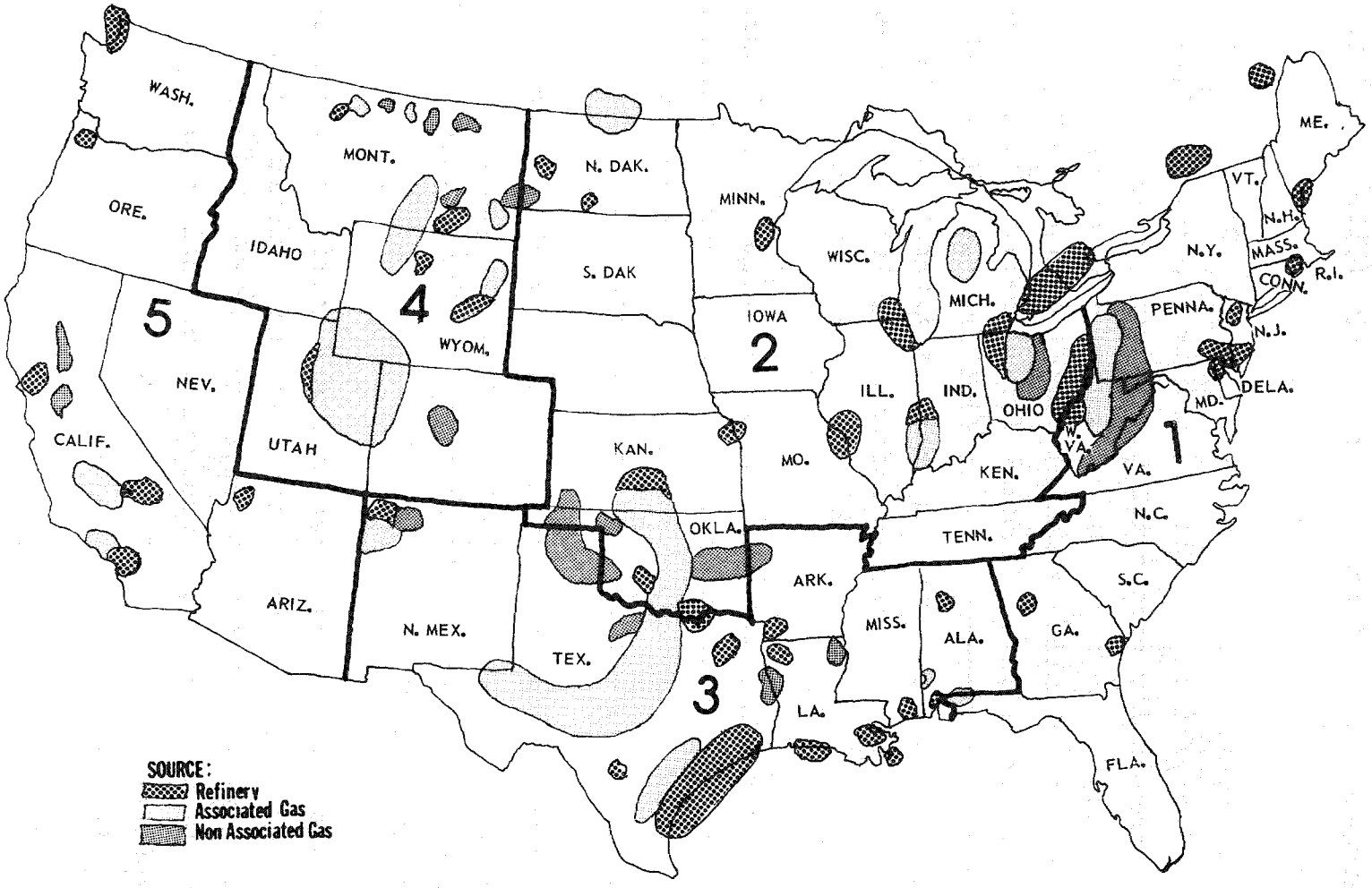
FIG. 14-5

MAJOR POTENTIAL INDUSTRIAL L P G DEMAND REGION



DERIVED FROM VARIOUS PIPELINE COMPANY OWNERS MAPS.

FIG. 14-6 LPG PRODUCTION AREAS



DERIVED FROM INTERNATIONAL PETROLEUM ENCYCLOPEDIA — 1977

Analyzing LPG supply and demand by P.A.D. (Petroleum Administration for Defense) District, the following picture emerges:

The eastern seaboard states in P.A.D. District 1 have found it increasingly difficult in recent years to acquire enough domestically produced LPG. Existing marine terminals supply that portion of demand not met by inter-district pipeline movement, minor indigenous production, and rail car imports from Canada. Natural gas curtailments to industry in this district have increased the need for imports. Bureau of Mines figures indicate that 7.7% of P.A.D. District 1 demand was met by overwater imports.

The Midwest region (P.A.D. District 2) is the highest LPG consuming area in the United States. Local production supplies 47% of demand and most of the rest is met by inter-district pipeline. Canadian imports supply 11%.

The Gulf Coast area (P.A.D. District 3) produces more LPG than it consumes, and most (52%) of the nation's overwater imports come into District 3. The surplus is piped to other Districts.

The Rocky Mountain area (P.A.D. District 4) moves its excess summer production to the large underground storage complex in Kansas (P.A.D. District 2). Winter demand exceeds the District's LPG production capability and shortages are met by rail from Canada.

In the West Coast region (P.A.D. District 5), California and Washington have substantial production, but the District imports 38% of its LPG from other P.A.D. districts and from Canada.

LPG supply and demand by P.A.D. District for 1975 is shown in Appendix XIV-1. As U.S. and Canadian LPG production declines, more overwater imports will be required to fill the increasing demand.

MARINE IMPORT TERMINALS

The first domestic LPG marine terminals were built in the 1950's to receive vessels carrying no more than 30,000 cubic meters. The LPG was shipped between coastal ports or exported. Pipelines from storage sites to terminals were also designed for small volume movements. Subsequently, these terminals were adapted to import LPG, but most cannot handle the much larger ships often used now.

Many present northeastern terminal sites have little room to expand. When space is available, expansion often is resisted by political, environmental, and safety oriented groups. Partly because of these problems, most new LPG import terminals are being planned for the Gulf Coast. The low priced salt dome storage in the area is also attractive to potential LPG importers.

Appendix XIV-2 describes the 16 existing import terminals, the five proposed terminals, and six potential sites. Six of the existing terminals have physical limitations that restrict their importation levels. The 15 major existing or proposed terminals will be capable of receiving 35.5 million cubic meters per year by 1980 and

61.4 million cubic meters per year by 1985. We estimate overwater LPG imports of 13.5 million cubic meters in 1980 and 26.9 million cubic meters in 1985.

Four major terminals, including two proposed terminals, are on the Houston Ship Channel. (In addition, Petro-Tex Chemical Corporation will receive smaller quantities of LPG.) According to our estimates, there will be 133 LPG ship arrivals in the Houston Ship Channel in 1980 and 188 in 1985. An average of one LPG ship per day will be moving into or out of the Channel in 1985.

When the Federal Power Commission (FPC) staff was assessing the proposed El Paso LNG marine terminal at Port O'Connor, Texas, it developed criteria for suitable navigational conditions. According to one of these criteria, "existing ship traffic should not be so heavy that closing down the approach channel for 2-4 hours every 2-2.5 days would impose excessive economic hardship on other shipping activities."[1]

The Final Environmental Impact Statement rejected three possible sites on the Houston Ship Channel, citing the density of ship traffic in the channel and navigational hazards including currents, obstructed areas in the channel, a turn of almost 90 degrees at Pelican Island, and a seaplane landing area located less than 0.5 miles from one portion of the channel.

Ships are permitted, however, to routinely deliver LPG and other highly hazardous materials to sites on the Houston Ship Channel. This makes no sense.

Because of drafting and storage restrictions, 75,000-cubic meter LPG vessels can currently offload only in the Gulf of Mexico and at the Sun Oil terminal at Marcus Hook, Pa.

The East and Gulf Coasts now have about equal offloading capacity, but if all announced terminal construction and expansion plans occur, the Gulf Coast offloading capacity will increase to 78% of the national total by 1980 and will continue at that level.

Table 14-2 classifies major existing and proposed import terminal sites by their location in relation to the edge of a densely populated area of at least 25,000 people: URBAN is defined as a site that is within four miles; SEMI-URBAN as a site that is between four and twelve miles; and RURAL as a site that is more than twelve miles. The table also indicates whether ships enroute to a site must pass by an urban area.

STORAGE

LPG is stored in large aboveground refrigerated storage tanks or, under pressure, in large underground salt domes and mined granite caverns or in small pressurized "bullet" storage tanks. About 86 percent of the LPG in bulk storage is stored underground, particularly in the excavated natural salt deposits in Texas, Louisiana, and Kansas.

TABLE 14-2 LPG IMPORT TERMINAL SITES

Urban Sites	Company	Distance to the Edge of a Densely Populated Area Miles	City	Population	Requires Ships To Pass By An Urban Area
San Pedro, Cal.	Petrolane	0.3	Los Angeles, Cal.	2,800,000	No
Providence, RI	Petrolane	0.6	Providence, R.I.	179,000	Yes
Everett, Mass.	Exxon	0.7 0.9	Boston, Mass. Everett, Mass.	641,000 42,000	Yes
Corpus Christi, Tex.	Coastal States	1.3	Corpus Christi, Tex.	204,000	No
Houston, Tex.	Warren Petroleum	1.8	Pasadena, Tex.	89,000	Yes
Marcus Hook, Pa.	Sun Oil	-0- 1.9 2.9	Marcus Hook, Pa. Chester, Pa. Claymont, Del.	3,000 56,000 7,000	Yes
Houston Tex.	Phillips Petroleum	2.1	Pasadena, Tex.	89,000	Yes
Chesapeake, Va.	Atlantic Energy	2.2 2.9	Portsmouth, Va. Chesapeake (South Norfolk) Va.	67,000 17,000	Yes
Houston, Tex.*	Oil Tanking of Texas	3.0	Pasadena, Tex.	89,000	Yes
Newington, N.H.	Sea 3	3.1	Portsmouth, N.H. Kittery, Me.	26,000 11,000	Yes
Semi-Urban Sites					
Plaquemine, La.*	Dow Chemical	1.4 7.0	Plaquemine, La. Baton Rouge, La.	7,800 166,000	Yes
Atkinson Island, Tex.*	Continental Oil	2.0 7.2	La Porte, Tex., Baytown, Tex.	7,000 44,000	Yes

Rural Sites	Company	Distance to the Edge of a Densely Populated Area Miles	City	Population	Requires Ships To Pass By An Urban Area
Hackberry, La.*	Cities	3.0	Hackberry, La.	<5,000	No
	Service	3.0	Grand Lake, La.	<5,000	
		12.0	Lake Charles, La.	79,000	
Sabine Pass, Tex.*	Mobil, NNG	5.0	Sabine Pass, Tex.	<5,000	No
	TET, Texaco	12.0	Port Arthur, Tex.	57,000	
Ferndale, Wash.	California	6.0	Ferndale, Wash.	<5,000	Yes
	Liquid Gas	12.0	Bellingham, Wash.	39,000	

*Under construction or proposed.

The major storage centers in the United States help to integrate imports of LPG with domestic production and to match winter demand with summer production. They also boost supply to regions whose rate of pipeline deliveries is inadequate during heavy demand periods.

Insufficient on-site or nearby storage often limits the through-put capacity of import terminals. Import terminals that have only enough on-site refrigerated storage space for about one shipload (56,000-95,000 cubic meters) must either adjust receiving schedules to ensure storage space for a full cargo, or arrange for delivery to more than one marine terminal, which substantially increases transportation and handling costs.

The import terminals with the largest through-put capacity have access to large underground storage complexes. The large capacity permits more timely receipt of vessels, and may offer greater flexibility to receive mixed or non-specification products. Underground storage is also much more economical than refrigerated tanks to construct and operate. Storage construction costs per cubic meter are: washed from salt, $12.50 to $31.50; mined (usually in granite), $41 to $88; refrigerated, $94 to $126; pressure tanks, $200 to $226.

The problem of inadequate storage at some facilities is compounded by insufficient pipeline capacity to deliver the LPG from the ship to on-site or off-site storage and then to the distribution network.

Table 14-3 shows the amount of storage available at each of the major existing and planned import terminals. It can be seen that almost all of the nation's connected storage capacity (94 percent) is in the Gulf Coast area,* with only 4 percent on the East and West Coasts.

This enormous concentration of LPG storage capacity reduces the flexibility of the domestic LPG distribution system.

Figures 14-7 and 14-8 show potential areas for underground storage complexes. Finding locations in the Northeast and on the West Coast for import terminals that are near potential underground storage areas is difficult.

*This does not give full weight to the terminals connected to the large storage complex at Mt. Belvieu, Texas, because some of the storage is used for domestically produced LPG. Only the storage directly connected to or owned in conjunction with each individual facility is considered.

TABLE 14-3 STORAGE AVAILABLE FOR LPG MARINE IMPORT TERMINALS IN 1977

(In units of 1,000 cubic meters)

TERMINAL LOCATION	OWNER	STORAGE CAPACITY	ON-SITE STORAGE
Newington, N.H.	Sea-3, Inc.	64	64 (aboveground)
Everett, Mass.	Exxon Company U.S.A.	64	64 (aboveground)
Providence, R.I.	Petrolane Inc.	64	64 (aboveground)
Marcus Hook, Pa.	Sun Oil Co.	333	333 (underground)
Chesapeake, Va.	Atlantic Energy Co.	76	76 (aboveground)
*Plaquemine, La.	Dow Chemical Co.	3,044	-
*Hackberry, La.	Cities Service Co.	1,350	-
*Sabine Pass, Tex.	Mobil/NNG/T.E.T./Texaco	1,700	-
*Houston, Tex.	Continental Oil Co.	**	-
*Houston, Tex.	Oiltanking of Texas, Inc.	**	-
Houston, Tex.	Phillips Petroleum Co.	916**	27 (aboveground)
Houston, Tex.	Warren Petroleum Co.	5,187**†	57 (aboveground)
Corpus Christi, Tex.	Coastal States Marketing, Inc.	1,493**	2 (aboveground)
San Pedro, Cal.	Petrolane Inc.	96	96 (aboveground)
Ferndale, Wash.	California Liquid Gas Corp.	56	56 (aboveground)
TOTAL STORAGE AVAILABLE		14,442	

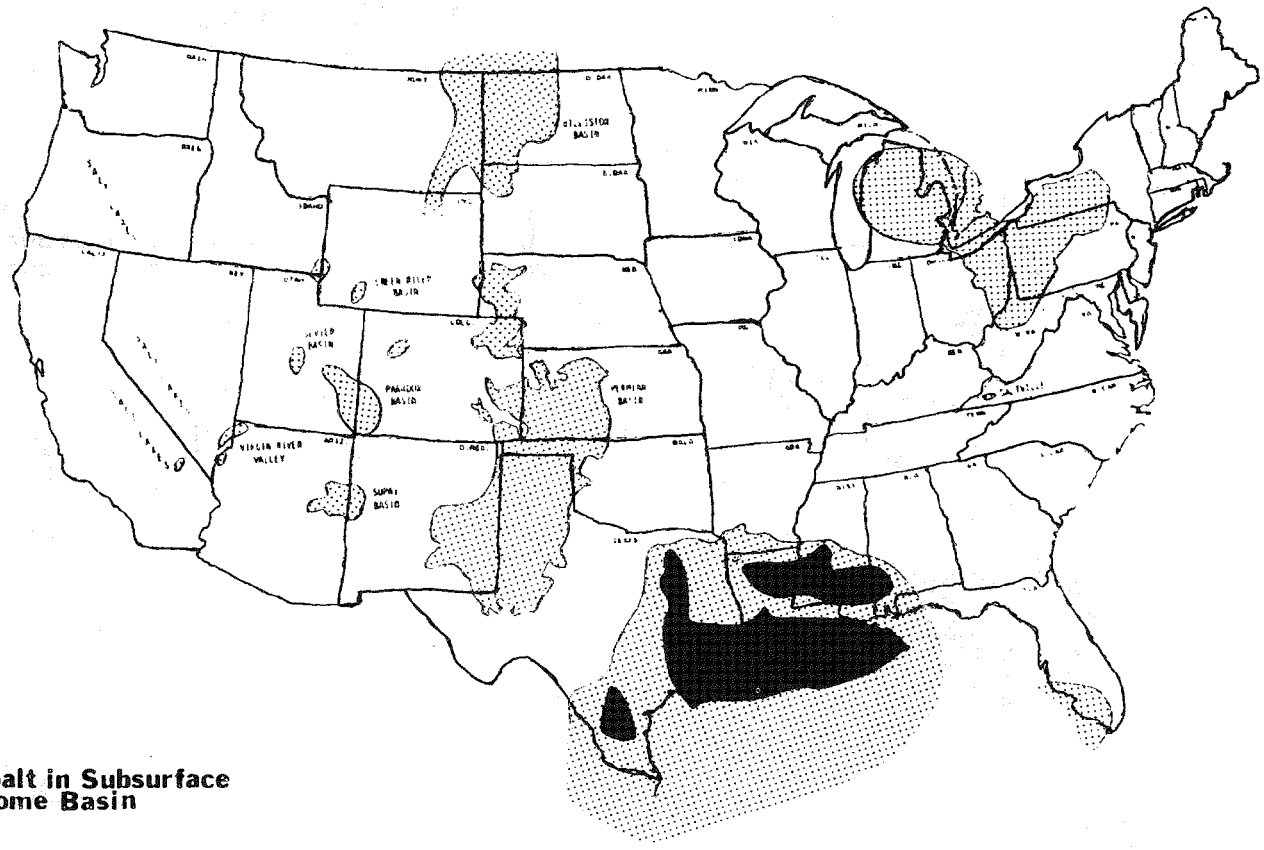
*LPG terminals under construction or proposed

**Connected to existing 14.3 million cubic meters storage at Mt. Belvieu, Texas

†Includes dedicated Warren storage at Mt. Belvieu

FIG. 14-7

MAJOR SUBSURFACE SALT DEPOSITS



Rock Salt in Subsurface
Salt Dome Basin

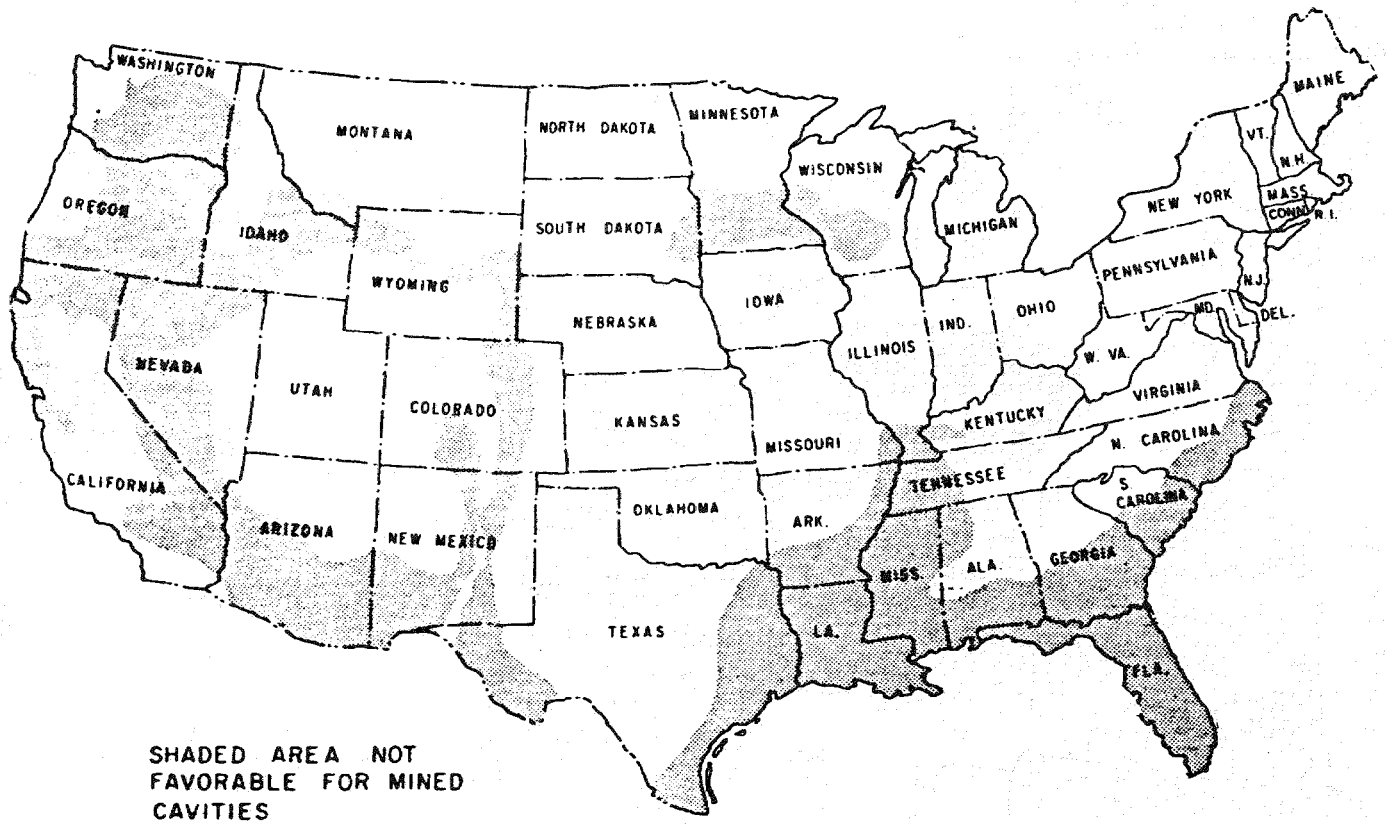


FIG. 14-8 **POTENTIAL MINED STORAGE AREAS**

FENIX + SCISSON ENGINEERING COMPANY.

FINDINGS

- In 1976 the United States imported over water about 1.9 million cubic meters of LPG.

- Almost all of the existing LPG marine import terminals have been built on urban sites. To reach most of the terminals, LPG ships must pass by urban areas. Many terminals have large aboveground refrigerated storage tanks on-site.

- Existing and announced non-urban terminals will have the capacity to receive 111 percent of projected LPG imports in 1985.

- Several non-urban terminal sites could inject LPG directly into natural gas pipelines to supplement domestic supplies. On the Gulf Coast, where natural gas transmission lines originate, volume through the potential Pascagoula, Miss. site could approach 3 million cubic meters annually. Smaller amounts (0.8 million to 1.6 million cubic meters) could be injected from each of the potential non-urban terminals on the East and West Coasts.

RECOMMENDATION

TO THE SECRETARY OF TRANSPORTATION

We recommend that the Secretary of Transportation develop a computer program able to analyze the capability of the national LPG storage and distribution system. Such a program should be able to determine the rate at which LPG

can be delivered - as LPG or as synthetic natural gas - from any point to any other point and the cost to increase this capability by any desired amount.

REFERENCE

1. Final Environmental Impact Statement for the Matagorda Bay Project, FPC, Docket No. CP77-330 et al., September, 1977.

CHAPTER 15

THE CAPACITY OF NON-URBAN SITES TO MEET TOTAL U.S. IMPORT REQUIREMENTS FOR LNG

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INTRODUCTION

As analyzed in Chapters 3, 4, 5, and 9, LNG terminals in densely populated areas pose risks to public safety. If LNG imports through these areas could be reduced or eliminated, the public would be exposed to far less risk. This brief chapter assesses the capacity of terminals in non-urban locations to handle all the LNG imports required by the United States through 1990.

DISCUSSION

The Federal Energy Administration projected U.S. LNG imports to expand from about 19 million cubic meters (.4 trillion cubic feet) in 1980 to a maximum of 142 million cubic meters (3 trillion cubic feet) in 1990.[1] The 1980 total is based on projects at Everett, Massachusetts; Cove Point, Maryland; and Elba Island, Georgia. The 1990 total is based on the import projects approved or currently before the Federal Energy Regulatory Commission (FERC) or the Economic Regulatory Administration (ERA), Department of Energy, and an assumed 4 to 6 new projects. In addition, Western LNG Terminal Associates has applied for a permit to receive 6.9 million cubic meters of LNG from southern Alaska.

These LNG projects are based on long-term contracts between subsidiaries of U.S. energy corporations and exporting countries, in order to protect the large

investments required by both importers and exporters. For instance, the El Paso "Algeria II" project proposal to import 16 million cubic meters at Port O'Connor, Texas is estimated to cost $4.5 billion (1976 dollars). This includes an estimated $2.3 billion for drilling, pipeline, and marine terminal facilities in Algeria and $856 million for six LNG carriers by subsidiaries of Sonatrach (the Algerian National Oil and Gas Corporation). The subsidiaries of the El Paso Company would invest $896 million for six LNG carriers and $456 million for marine terminal facilities at Port O'Connor.[2]

There are 11 applications approved or presently before FERC and ERA for permits to build LNG marine terminal facilities. Table 15-1 classifies the existing and proposed terminal sites by their location in relation to the edge of a densely populated area of at least 25,000 people: URBAN is defined as a site that is within four miles; SEMI-URBAN as a site that is between four and twelve miles; and RURAL as a site that is more than twelve miles. The table also indicates whether ships approaching each site must pass by an urban area.

Table 15-2 shows the handling capacity of urban and non-urban marine terminals. The import data were provided by the terminal companies. The table indicates that the non-urban projects propose to import more than two times as much LNG as the urban projects. With additional ship berths, storage tanks, regasification equipment and natural gas pipelines, the non-urban terminals could easily handle all of the LNG imports projected for 1990.

TABLE 15-1 LNG MARINE TERMINAL SITES

Urban Sites	Company	Distance to the Edge of a Densely Populated Area Miles	City	Population	Requires Ships To Pass By An Urban Area
Providence, RI	Algonquin	0.6	Providence, RI	179,000	Yes
Everett, Mass.	Distrigas	0.6	Boston, Mass.	641,000	Yes
			Everett, Mass.	42,000	
Oxnard, Cal.	Western LNG	0.9	Oxnard, Cal.	71,000	No
Los Angeles, Cal.	Western LNG	1.1	Los Angeles, Cal.	2,800,000	No
Staten Island, NY	Public Service Electric & Gas	1.5	Staten Island (Eltingville, Annandale Princess Bay), N.Y.	295,00	Yes
		1.5	Carteret, N.J.	23,000	
		2.5	Woodbridge, N.J.	99,000	
West Deptford, N.J.	Tenneco	1.8	Woodbury, N.J.	12,000	Yes
		3.6	Philadelphia, Pa.	1,950,000	
Elba Island, Ga.	Southern Energy	3.6	Savannah, Ga.	118,000	No
Semi-Urban Sites					
Lake Charles, La.	Trunkline	6.0	Lake Charles, La.	79,000	No
Rural Sites					
Ingleside, Tex.	Natural Gas Pipeline	3.3	Ingleside, Tex.	<5,000	No
		7.6	Portland, Tex.	7,000	
		12.0	Corpus Christi, Tex.	204,000	
Port O'Connor, Tex.	El Paso	3.5	Port O'Connor, Tex.	<5,000	No
Cove Point, Md.	Columbia/ Consolidated	7.0	Solomons, Md.	<5,000	No
		11.0	Lexington Park, Md.	9,000	
Point Conception, Cal.	Western LNG		no towns in vicinity		No

TABLE 15-2. LNG MARINE TERMINAL HANDLING CAPACITY: URBAN SITES vs. NON-URBAN SITES[1]

Urban Sites	Proposed (million cubic meters/year landed)	Potential (million cubic meters/year landed)	Non-Urban Sites	Proposed (million cubic meters/year landed)	Potential (million cubic meters/year landed)
Everett, Mass.	2.0	2.0	Cove Point, Md.	11.2	25.8
			Lake Charles, La.	8.4	16.8
Providence, RI[2]	3.0	4.2	Port O'Connor, Tex	16.0	48.1
Staten Island, N.Y.[3]	6.4	12.4	Ingleside, Tex.	6.9	20.7
West Deptford, N.J.	8.6	34.4	Point Conception, Cal.[4]	15.5	68.9
Elba Island, Ga.	6.0	17.2		58.0	180.3
	26.0	70.2			

1. Data provided by the companies. Proposed quantities are based on the companies' applications to FPC. Potential quantities reflect the amount of LNG that could be received through the terminal with additional ship berths, in some cases, storage tanks, regasification equipment, and natural gas pipeline capacity.

2. The "Proposed" quantity reflects the original filing with the FPC by Eascogas LNG, Inc. Algonquin plans to develop a new import project.

3. Public Service Electric and Gas plans to import 60% of the original filing with the FPC by Eascogas LNG, Inc.

4. In September 1977, the State of California enacted a law authorizing the construction of one non-urban LNG marine terminal. In November 1977 Western LNG Terminal Associates amended its applications to the ERA and the FERC shifting the receiving terminal sites from Oxnard and Los Angeles, California to Point Conception.

If the inherent danger of living near an LEG terminal is insufficient to keep large numbers of people from moving nearby, a non-urban site might become an urban site over the lifetime of a facility. Thus, it is necessary to predict the population pattern of the site area for the projected lifetime of the facility. The Nuclear Regulatory Commission requires such predictions for nuclear facilities, and they have proved to be accurate.

Table 15-3 shows a regional breakdown of the existing and proposed LNG marine terminals. The five non-urban terminals are located in the Northeast, the Gulf Coast, and the West Coast.

FINDING

- The Federal Energy Administration projected maximum U.S. LNG imports in 1990 to be 142 million cubic meters. In addition, Western LNG Terminal Associates has applied to receive 6.9 million cubic meters from southern Alaska. Non-urban LNG marine terminals have the potential capacity to receive 180.3 million cubic meters. Thus, non-urban LNG terminals could easily handle all of the LNG imports projected for 1990. We have not looked at the capacity of the main gas transmission lines to distribute these quantities.

TABLE 15-3. LNG MARINE TERMINAL HANDLING CAPACITY: BY REGION

	Proposed	Potential
	million cubic meters/year landed	
Northeast		
Everett, Massachusetts	2.0	2.0
Providence, Rhode Island	3.0	4.2
Staten Island, New York	6.4	12.4
West Deptford, New Jersey	8.6	34.4
Cove Point, Maryland	11.2	25.8
	31.2	78.8
Southeast		
Elba Island, Georgia	6.0	17.2
Gulf Coast		
Lake Charles, Louisiana	8.4	16.8
Port O'Connor, Texas	16.0	48.1
Ingleside, Texas	6.9	20.7
	31.3	85.6
West Coast		
Point Conception, California	15.5	68.9
	15.5	68.9

AGENCY COMMENTS AND OUR EVALUATION

The Department of Energy suggests that we should ". . .fully document the conclusion that LNG supplies projected for 1990 could be handled in non-urban sites. The volumes are so substantial that absent of a discussion of ship requirements, berth facilities, etc., the statements per se are inconclusive." Several companies make similar comments.

We obtained our estimates for the potential LNG imports that could be received through the marine terminals, shown in Table 15-2, from the terminal companies involved. We mention several ways in which existing facilities and pipelines might have to be expanded. We have not analyzed the possible costs.

REFERENCES

1. Statement of an official of the Office of Oil and Gas, Department of Energy, in a telephone conversation on October 13, 1977.

2. Federal Energy Regulatory Commission "Initial Decision upon Applications to Import LNG from Algeria," Administrative Law Judge Southworth Presiding, October 25, 1977, pp. 4-5.

CHAPTER 16

FEDERAL, STATE, AND LOCAL REGULATIONS

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INTRODUCTION

This chapter evaluates and compares safety laws and regulations for large LEG and naphtha storage facilities, focusing on 12 special issues. It gives an overview of transportation regulations which are discussed more fully in Chapters 6 and 17. Our review covered the Federal Government, the 50 states, and 30 representative localities listed in Table 16-1.

The survey shows that substantive regulation of the storage and handling of bulk LNG, LPG, and naphtha remains under the jurisdiction of the states.

Except for a few municipalities that have their own codes, city and county authorities follow state regulations for enforcement and inspection purposes.

Federal regulations are similar to those of the states and municipalities because they all rely heavily on National Fire Protection Association (NFPA) standards.

Appendix XVI-1 lists all U. S. facilities having LNG, LPG, or naphtha storage in excess of 23,000 cubic meters (m^3), or a monthly throughput greater than that figure. Appendix XVI-2 describes 12 large LEG facilities that we visited.

THE EVOLUTION OF SAFETY STANDARDS

Most regulations governing the siting, design, testing, inspection, and operation of LNG, LPG, and naphtha facilities evolved within the industry. The first major LNG facility, constructed in Cleveland in the early

TABLE 16-1 LOCALITIES WHOSE LEG AND NAPHTHA SAFETY REGULATIONS WERE REVIEWED

State	City	Fuel(s)
California	Chula Vista	LNG, naphtha
	Los Angeles	LNG*, LPG, naphtha
	Oxnard	LNG*
Connecticut	Rocky Hill	LNG
Delaware	Claymont	naphtha
Georgia	Elba Island	LNG*
Idaho	Boise	LNG
Illinois	Fisher	naphtha (SNG), LNG
Kentucky	Calvert City	LPG (cavern)
Louisiana	Lake Charles	LNG*
Maryland	Cove Point	LNG
Massachusetts	Dorchester	LNG
	Everett	LNG, LPG
	Boston	naphtha
	Lowell	LNG
Michigan	Marysville	naphtha (SNG)
Minnesota	Burnsville	LNG
Nebraska	Omaha	LNG
New Jersey	Linden	naphtha (SNG)

New York	New York:	
	Brooklyn	LNG, naphtha (SNG)
	Astoria	LNG
	Staten Island	LNG*
	Jamaica	naphtha
	Queens	naphtha
Ohio	Green Springs	naphtha (SNG)
Oregon	Newport	LNG
Pennsylvania	Marcus Hook	naphtha, LPG
	Philadelphia	LNG
Puerto Rico	Puneulas	naphtha
Rhode Island	Providence	LNG, LPG
Tennessee	Memphis	LNG
Texas	Houston	naphtha, LPG
	Ingleside	LNG*
Virginia	Tidewater	LNG
Washington	Plymouth	LNG

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* not operating

1940's, was designed on the assumption that credible accidents would involve leaks that were no faster than those from a major piping accident. Present LEG codes and standards are more stringent than those used at Cleveland, but they are still designed to handle only the same limited leakage.

Regulations governing LEG and naphtha storage are based on NFPA and other professional group standards. LPG and naphtha have been in widespread use for many years, and the regulations controlling them are more nearly uniform than those for LNG. The American Petroleum Institute (API), the NFPA, and some localities have special rules covering bulk storage of refrigerated LPG.

NFPA Standard 58, "Storage and Handling of Liquefied Petroleum Gases," was first adopted in 1932. Between 1932 and 1940 the rapidly growing use of LPG led to several separate NFPA standards for different LPG applications. In 1940 these were combined into Standard 58. The Standard has been revised about every two years since. The current version is the 1974 edition. This standard is accepted by nearly all state and local fire agencies.

NFPA Standard 59, "Storage and Handling of Liquefied Petroleum Gases at Utility Gas Plants," was originally developed in 1949. The 1974 version was the product of a cooperative effort between the American Gas Association and the NFPA. This standard is usually adopted by utility regulatory bodies because of its specific application to utility plants.

NFPA Standard 59A, "Storage and Handling of Liquefied Natural Gas," as revised in 1972, is the common minimum standard for LNG. The 1975 revision is now being adopted by states and localities.

NFPA Standard 30, "Flammable and Combustible Liquids Code," is used for naphtha. It was originally developed in 1913 as a suggested ordinance for the storage and handling of flammable liquids, and it has been the basis for most subsequent regulations for liquid fuels such as naphtha. The text was expanded over the years, and in 1957 was changed to a recommended Code in recognition of the tendency toward statewide regulation. The current edition was published in November, 1976.

API Standard 2510 is sometimes adopted by regulatory groups. It does not apply to LPG installations covered by NFPA 58 or 59, but rather to those at marine and pipeline terminals, refineries, or tank farms. In some criteria API 2510 is more stringent than NFPA 58, in others less.

API Standard 620 is entitled "Recommended Rules for Design and Construction of Large, Welded, Low-Pressure Storage Tanks." The sixth edition, released on July 15, 1977, has an appendix which applies specifically to LNG tanks.

API Standard 650 (1977 ed.), "Welded Steel Tank for Oil Storage," applies to naphtha tanks. Pressure vessels such as non-refrigerated LPG tanks are designed to American Society of Mechanical Engineers (ASME) pressure vessel codes.

FEDERAL REGULATION OF LEG AND NAPHTHA SAFETY

Federal regulations covering land storage facilities are not well coordinated for LNG and are minimal for LPG or naphtha. The LNG regulations incorporate NFPA 59A. There are no specific Federal laws or regulations covering minimum liability insurance requirements for LEG or naphtha facilities.

In the Federal regulation of LNG storage facilities, there have been areas where jurisdiction among agencies has been unclear. Two DOT agencies—the Office of Pipeline Safety Operations (OPSO), in the Materials Transportation Bureau (MTB), and the U.S. Coast Guard—have each exercised authority over LNG facilities adjoining the navigable waters of the United States. The former Federal Power Commission (FPC) also had certain responsibilities for the safety of LNG import terminals and some peakshaving plants.

On February 7, 1978, the MTB and the Coast Guard signed a two-page Memorandum of Understanding which specifies the responsibilities to be carried out by each agency. This action, which took more than three years of negotiations, should reduce the duplication of effort and speed the promulgation of needed regulations.

The Coast Guard will be responsible for establishing regulatory requirements for:

(1) Facility site selection as it relates to management of vessel traffic in and around a facility;

(2) Fire prevention and fire protection equipment, systems, and methods for use at a facility;

(3) Security of a facility; and

(4) All other matters pertaining to the facility between the vessel and the last manifold (or valve) immediately before the receiving tank(s).

Except as provided in those paragraphs, the MTB (through OPSO) will be responsible for site selection and all other matters pertaining to the facility. This division of responsibilities appears to be appropriate. The two agencies agreed to cooperate in carrying out their enforcement activities and to consult with each other before issuing proposed and final regulations.

Appendix XVI-3 includes the full memorandum and a discussion of the statutory authority of the two agencies. This appendix also includes an analysis of the relationship between OPSO and the FPC.

Several DOT offices are also responsible for setting and maintaining safety standards for interstate trucks and railcars carrying LEG. This chapter discusses only the regulations issued by MTB and its Office of Hazardous Materials Operations (OHMO). The Interstate Commerce Commission (ICC) is also involved in LEG transportation, since only it can revoke or suspend the certificates of interstate carriers found to be unsafe. The Coast Guard has Federal jurisdiction over LEG and naphtha shipping.

Office of Pipeline Safety Operations

Responsibilities for LNG Facilities

OPSO is responsible for prescribing and enforcing Federal safety regulations for LNG storage facilities connecting with a pipeline in or affecting interstate commerce. See 49 CFR Parts 191 and 192. These regulations incorporate the 1972 version of NFPA Standard 59A. The facility design regulations apply only to LNG pipeline-connected facilities for which construction began after January 1, 1973, but the operating and modification provisions apply to all facilities. Currently, OPSO has an Advance Notice of Proposed Rulemaking on "Liquefied Natural Gas Facilities, Federal Safety Standards," which could add a new Part 193 to Title 49, CFR (42 Fed. Reg. 20776, dated April 21, 1977). It expands on the 1975 edition of NFPA 59A, uses safety performance standards, and includes some specific new technical requirements. The new design standards will apply to existing facilities only if they are modified in the future.

OPSO carries out its pipeline safety program across the United States through its five regional offices, each staffed by two professionals and a secretary. OPSO plans to increase the number of professionals in the field offices to 45, but eight will be assigned to the Alaska gas pipeline project.

OPSO mainly relies on certified state agencies for the inspection of LNG storage facilities. (This certification program is described below.) In 1977, OPSO made three inspections, including the Cove Point, Md. marine terminal. State agencies made 242 inspections of

74 LNG storage facilities in 1977. OPSO records do not indicate the extent of the state inspections.

A more comprehensive review of OPSO's authority, regulations, and performance is presented in GAO's report, "Pipeline Safety--Need for a Stronger Federal Effort" (CED-78-99). One of its conclusions is that OPSO's staffing, particularly in the regional offices, is not adequate for carrying out its present mandated responsibilities in a comprehensive, effective, and timely manner.

OPSO regulations require LNG storage facilities to report at the earliest practicable moment by telephone any leak that causes death or injury, property damage of more than $5,000, or gas ignition. No written follow-up report is required if the facility serves fewer than 100,000 customers. For example, the owners of the Cove Point import terminal, whose only customers are other pipeline companies, would not have to file a written report.

In the annual report required of all gas transmission companies, all leaks must be described. There is no requirement, however, by OPSO or any other Federal agency, for the reporting of other unusual occurrences, such as the venting of vapor from storage tanks or the breakdown of vital machinery. Gas utility companies do not have to identify the type of facility where a leak occurred. It would not be clear, for example, whether a leak occurred at an LNG peakshaving facility or in the natural gas pipeline.

Responsibilities for LPG and Naphtha Facilities

OPSO's regulation of LPG and naphtha pipelines is authorized under the Transportation of Explosives Act of 1908, 18 U.S.C. 831-835, and the Hazardous Materials Transportation Act, 49 U.S.C. 1801 et seq. The Explosives Act gives OPSO responsibility over interstate and foreign commerce by these pipelines, but it does not cover interstate pipelines and facilities that merely affect interstate commerce. The Hazardous Materials Transportation Act excludes interstate liquid pipelines covered under the Explosives Act from its provisions. OPSO further interprets the Act to exclude jurisdiction over intrastate liquid pipelines affecting interstate commerce. We disagree. We believe that intrastate LPG and naphtha pipelines, including connecting import terminals and storage complexes, affecting interstate commerce are under OPSO's jurisdiction and that OPSO should extend its regulations to cover these pipelines.

Under the Explosives Act, the Director of OPSO cannot levy civil penalties for violations. In order to penalize violators, he must initiate criminal charges. If no death or serious injury resulted from the violation, the maximum penalty is $1,000 and one year imprisonment.

According to OPSO regulations, 49 CFR 195.264, LPG and naphtha storage tanks under its jurisdiction are only required to provide a means to contain liquid in the event of a spill or tank failure, to protect against unauthorized entry, and to provide normal and emergency

relief venting. These regulations do not require a particular percentage of the liquids spilled to be contained, or say what constitutes adequate protection against unauthorized entry.

U.S. Coast Guard

The U.S. Coast Guard regulates various aspects of the design, construction, and harbor movements of seagoing vessels and cargo tanks for LEG and naphtha (46 U.S.C. 391a). It has issued regulations on the design and operation of tank vessels transporting LEG and naphtha, in 46 CFR Parts 30 to 40; and for the transportation of liquefied flammable gases in portable containers stored on deck for use as ships' stores and supplies, in 46 CFR Part 147. It has regulations on hull and tank construction for liquefied gases, 46 CFR Parts 151 and 152, and for the maintenance of standards on foreign vessels, 46 CFR Part 154. Coal tar naphtha is regulated under 46 CFR Part 153 as a bulk liquid chemical.

In October, 1976, the Coast Guard published proposed standards for new self-propelled vessels carrying bulk liquefied gases. The Coast Guard has not promulgated regulations directly relating to LNG land facilities but had announced an intention to do so. Under the new Memorandum of Understanding, the Coast Guard's rule-making will be coordinated with OPSO's.

The Coast Guard is responsible for designating security zones on land to guard against sabotage, and it issues permits and maintains precautions relevant to the handling of dangerous cargo in or contiguous to waterfront facilities, pursuant to 33 CFR Parts 6 and 124-127.

Materials Transportation Bureau

MTB has promulgated detailed regulations on the transportation by rail, highway, air, or water, of hazardous materials in commerce. These, set forth in 49 CFR Parts 171-179, identify hazardous materials by classes (LNG and LPG are flammable gases) and require specific design standards for hazardous materials containers, including railcars and tank trucks. At present, however, no regulations for the design of cryogenic tank trucks exist, and MTB (through OHMO) approves LNG tank truck designs by exemption. The regulations in 49 CFR Parts 171-179 incorporate parts of NFPA Standard 58 and other standards of private organizations.

Federal Power Commission

The Natural Gas Act of 1938, 15 U.S.C. Section 717 et seq., authorized the Federal Power Commission to regulate the transportation and sale for resale of natural gas in interstate commerce, including, under Section 717f, the regulation of facilities. In addition, the Commission has exercised jurisdiction over import facilities under its authority to regulate imports of natural gas (15 U.S.C. 717b). Regulations in 18 CFR Part 3 Appendix B, Guideline 9.4.1., which were adopted pursuant to the National Environmental Protection Act, require that Environmental Impact Statements be prepared for LNG transport, storage, and regasification facilities. These must include a description of compliance with the relevant OPSO and Coast Guard safety regulations.

U.S. Army Corps of Engineers

The U.S. Army Corps of Engineers has the authority under 33 U.S.C. Section 401 to regulate the construction of bridges and wharves, and other activity or construction which affects navigable waters. In this capacity, the Corps issues permits relevant to the construction of waterfront LNG terminals, but lacks authority to otherwise regulate either LNG ships or terminal facilities. Permit regulations are found in 33 CFR Part 209.

Interstate Commerce Commission

The ICC, under its basic grant of authority in 49 U.S.C. Section 1 et seq., has general authority over interstate surface transportation. Its control over the safety aspects of different modes of transportation and its specific powers to regulate the transportation of dangerous materials was transferred to DOT by the DOT Act of 1966, as amended (49 U.S.C. 1651 et seq.).

Federal Aviation Administration

The Federal Aviation Administration has the authority to certify airports and set standards for the storage and inspection of fuel storage (14 CFR 139.1 et seq. and 139.51). This includes naphtha, but not LNG or LPG, since they are not used for aircraft fuel.

Environmental Protection Agency; Council on Environmental Quality

The Environmental Protection Agency has several regulations which potentially affect LEG and naphtha facilities. They are somewhat removed, however, from the issues which are the subject of this inquiry. Some examples are regulations on Ambient Air Quality Standards, 40 CFR Part 50; Registration of Fuels and Fuel Additives, 40 CFR Part 79; Energy Related Authority, 40 CFR Part 55; and Hazardous Substances, 40 CFR Parts 116-119. The regulations of the Council of Environmental Quality pertinent to the National Oil and Hazardous Substances Contingency Plan, 40 CFR Part 1510, fall in this same category.

The Coastal Zone Management Act

The Coastal Zone Management Act of 1972, under 16 U.S.C. 1451 et seq., encourages state regulation of coastal land use. This could have an impact on LEG import facilities, since no license or permit shall be granted by a Federal agency for such an area unless the state concurs with the applicant's certification that the proposed activity complies with the state's approved coastal zone management program. There is provision, however, for the Secretary of Commerce to find, after providing a reasonable opportunity for detailed comments from the Federal agency involved and the state, that the proposed activity is consistent with the objectives of the Act or is otherwise necessary in the interest of the national security. See 16 U.S.C. 1456(c).

Findings

- Federal regulation of LNG storage facilities has not been well coordinated. The February 1978 Memorandum of Understanding between the U.S. Coast Guard and MTB should reduce the duplication of effort and speed the promulgation of needed regulation of waterfront LNG facilities.

- Prompt reporting of all unusual occurrences at LNG facilities is needed. OPSO requires gas transmission companies to report all spills in the annual reports submitted to OPSO, but only major spills must be reported by telephone immediately. A company with fewer than 100,000 customers, such as an LNG importing company, does not have to submit a written, follow-up report. No Federal agency requires companies to report other unusual occurrences such as the venting of gas or the breakdown of vital machinery at LNG storage facilities.

- There are no Federal regulations for intrastate LPG pipelines and connecting storage facilities that affect interstate commerce. OPSO interprets the Hazardous Materials Transportation Act as excluding jurisdiction over these pipelines and storage facilities. Under the Transportation of Explosives Act of 1908, OPSO may initiate only criminal charges in court against violators of LPG interstate pipeline regulations. No civil penalties are available.

STATE AND LOCAL REGULATIONS

State Regulations

Enabling legislation usually delegates a state's responsibility for developing LEG and naphtha regulations to a specific agency, which promulgates standards. Most state agencies incorporate or follow NFPA Standards. Appendix XVI-4 contains summaries of the state regulations. Appendix XVI-6 includes a list of state agencies with LEG and naphtha regulatory responsibilities.

Section 5 of the Natural Gas Pipeline Safety Act (49 U.S.C. Section 1674) authorizes OPSO to establish a voluntary program for state agencies to assume Federal inspection and enforcement responsibilities for intrastate gas pipelines and connecting facilities. Agencies, typically public service or utilities commissions, from all 50 states, the District of Columbia, and Puerto Rico are currently participating. Almost all LNG peakshaving facilities are regulated by the state agencies through the OPSO program. A few states, including New York and Massachusetts, have regulations which exceed OPSO's requirements in some respects.

In more than half the states, the State Fire Marshal's Office regulates liquid fuels, including LPG. This office often is part of a larger agency charged with overall law enforcement, policy, or public safety responsibilities. Historically, these state offices dealt with naphtha and other nonpressurized, usually petroleum-based, combustible or flammable fuels. Subsequently, regulations were developed for pressurized LPG.

State public service or utilities commissions participate in the OPSO certification program because they regulate natural gas. Occasionally they have regulations for LPG handling and storage, but only rarely for naphtha.

Other state agencies with regulations applicable to the transportation, storage, or handling of LEG or naphtha include Departments of Labor and Industry (or Industrial Relations, or the like). The regulations of such agencies are often heavily oriented toward the protection of workmen. Their safety concerns encompass only the areas of labeling, packaging, and related requirements associated with small amounts of fuel. In New Jersey, the Department of Labor and Industry is the primary regulatory body for LEG and naphtha. Many states also [illegible] motor vehicle transportation regulations, such as requiring trucks transporting LNG to come to a full halt at railroad crossings. Kentucky and Louisiana have LPG Commissions whose regulations extend to bulk storage of LPG in salt dome cavities. None of these regulations, however, covers the seismic design of LPG caverns. Illinois covers the same subject area under the State Environmental Protection Agency.

In the last three years, there has been a trend at the state level toward the formation of Energy Departments, Energy Facilities Siting Councils or Commissions, and Environmental Protection Agencies. With few exceptions, New York for example, offices of this kind show an interest only in the location of LNG facilities. A similar interest is shown by the Coastal Zone Management Councils which have been formed as the result of the Federal Coastal Zone Management Act in states including California, Delaware, Massachusetts, and Oregon.

The central concern of agencies of this type is in locating facilities in harmony with energy resource planning, or other land use patterns. Thus, while safety is a matter of concern, it appears at a generalized level rather than in the context of specific requirements affecting construction and management. These agencies have generally deferred to the specific standards established by other state agencies.

Local Regulations

Except for a few large cities that have detailed fire codes, city and county authorities follow state regulations for enforcement and inspection purposes. State-imposed standards are usually followed even in those cases where independent rulemaking authority clearly exists at the local level. Like the state agencies, local authorities often adopt NFPA Standards on a de facto basis without the trappings of official promulgation. This is important, since local officials play a more significant role than state officials in overseeing the construction of facilities and in periodically inspecting them for compliance with operational requirements.

Some cities have adopted official facility standards because of a void in state and Federal law, as in the case of Houston, or because of the pressure for greater safety scrutiny arising from high population densities and the concentration of bulk storage facilities for many hazardous substances in a small area.

New York is the only city with comprehensive local LNG standards. When the first LNG peakshaving facility in the New York metropolitan area was proposed in the 1960's,

the New York City Fire Department (NYCFD) became concerned about the siting of such a facility in a congested urban area and developed informal requirements for it. These were later translated into a detailed set of written regulations which exceed those of NFPA in a number of ways. The New York State Public Service Commission later adopted its own standards for LNG facilities, drawing on and somewhat modifying both the NFPA standards and the NYCFD requirements. In June, 1976, New York State enacted the Liquefied Natural and Petroleum Gas Act making the safety of LNG facilities the responsibility of the State Department of Environmental Conservation.

Local building and zoning codes do not focus on LEG facilities, as such, but building codes are used to set design criteria for the construction of storage tanks. Building codes are usually adopted at the state level. These codes are fashioned after models provided by professional organizations, such as the International Conference of Building Officials, whose codes incorporate some NFPA regulations. Zoning codes are primarily land-use oriented and do not provide specific safety criteria applicable to fuel facilities of any kind.

Permit Granting Agencies

At both state and local levels the authorization of many governmental organizations may be required before an LEG facility can be constructed. At the local level, zoning boards present the most common example. At the state level, there has recently been a proliferation of agencies whose permits must also be obtained, causing an overlap of authority with more traditional regulatory bodies. For example, a proposed LNG facility might

require the permit or certification of an Environmental Protection Agency, the Energy Facilities Siting Council and/or a Coastal Zone Management group, as well as that of a Fire Marshal and a Public Utilities body, and appropriate local agencies.

The more recently created bodies tend to be primarily concerned with land use and/or energy resource planning. In general, specific safety issues are not an abiding or primary concern. As a result, those agencies have few regulations that are directly relevant to this study. Their authority is sufficiently broad, however, to allow issues such as compliance with NFPA or other standards to become a part of their decision-making on a given application. However, this pattern at the state level is too recent to have given rise to a body of legal precedent. At least one state, Alaska, is attempting to consolidate the permitting structure for LNG facilities into a single agency process.

It is not clear whether a facility plan approved by the FPC or the Department of Energy could be blocked by state land use groups, such as Coastal Commissions or Energy Facilities Siting Councils. Historically, the FPC has respected the decisions of local and state authorities and avoided any conflict. State agencies have generally been granted final authority over land use issues. This point has not yet been tested in the courts since a significant conflict has not yet arisen.

Airports

LEG bulk storage facilities are not generally located at airports. Naphtha, however, because it is a common component of jet fuel, is stored at airports.

Since airports are typically under both state and local jurisdiction, any fuel facilities constructed on them are subject to the regulatory patterns described above. In addition, airports are subject to requirements imposed by the FAA. However, as discussed earlier in the context of Federal standards, these requirements are not directly relevant to this study. Aviation or aeronautics agencies take a similar regulatory approach. The tendency of airport regulatory bodies is to informally adopt NFPA standards, or to defer to the specific requirements of other state agencies for fuel facilities.

Insurance and Liability Standards

With the exception of New York State, which imposes strict liability for LNG and LPG, we found no specific state or local requirements concerning insurance or the imposition of special liability standards which have any applicability to LNG facilities. Ten states have insurance requirements for LPG transportation. However, the required coverage is small, ranging from $10,000 per person injured to a maximum of $100,000 per accident. This leads us to believe that the basic concern of these requirements is with storage, transportation, and handling of relatively small containers of LPG rather than bulk quantities.

Findings

- Almost all state and local regulations are based on NFPA standards. The exceptions include somewhat more stringent regulations developed by the New York State Public Service Commission and the New York City Fire Department.

- Most responsibility for the safety of LEG and naphtha has traditionally been under state and/or local fire marshals. LEG at public utilities is also regulated by State Public Service or Utilities Commissions. Energy Facilities Siting Councils and Coastal Commissions have recently been given jurisdiction over the development of new large energy facilities. However, such groups are too new to have established much state law precedent.

- Permit requirements are becoming increasingly cumbersome as agencies proliferate. Some states are attempting to simplify this problem for LNG facilities by consolidating the process under a single agency.

- New York State imposes strict liability for LNG and LPG facilities. In other states, LNG storage is not subject to specific regulatory provisions imposing liability for injury to persons or property, or requiring that insurance be carried against whatever liability would be imposed by courts under general tort law.

FINDINGS OF SPECIAL ISSUES ANALYSIS

This section lists our findings for the following 12 special issues for LNG, LPG, and naphtha:

1. The Minimum Distance Required Between the Tanks or Dike and Residential, Social, Business, and Government Facilities.

2. The Minimum Distances Required Between LNG, LPG, or Naphtha Tanks and Tanks Holding Other Flammable, Explosive, Poisonous, or Toxic Materials.

3. Security Requirements.

4. Diking Requirements.

5. Requirements For Resistance to Natural Phenomena.

6. Requirements For Operating Procedures and Personnel Training.

7. Materials Specifications For Storage Tanks.

8. Materials Specifications For Truck Trailers and Rail Cars.

9. Requirements For Harbor Movements and Unloading of LEG and Naphtha Tankers.

10. Requirements For Tanker Construction.

11. Liability.

12. Liability Insurance Requirements.

Our detailed analyses are in Appendix XVI-5. Only those state and local regulations which supplement or modify the Federal regulations applying to a particular issue are cited.

1. The Minimum Distance Required Between Tanks or Dikes and Residential, Social, Business, and Government Facilities.

One concern in siting a major energy facility is to protect the people living and working in surrounding areas from the consequences of credible major accidents at the facility.

Basic protection is provided by requiring adequate separation between the fuel storage area and any property line that abuts other property which is in use. Additional requirements are imposed in a few jurisdictions if the site is located near critical occupancy buildings such as schools, hospitals, and places of public assembly.

To obtain some idea of the range of distance requirements, an example may be helpful. If a 25,000 cubic meter (m^3) capacity storage tank with a diameter of 120 ft and a 80 ft liquid height were surrounded with a 100% capacity square dike 20 ft high, the length of one side of a square dike would be about 210 ft. A tank with twice that volume (50,000 m^3) and with the same liquid height and dike height would require a tank diameter of 170 ft and a dike side of 300 ft; a 100,000 m^3 tank would have a 240 ft diameter and dike sides of 420 ft.

For these three size tanks, Table 16-2 shows the exclusions distances required for LNG, LPG, and naphtha by different codes and jurisdictions.

Findings

- There is a considerable variation in buffer zone requirements. The NFPA 59A - 49 CFR Part 192.12 standards for LNG require smaller exclusion distances for the smaller tanks than those recommended by NFPA 59 for LPG and NFPA 30 for fixed roof tanks with emergency relief vents. (All LNG tanks have fixed roofs and emergency relief valves.) The LNG buffer zones set by New York State and the New York City Fire Department are more consistent with the distances required for LPG and naphtha. Buffer zones for LPG are close to those for naphtha.

- A very few jurisdictions recognize certain critical occupancy buildings (such as schools, hospitals, places of public assembly, etc.), and require additional separation ranging from 300 ft for naphtha (Connecticut) to 1,000 ft for LNG (NYCFD). No consistent criteria have yet been published relating to flammable vapor travel. Flammable vapor cloud migration offsite is not considered *per se* in LPG siting regulations. It is mentioned for LNG in the 1975 NFPA 59A, but the criteria for assessing acceptable safety are vague and the suggested computational methods are inappropriate. The NYCFD requires submission of vapor travel analyses for LNG facilities but does not state methodology or criteria.

TABLE 16-2 EXCLUSION DISTANCES FROM THE TANKS TO THE PROPERTY LINE

Agency Regulation	Exclusion Distance to Property Line		
	25,000 m^3	50,000 m^3	100,000 m^3
LNG			
49 CFR 192.12 (NFPA 59A)			
from dike	160'	228'	320'
from tank	200'	285'	400'
New York State			
from dike	400'	570'	800'
from tank	440'	627'	880'
NYCFD			
umbermed	400'	570'	800'
bermed	250'	250'	300'
from critical occupancy	1,000'	1,000'	1,000'
Massachusetts			
from dike	160'	228'	320'
from tank	100'	100'	100'
LPG (Refrigerated)			
NFPA 59			
from tank	400'	400'	400'
API 2510			
from tank	200'	200'	200'
California-PUC			
to schools	500'	500'	500'
from tank	50'	50'	50'
Pennsylvania			
from tank	50'	50'	50'
NAPHTHA			
NFPA 30			
float roof	120'	170'	175'
fixed roof	350'	350'	350'

Agency Regulation	Exclusion Distance to Property Line		
	25,000 m^3	50,000 m^3	100,000 m^3
Connecticut			
float roof or extinguishing system	120'	120'	120'
Florida			
float roof	120'	170'	175'
fixed roof	350'	350'	350'
Indiana			
float roof	120'	170'	175'
fixed roof	350'	350'	350'
Michigan			
float roof or extinguishing system	120'	120'	120'
Pennsylvania			
float roof	120'	170'	175'
fixed roof	350'	350'	350'

- In most situations, for a given volume, LPG is more dangerous than LNG and LNG is more dangerous than naphtha. The minimum exclusion distances imposed by NFPA standards and states and localities do not reflect this. Buffer zones for naphtha are often close to or even greater than those for LPG, and buffer zones for LNG are often substantially less than those for naphtha.

2. The Minimum Distances Required Between LNG, LPG, and Naphtha Tanks, and Tanks Holding Other Flammable, Explosive, Poisonous, or Toxic Materials.

The following table presents separation distances for the same three sizes of tanks discussed in Issue One. The separation distance applies to two tanks of the size indicated.

TABLE 16-3 EXCLUSION DISTANCES BETWEEN STORAGE TANKS

Agency Regulation	Inter-tank Exclusion Distance 25,000 m^3	50,000 m^3	100,000 m^3
LNG			
49 CFR 192.12 (NFPA 59A)	60'	85'	120'
California	60'	85'	120'
New York State	250'	357'	500'
NYCFD	250'	357'	500'
Massachusetts	60'	85'	120'
LPG*			
NFPA 59 (1976)	60'	85'	120'
NFPA 58 (1976)	60'	85'	120'
API 2510 (1970)	60'	85'	120'
California	18"	18"	18"
Kansas	60'	85'	120'
Mississippi	60'	85'	120'
New Jersey	60'	85'	120'
Pennsylvania	3'	3'	3'
Wisconsin	60'	85'	120'
NAPHTHA**			
NFPA 30 (1976)	60'	85'	120'
California	18"	18"	18"
Connecticut	60'	85'	120'
Florida	40'	57'	80'
Indiana	40'	57'	80'
Michigan	60'	85'	120'
Pennsylvania	40'	57'	80'

* Refrigerated Containers
** Floating Roof Tank

Findings

- Basic NFPA standards give inter-tank separation distances of one-fourth the sum of the diameters of adjacent tanks for LNG and LPG tanks. For naphtha tanks the separation distance generally is one-sixth this sum except for very large naphtha tanks with fixed roof design and large impounding areas. API 2510 has spacing requirements for LPG tanks that are in some cases less stringent than those of NFPA 58 and 59. State requirements generally are the same as or less stringent than NFPA standards. The NYCFD, however, requires spacing between two LNG tanks to be the greater of 250 ft or 1.25 tank diameters.

- The NFPA 59A LNG container spacing requirement does not take into account the dike design or the location of the tanks within the dikes.

- Requirements for inter-tank spacing are not logically related to the different hazards presented by the different fuels and are frequently no more stringent for LEG than for naphtha. They usually are no more stringent for LPG than for LNG. They are sometimes more stringent for naphtha than for LPG.

3. Security Requirements.

Findings

- In light of the potentially severe consequences of sabotage, the required deterrents are weak. Most of the codes require only fencing, without mentioning locks, and none of the codes mentions additional perimeter security measures. NFPA 59 requires that any locks used be breakable (to ease the entrance of firemen). The NYCFD requires locked gates at LNG facilities.

4. Diking Requirements.

An important aspect of energy facility safety is to assure that any accidental fuel releases will be contained in limited areas on-site, preferably in impounding areas of adequate capacity and minimum surface area. Also, facilities should be designed so that an impounding area fire does not jeopardize other critical parts of the facility or its environs.

Findings

- Diking is required for LNG, refrigerated LPG, and naphtha. Pressurized LPG is not considered under either NFPA 58 or API 2510 to need diking, although the API Standard suggests area grading so that any

spills will flow away from the storage area to a safe impounding location.

- For LNG, refrigerated LPG, and naphtha, NFPA standards require that dike volumes be at least equal to the maximum storage volume of the tank they protect. If a dike protects more than one tank, the dike volume must at least equal that of the largest tank contained in the dike. Any LEG outer tank walls that might be wetted in a spill must be able to withstand low temperature exposure.

- Dike design requirements are more comprehensive in the NFPA standard covering naphtha than in the NFPA standards for LNG and LPG.

- New York State and the New York City Fire Department require 150% capacity diking for LNG and prohibit multiple tanks in a single dike.

- The NYCFD now allows only bermed LNG tanks surrounded by an additional dike with height at least half the maximum tank liquid level height. Most other codes treat bermed tanks as tanks with integral dikes and do not require secondary diking.

5. Requirements for Resistance to Natural Phenomena.

Hazardous facilities should be designed to withstand any severe environmental conditions which might occur during the lifetime of the facility. Such conditions include high winds, tornadoes, earthquakes, floods, rapid atmospheric temperature and pressure changes, snow loads, etc. Building codes usually specify a design event for these natural phenomena. Most petrochemical facilities have been designed to meet normal building code standards. Frequently, the design event (the event the facility is designed to withstand without endangering the public) is the worst occurrence in the area for the period in which catastrophic events are documented. This amounts to a 200 - 300 year data base in most of the United States. Often it is only the worst event in the area in the past 50 years. NRC imposes much stricter requirements on nuclear plants.

Current OPSO standards are based on NFPA 59A (1972) and thus do not include certain changes made in NFPA 59A (1975) such as the need for a detailed geotechnical site investigation in seismic areas. There is no such requirement for equally large tanks of LPG.

The draft LNG regulations developed for comment by OPSO suggest a design event for each natural phenomena for which there is only a 0.5% probability of a more severe event occurring during a 50 year period. This is equivalent to an average repeat interval of about 10,000 years, which seems adequate. However, if there are 50 LNG facilities, there is a 22% chance that a larger than design event will occur at the site of one or more of them during a 50 year period. For 100 facilities the chance is

39%. For 100 facilities and three independent phenomena, such as earthquakes, winds, and floods, the chance is 78%. There are already more than 100 LEG aboveground storage facilities, including 68 with at least 23,000 cubic meters of storage. What is more, most of these are built to the much lower standards of the building code.

The probability that one of the design events of the facilities will be exceeded can be characterized by a parameter L. L is defined as the number of sites (s), multiplied by the number of years an average site is expected to operate (y), multiplied by the number of independent natural phenomena the site is designed to resist (p), divided by the repeat interval of the phenomena (r). In equation form we have:

$$L = syp/r$$

If we have three phenomena, such as earthquakes, winds, and floods, and floods tend to be correlated with high winds, then instead of p being 3 it would be between 2 and 3. If design event floods only occurred at the same time as design event winds, then p would be 2.

Figure 16-1 gives the probability (in percent) of having N or more events which exceed the design event, for various values of L. For L = 100, for example, there is a 51 percent chance of at least 100 greater than design events occurring and a 99 percent chance of having at least 79.

L=(NUMBER OF SITES) x (NUMBER OF YEARS) x (NUMBER OF INDEPENDENT PHENOMENA)/(REPEAT INTERVAL)

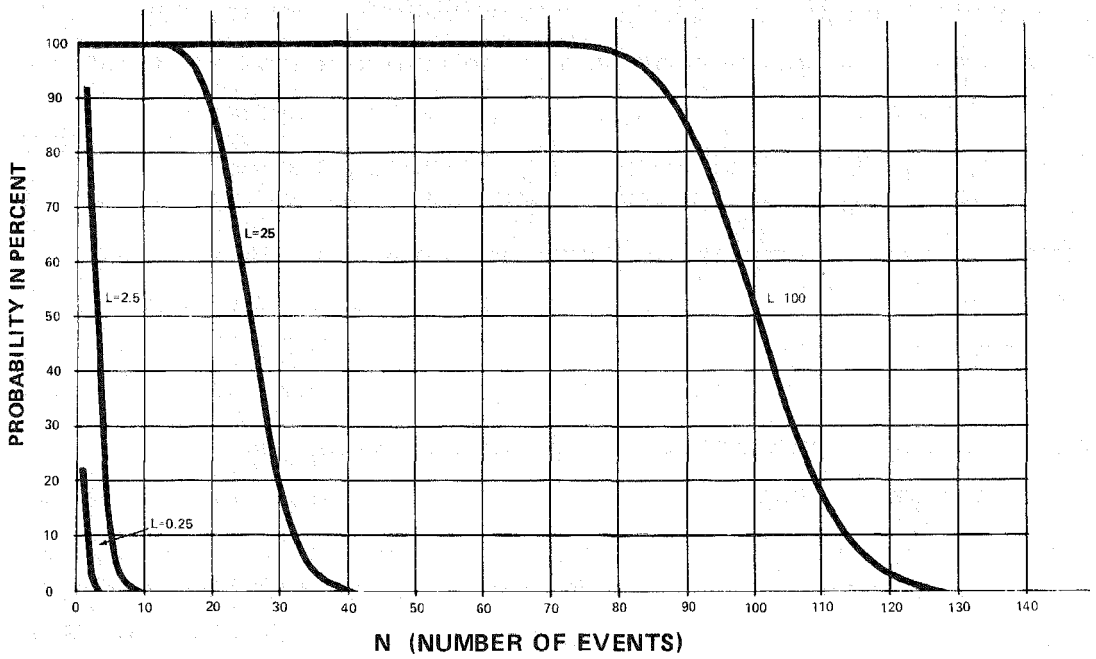


FIG. 16-1 THE PROBABILITY (IN PERCENT) OF HAVING N OR MORE EVENTS WHICH EXCEED THE DESIGN EVENT, FOR VARIOUS VALUES OF L.

In general, structures can survive stresses greater than design load stresses (those generated by design events). The safety factor is the ratio of the allowable stress (the maximum stress in a structure allowed by building codes) to the design load stress (the maximum stress in a structure produced by the loads that the codes require the equipment to withstand). In Chapter 3 we show that the natural phenomena safety factors for many large LEG tanks are quite low. This is even more disturbing since even during the lifetime of present large LEG facilities the design events are certain to be exceeded many times.

The design requirements discussed above apply to critical structures such as LNG storage and dike systems. OPSO, for example, proposes that less important components be designed for events with a 475 year repeat interval. For three phenomena this gives an L close to 25.

Findings

- Most LEG and naphtha facilities have been designed to meet normal building code standards; thus, design standards for naphtha are essentially as strong as those for LEG.

- The design event (the event the facility is designed to withstand without endangering the public) for each type of phenomenon (earthquakes, winds, floods, etc.) is usually the worst occurrence in the area in some past period. The period is 50 years for some jurisdictions and 100-300 years in others. In a few areas it is longer. OPSO's draft LNG regulations

use 10,000 years. NRC usually imposes even stricter requirements on nuclear plants.

- There are more than 100 LEG aboveground storage facilities, including 68 with at least 23,000 cubic meters of storage.

- It is virtually certain that design events will be exceeded a large number of times during the lifetime of present large LEG facilities. This is particularly serious because of the low safety factors of many large LEG tanks. (See Chapter 3.)

- Large scale urban area storage of hazardous materials in facilities built according to normal building code standards is common and highly dangerous. Even if OPSO's guidelines are adopted and precisely implemented, they are still not strict enough to allow urban area siting.

6. Requirements For Operating Procedures and Personnel Training.

Detailed operating procedures and competent and well-trained personnel are important factors in facility safety. All facilities have operating procedures, but there is considerable variation in their completeness and whether they are strictly enforced or just intended as recommended guidelines for operating personnel.

Findings

- Outside of some specific technical operating requirements scattered through the various regulations, there are only quite general references to the desirability of operator qualification and training. The NYCFD certifies LNG plant operators. A few states certify operators at LPG facilities. There are no comprehensive requirements for the development of formal operating procedures and training programs or for the review of such procedures by jurisdictional agencies.

7. Materials Specifications for Storage Tanks.

Findings

- Materials standards for a high level of structural integrity appear to be well defined and documented in the relevant codes. Materials standards for metal and concrete tanks are generally well standardized and documented in ASME and ACI Codes. Testing and inspection procedures are also included in the codes to verify materials performance.

- Insulation for storage tanks should be non-flammable. Where insulation is used to protect LPG or naphtha tanks from external fires, the insulation should be designed to maintain its integrity during prolonged exposure to impinging flames.

- Some states have developed extensive requirements for corrosion control (such as coating, cathodic protection, etc.) which supplement the basic requirements of the design codes.

8. Materials Specifications for Truck Trailers and Railcars.

Large quantities of LNG are moved by truck. Trucks and railcars transport LPG and naphtha. The mobility of such vehicles often brings them into areas of high population density and increases their chance of being in an accident.

Findings

- Tank vehicle safety is largely regulated by DOT regulations on brakes, lights, etc., and by Federal, state, and local standards for tank design. Naphtha transport, like gasoline transport, is considered routine.

- A standard developed by the Compressed Gas Association which requires 3/32-inch steel insulation jackets for LNG carriers and other requirements is generally followed. To date, OHMO has been extremely slow in promulgating similar Federal standards for LNG tank vehicle design, and approves designs on an individual basis through a special permit or exemption process.

NOTE: LEG truck and train transportation is discussed in detail in Chapters 7 and 8. The regulations governing this transportation are discussed in Chapter 17.

9. Requirements for Harbor Movements and Unloading of LEG and Naphtha Tankers, and

10. Requirements for Tanker Construction.

Findings

- Coast Guard regulations are quite comprehensive, covering vessel design, operation, and inspection. At present, however, many of the detailed operating requirements are at the discretion of the Commandant or the Captain of the Port(COTP). (See Chapter 6.) It is Coast Guard policy to follow unofficial regulations which have been published (October 1976) as proposed rules.

- Naphtha is included in the general category of flammable liquid cargoes for which there are weaker standards for ship survivability in the event of stranding or collision. Some cargo loss under such conditions is not unlikely.

- LEG carriers are designed to a higher standard of survivability and are designed to contain cargo in case of stranding or minor side damage. Refrigerated LPG ships, however, can be single-hulled.

- The operational requirements for LEG carriers entering U.S. ports are under the jurisdiction of the Captain of the Port concerned. Although Coast Guard position papers have outlined comprehensive typical requirements for COTP's, these are discretionary.

11. Liability.

Findings.

- New York State imposes strict liability for offsite damages against persons engaged in the storage, handling, and transportation of both LNG and LPG, but not naphtha. Maine has adopted strict liability for injuries arising from natural gas operations generally without specifying its applicability to LEG or naphtha. There are no other regulatory provisions that deal specifically with liability for

handling these fuels. As a result, the extent to which responsible persons will be liable for offsite damages is determined by judicial case law standards in the various states.

12. Liability Insurance Requirements

Findings

- Ten states require proof of public liability insurance in amounts varying from $10,000 to $100,000 for any single accident involving LPG. There are currently no specific requirements for liability insurance for owners of LPG facilities in the remaining 40 states. There are no insurance requirements applicable to owners of LNG or naphtha facilities in any of the states.

RECOMMENDATIONS

TO THE CONGRESS

We recommend that the Congress:

- enact legislation which prohibits, except in remote areas, the construction of new--or the expansion in size or use of existing--facilities for the storage of highly dangerous materials (including LEG) unless the storage tanks are inground with the highest level of fluid below ground level, or built to standards similar to those demanded for licensed nuclear installations in remote areas.

TO THE SECRETARY OF TRANSPORTATION

We recommend that the Secretary of Transportation:

- require companies handling hazardous materials to file routine operation summaries annually and to report any unusual occurrences within 48 hours to the Department of Transportation in a manner analogous to the reports required by the Nuclear Regulatory Commission. Reportable occurrences should include any venting or leakage of hazardous material; any overpressuring of tanks; any transportation breakdown; any vital machinery breakdown; and any attempt by unauthorized persons to enter company premises. These reports should be available to the public in Washington, D.C. and at an appropriate office near the site of the unusual occurrence.

- form a central analysis group which would have the staff and resources to discover patterns in the data reported by companies handling hazardous materials. It makes no sense to require companies to go through the expense and trouble to submit annual operations reports and unusual occurrence reports if they are not going to be analyzed in sufficient depth so that serious malfunctions can be prevented. The Accident Analysis Branch in OHMO does not operate in this fashion. (See Chapter 17.)

- require OPSO to issue detailed standards for operating procedures and for operator qualification and training at LEG facilities. It should periodically review the operation of LEG facilities to see that they are meeting those standards.

- require OPSO to extend its regulations to cover intrastate LPG and naphtha pipelines, including connecting import terminals and storage complexes, affecting interstate commerce. GAO made this recommendation in its earlier report on pipeline safety, "Pipeline Safety—Need for a Stronger Federal Effort" (CED-78-99).

- require OHMO to promulgate standards for LNG vehicle design.

AGENCY COMMENTS AND OUR EVALUATION

Comment on Special Issue 5

The Department of Transportation asks:

> "How does one get from a 78 percent chance that one of three phenomena will occur at 1 of 100 facilities in 50 years to virtually certain (i.e., 100 percent chance) that design events will be exceeded a "large number" of times?"

Our finding that it is virtually certain that design events will be exceeded a large number of times during the lifetime of present large LEG facilities is based on our analysis in Chapter 3 of Uniform Building Code design standards, as discussed elsewhere in Special Issue 5. The 78 percent chance that one of three phenomena will occur at 1 of 100 facilities in 50 years applies to the stronger design standards in OPSO's Advance Notice of Proposed Rulemaking.

Comment on Special Issue 9 and 10

The Department of Transportation suggests that we delete the sentence, "Refrigerated LPG ships, however, can be single-hulled," because they say it implies that LPG ships are similar to conventional tankers and are somehow less protected than LNG ships.

We disagree. The sentence is accurate, and the implication that single-hulled vessels are less strong than those with double hulls is justified.

Comments on Recommendations

The Department of Transportation says that our recommendation--that OPSO issue standards specifying operating procedures, operator qualifications, and OPSO inspections of LEG pipeline facilities--is included in OPSO April 1977 Advance Notice of Proposed Rulemaking for LNG Facilities. DOT notes that additional detail may be appropriate and will be considered.

Our recommendation addresses LEG facilities, LPG as well as LNG. DOT does not describe any plans to promulgate similar standards for LPG pipeline facilities. We believe DOT should do so.

The Department of Transportation, commenting on our recommendation that OHMO promulgate standards for LNG vehicle design, states that these standards currently are being developed.

The standards (HM115 "Cryogenic Liquids") were originally published in the Federal Register as a Proposed Notice of Rulemaking in March 1974. Because of the volumes of comments, MTB revised the proposed notice to an Advance Notice of Proposed Rulemaking in September of 1974. MTB has not issued a new proposed notice since then.

REFERENCES

GENERAL CODES

NBC

The National Building Code—Recommended by the American Insurance Association, 1976 Edition.

UBC

Uniform Building Code—Enacted by the International Conference of Building Officials, 1973 Edition.

ASME

Section VIII of the American Society of Mechanical Engineers, "Rules for Construction of Pressure Vessels," Division I and II, 1974 Edition.

Section II of the American Society of Mechanical Engineers, "Material Specifications," Parts A, B, and C, 1974 Edition.

ACI

American Concrete Institute 311-64, "Recommended Practice for Concrete Inspection," 1964 Edition.

LNG CODES AND STANDARDS

NFPA 59A

National Fire Protection Association 59A, "Liquefied Natural Gas Storage and Handling," 1972 and 1975 Editions.

API 620

American Petroleum Institute 620—"Recommended Rules for Design and Construction of Large, Welded, Low-Pressure Storage Tanks," (1977). Appendix Q - LNG.

NY STATE PSC

State of New York Public Service Commission, Case 26180—"Liquefied Natural Gas," 16 NYCRR, Part 259 and revised draft.

NY—1976 LAWS

New York Liquefied Natural and Petroleum Gas Act of 1976.

MASS DPU

Massachusetts Gas Distribution Code, Section 5, Department of Public Utilities, 1972 Edition.

NYCFD

New York City Fire Department, "Rules and Regulations Governing the Manufacture, Storage, Transportation, Delivery, and Processing of Liquefied Natural Gas," 1977 Edition.

API 2510A

API 2510A, "Design and Construction of LNG Installations at Petroleum Terminals, Natural Gas Processing Plants, Refineries and Other Industrial Plants."

LPG CODES AND STANDARDS

NFPA 58

NFPA 58, "Liquefied Petroleum Gases, Storage, and Handling," 1976 Edition.

NFPA 59

NFPA 59, "Liquefied Petroleum Gases at Utility Gas Plants," 1976 Edition.

API 2510

API 2510, "Design and Construction of LP-Gas Installations at Marine and Pipeline Terminals, Natural Gas Processing Plants, Refineries and Tank Farms," 1970 Edition.

CAL-PUC

California Public Utilities Commission Order 94-B.

FLA-FIREM

Florida Rules of the State Fire Marshal - LPG.

GA-FIREM

Georgia Rules of the Safety Fire Commissioner - LPG.

ILL-LPG

Illinois Liquefied Petroleum Gases - Rules and Regulations.

LA-LPG

Louisiana Liquefied Petroleum Gas Commission.

MASS-DPU

Massachusetts Department of Public Utilities.

MISS-MV

Mississippi Motor Vehicle Comptroller Liquefied Gas Division.

NM-LPG

New Mexico Liquefied Petroleum Gas Rules and Regulations.

SD-DPS

South Dakota Rules of the Department of Public Safety LPG.

NJ-AC

New Jersey Administrative Code-Liquefied Petroleum Gas.

NY - 1976 LAWS

New York Liquefied Natural and Petroleum Gas Act of 1976.

PA-DLI

Pennsylvania Department of Labor and Industry Liquefied Petroleum Gas.

TX-RRC

Texas Railroad Commission Rules and Regulations Division II.

WISC-AC

Wisconsin Administrative Code Liquefied Petroleum Gases.

NAPHTHA CODES AND STANDARDS

NFPA 30

NFPA 30 - "Flammable and Combustible Liquids Code," 1976 Edition.

CAL-PUC

California Public Utilities Commission Order 94-B

CONN-SP

Connecticut Commission of State Police Flammable Liquid Regulations.

FLA-FIREM

Florida Rules of the State Fire Marshal Flammable or Combustible Liquids.

IND-FIREM

Indiana Rules of the State Fire Marshal Flammable Liquids.

MASS-DPU

Massachusetts Department of Public Utilities Fire Protection Regulations.

MICH-FLAM

Michigan Flammable Liquids Regulations.

PA-SP

Pennsylvania State Police Regulations - Flammable Liquids

PR-FS

Puerto Rico Fire Service: Storage and Handling of Flammable Liquids.

CHAPTER 17

FEDERAL REGULATION OF LEG TRUCKS AND RAILCARS

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TRUCK REGULATIONS

Introduction

Several offices in the Department of Transportation (DOT) are responsible for setting and maintaining safety standards for interstate trucks carrying liquefied energy gases. The Interstate Commerce Commission (ICC) is also involved, since only it can revoke or suspend the certificates of interstate carriers found to be unsafe.

The diffusion of responsibility among several agencies and a lack of effective administration have hampered the formulation of uniform safety standards and have made enforcement difficult in three significant areas:

- the design and reliability of equipment;
- the safeguarding and control of LEG as it is loaded, transported, and unloaded; and
- the qualifications of LEG truck drivers.

Three DOT organizations are concerned with interstate LEG trucking.

- The Federal Highway Administration (FHWA) administers the provisions of the Motor Carrier Act of 1935 (49 U.S.C. 304) regulating qualifications and maximum hours of service of employees, and safety of operation and equipment.

- The National Highway Traffic Safety Administration (NHTSA) administers the National Traffic and Motor Vehicle Safety Act of 1966 (15 U.S.C. 1381 et seq.), under which safety standards for trucks and trailers are promulgated.

- The Materials Transportation Bureau's (MTB) Office of Hazardous Materials Operations (OHMO) prescribes regulations under the Transportation of Explosives Act of 1908 (18 U.S.C. 831-835) and the Hazardous Materials Transportation Act (49 U.S.C. 1801 et seq.), regulating the packaging, handling, and routing of hazardous materials.

By successive delegations from the Administrator of the FHWA, the Director of the Bureau of Motor Carrier Safety (BMCS) issues federal motor carrier safety regulations and enforces those of the MTB relating to transportation of hazardous materials by highway.

Federal Highway Administration,
Bureau of Motor Carrier Safety

The FHWA is responsible for reducing interstate commercial vehicle accidents, fatalities, injuries, and property losses. The Administrator has delegated responsibility to the BMCS to issue regulations applying to drivers, facilities, and the operational safety of motor carriers used in interstate transportation.

The Regulations Division of BMCS makes new safety regulations and modifies old ones. Its Compliance Division may intervene before the ICC, asking for the revocation or suspension of the certificates of carriers violating regulations.

BMCS and FHWA share responsibility for the 128 BMCS inspectors who monitor more than 160,000 carriers and 3,000,000 motor carrier vehicles. They work under the supervision of Directors of Regional Motor Carrier Safety Offices and make inspections only at terminals or at highway inspection stations, checking trucks which look or sound faulty. In 1974, 21 percent of the vehicles inspected were so unsafe that they were declared out-of-service.[1]

Of 4,112 violations reported in 1976, only 41 involved trucks carrying "flammable compressed gases", a category which includes LPG but not LNG.

The Regional Motor Carrier Safety Directors who supervise the inspectors have qualified as "hazardous materials specialists" through in-house programs. Most inspectors were formerly truck drivers or police officers, and some have formal training in transportation, business administration, or public administration. None have science or engineering degrees or formal training in the properties of cryogenic materials.

Carriers found in violation of safety regulations are fined. Those with repeated violations, about 20 carriers per year, are required by the FHWA to set up internal safety organizations. Inspectors check on compliance the next time they visit a terminal of the carrier involved.

The ultimate sanction on carriers is revocation of their permanent ICC certificates. The FHWA has recommended revocation eight times in five years, but none of the eight certificates were revoked by the ICC. At the FHWA's request, the ICC did refuse to renew "temporary authority" or "emergency temporary authority" certificates for 140 carriers between July 1, 1975 and June 1, 1977, on the basis of "unsatisfactory reports" filed by the BMCS.

In March 1973, the BMCS sent out an Advance Notice of Proposed Rule Making on repair and maintenance of motor carrier vehicles. These proposed rules would require pre-trip and post-trip equipment inspections for all interstate trucks, written records of inspections, retention of such records in the vehicles for 30 days, and correction of any safety-related deficiencies prior to operation.[2] The BMCS then hired the University of Michigan's Highway Safety Research Institute to study the effectiveness of preventive maintenance. The study concluded that interstate motor carrier vehicle inspection and preventive maintenance can reduce accidents.[3] The BMCS issued the Notice of Proposed Rule Making on April 5, 1977. After nearly five years, BMCS still has not incorporated these requirements into final rules on motor carrier repair and maintenance.

National Highway Transportation Safety Administration

NHTSA has jurisdiction over safety performance standards for trucks and trailers. Its Office of Crash Avoidance (OCA) has issued standards for tires and brakes. However, these were tested only on trucks carrying the maximum allowed loads, and their effectiveness on overloaded trucks is not known. Our examination of bills

of lading indicates that propane trucks are sometimes overloaded during seasons of high demand.

The brake regulations authorize anti-skid and anti-locking "121" systems, but BMCS has not been able to inspect for compliance because it has not published its procedures for such inspections. Only "courtesy" inspections of the NHTSA brake regulations are planned through 1978.

NHTSA has not:

- Set standards for under-ride protection to prevent automobiles from going under trailers.

- Crash-tested tank trailers.

Office of Hazardous Materials Operations

The Office of Hazardous Materials Operations (OHMO), in DOT's Materials Transportation Bureau (MTB), has authority to issue regulations governing the manufacture and use of LEG shipping containers. OHMO sets standards for packaging, handling, and routing, and for personnel qualifications and training requirements. It establishes criteria for inspections and for equipment for the detection, warning, and control of hazardous materials. Through the Secretary of Transportation, it may conduct investigations and hearings, issue subpoenas, and compel disclosure of documents.

Section 109(d) of the Hazardous Materials Transportation Act requires the Secretary to maintain facilities and staff to provide, within the Federal

Government, the capability to evaluate risks involved in the transportation of hazardous materials, and to conduct a "continuing review" to determine procedures necessary for the safe transportation of hazardous materials.

The standards for LPG trailers, however, were developed before OHMO was established and no LNG trailer standards have been issued. Instead of permits, OHMO issues "exemptions" to LNG trailer manufacturers and transporters. Manufacturers' applications for exemptions contain engineering drawings, but transporters do not state proposed routes, even though OHMO has the power to regulate routing. The engineering drawings are considered trade secrets and are not available to the public. Renewal of exemptions appears to be almost automatic. No application for renewal has ever been denied, but modifications have sometimes been imposed as a condition of renewal.

Each transporter applicant must instruct its drivers in procedures to prevent or control overpressurization during prolonged shipping delays, but the transporters themselves decide the procedures.

OHMO's compliance staff has only three professionals and a secretary. Three lawyers from the DOT General Counsel's Office have recently been assigned to help, permitting OHMO to begin enforcement efforts for the first time. Occasionally it inspects plants manufacturing pressurized cylinders.

OHMO's Accident Analysis Branch has five professionals and one secretary. It receives, processes, and stores reports on the "release of hazardous materials." Such incidents range from the spilling of hot fluid

concrete to the release of poisonous or explosive gases. The branch spends most of its time responding to requests for routine information from DOT personnel and from carriers settling damage claims.

About 1,500 reports of hazardous material releases are received monthly, very few of which involve LEG. Reports are required by regulation, but the branch head estimated that only one-tenth of the actual instances are reported. (See Chapter 7.)

OHMO has only three persons with technical competence in cryogenic areas. Only one of them is available for monitoring work. Only 250 inspections of trucks carrying hazardous materials were conducted in 1976.

Driver Qualifications

FHWA regulations require road tests and physical examinations for all interstate truck drivers. Each driver must furnish the carrier with a written history of his driving, and the carrier must investigate it within 30 days of his employment. Thorough physical examinations are given at 2 year intervals.

Drivers must either take a road test or have a state license for the category of vehicle to be driven. The requirement that drivers also take a written examination is misleading. The Federal Motor Carrier Safety Regulations state that:

> The objective of the written examination is to instruct prospective drivers in the rules and regulations established by the Federal Highway Administration pertaining to commercial vehicle safety. It is an instructional tool only, and a person's qualifications to drive a motor vehicle under the rules in this part are not affected by his performance on the examination. . .

In other words, even if a driver answers every question wrong, he is issued a license.

Intermittent or temporary drivers are excused from the written test, road test, and background test, but they must meet the physical requirements.

The limited data available suggest that drivers of hazardous materials trucks may work longer hours than those handling general cargo.[4]

RAILCAR REGULATIONS

Safety regulation of LPG rail transportation is the responsibility of DOT, acting through the Federal Railroad Administration (FRA) and through OHMO within MTB. Economic regulation and certification for entry into the interstate railroad industry remains with the ICC. LNG is not moved by rail.

OHMO - Federal Railroad Administration

The FRA has general authority to investigate the safety compliance of any applicant seeking railroad carrier operating authority from the ICC. The FRA's safety regulatory authority covers: safety appliances and equipment, safety methods and systems, and hours of service

of employees. The FRA administers the Federal Railroad Safety Act of 1970 (45 U.S.C. 421 et seq.) to reduce accidents, deaths, injuries, and property damage by prescribing railroad safety rules and standards to supplement existing laws. The Act declares that laws, rules, regulations, and orders shall be nationally uniform to the extent practicable.

The FRA's own safety regulations cover locomotive inspection, hours of service of employees, operating rules, accident reporting, and standards for safety appliances, power brakes, track safety, and freight car safety.

OHMO prescribes rules under the Transportation of Explosives Act of 1908 and the Hazardous Materials Transportation Act. These acts authorize regulation of the shippers and manufacturers of containers used in or affecting interstate transportation of hazardous materials, including their packaging, labeling, handling, and routing. There are regulations that specifically address LPG railroad tank car design and operation requirements.

Hazardous Materials Division

The Federal Railroad Safety Authorization Act of 1976 divides the FRA on a geographical basis into no fewer than 8 safety offices to administer all federal railroad safety laws. The FRA has authority to issue an order prohibiting further use of any facility or piece of equipment in an unsafe condition involving a hazard of death or injury. For enforcement, the FRA has established a Hazardous Materials Division (HMD) which has 18 full-time inspectors and also uses the FRA's 180 general railroad inspectors on a part-time basis. Pursuant to Federal regulations (49 CFR

179.3-179.5), HMD and the Association of American Railroads (AAR) work closely together on tank designs and testing, and on developing regulations.

Chapter 8 deals with the hazards of LPG rail shipments and the effectiveness of regulations.

FINDINGS

TRUCK REGULATIONS

- The Interstate Commerce Commission has never revoked a permanent certificate because of a Federal Highway Administration request.

- Nearly five years after its Advance Notice of Proposed Rule Making on repair and maintenance of commercial vehicles, the Bureau of Motor Carrier Safety has not promulgated final rules.

- The National Highway Transportation Safety Administration has not:

  - o been able to inspect for compliance with its anti-skid and anti-locking brake systems regulations, because it has not published its procedures for such inspections.

  - o set standards for under-ride protection.

  - o crash tested tank trailers.

- The standards for LPG trailers were developed before the Office of Hazardous Materials Operations was established and no LNG trailer standards have been issued.

- The Office of Hazardous Materials Operations:

- issues "exemptions" instead of permits to LNG trailer manufacturers and transporters. No application for renewal of an exemption has ever been denied, although modifications have sometimes been imposed as a condition of renewal.

- receives about 1,500 reports of hazardous material releases monthly, very few of which involve LEG. Reports are required by regulation, but the head of the Accident Analysis Branch estimated that only one-tenth of the actual instances are reported.

RECOMMENDATIONS

TO THE SECRETARY OF TRANSPORTATION

We recommend that the Secretary of Transportation:

- Develop standards for hazardous material trailer manufacturers which would complement the standards for shippers and enforce both with the same inspection and compliance apparatus.

- Impose harsh penalties on companies that fail to report hazardous material releases.

TO THE CONGRESS

We recommend that the Congress enact legislation to protect drivers from discharge or discrimination on account of information or complaints they provide DOT. Drivers are now largely excluded from protection under the Occupational Safety and Health Act of 1970 (29 U.S.C. 660(c)).

AGENCY COMMENTS AND OUR EVALUATION

The Department of Transportation says:

> "As noted in this chapter and in Chapter 7, there are very few inspectors for hazardous materials tank cars and trucks. Considering the number of Coast Guard inspectors per ship carrying hazardous materials, it is strange that Chapter 6 calls for more Coast Guard personnel, but Chapter 17 does not do likewise for the other modes. Similarly, more training of Coast Guard inspectors is called for. yet no recommendation is made for FHWA or FRA."

LNG ships carry 3,000 times more liquefied gas than LNG trucks, and the new LPG ships carry 650 times more LPG than railcars and 1,800 times more LPG than trailer trucks.

REFERENCES

1. BMCS Notice of Proposed Rule Making, April 5, 1977.

2. Docket MC-48, 39 Federal Register 7127.

3. Effect of Commercial Vehicle Systematic Preventive Maintenance on Specific Causes of Accidents, University of Michigan Highway Safety Research Institute; July 1975.

4. Canyon Research Group, Inc. "A Nationwide Survey of Truck and Bus Drivers," BMCS Contract NO-DOT FH-11-8817.

CHAPTER 18

THE FEDERAL POWER COMMISSION

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INTRODUCTION

This chapter discusses the former Federal Power Commission's (FPC) role in assessing the safety of proposed LNG projects. The FPC has inadequately assessed the hazards of LNG shipping and storage. Safety issues have been considered on a case-by-case basis and have often been overshadowed by economic considerations. Decisions are based on evidence presented at formal hearings, at which the FPC staff testifies. The staff's testimony has often been based on insufficient independent investigation. The FPC has been disbanded, and its functions have been assumed by the Federal Energy Regulatory Commission (FERC) and other parts of the Department of Energy (DOE). This chapter is written in the present tense, as if the FPC still existed, to make it easier to read.

The FPC has statutory jurisdiction over the sale of natural gas in interstate commerce for resale. It also has statutory jurisdiction over interstate pipeline transportation and importation of natural gas. This includes authority over the site, design, construction, and operation of liquefied natural gas import and export terminals, storage facilities, and pipelines in interstate commerce.

FPC's authority to assess the safety of proposed projects is derived from provisions in the Natural Gas Act and the National Environmental Policy Act. See Chapter 11. This authority was not diminished by the Natural Gas Pipeline Safety Act of 1968, Public Law 90-481, 49 U.S.C. 1671, et seq. That Act led to the creation of the Office of Pipeline Safety Operations in the Department of Transportation. The legislative history includes the

statement that:

> ". . .The Federal Power Commission presently has exercised certain safety regulatory authority over interstate transmission lines under the Natural Gas Act. The Commission considers and takes action on some elements of the safety of transmission proposals in acting on applications for new or extended authority and it is not intended that the passage of this act will diminish that authority and responsibility of the Commission. In order, however, that the Commission not be placed in the position of having to determine whether the construction and operation details of a proposed service conform to the {DOT} Secretary's standards, an applicant may certify to this effect and the certification will be conclusive on the Commission. . . .It is not intended by the committee that this process of certification of compliance with the Secretary's standards will bar the Commission from continuing to consider safety in the same fashion it presently does in connection with awarding certificates of public convenience and necessity."[1]

Later amendments to the Act left the FPC's safety responsibilities intact. (See conference report on Natural Gas Pipeline Safety Act Amendments of 1976, H.R. Rep. No. 1660, 94th Cong. 2nd Sess. 7.)

The Commission's control is limited, both in law and practice. It has no authority over intrastate facilities, including most peakshaving and satellite storage facilities. LPG facilities do not come under FPC jurisdiction, and only those LPG facilities that are part of an interstate pipeline are regulated by OPSO. Thus, many large LEG facilities are not regulated by either agency. Large LPG import terminals have been built without any Federal assessment of siting and safety, even though in most situations, for a given volume, LPG is more dangerous than LNG.

The Commission's major concern in LNG commerce has been economic, in accordance with its statutory mandate. It has focused on rate questions and on the certification of large, import facilities, built for deepwater shipping.

It has not prepared Environmental Impact Statements for all peakshaving facilities under its jurisdiction. Further, it has not considered the public risks from trucking LNG to and from the storage sites it licenses and it has not fully considered shipping hazards.

Until March 1978, the only LNG import facility in operation was at Everett, Mass. It has operated for seven years without final certification. An Administrative Law Judge has ruled that its design and operation are safe, but the Commission has never made a final safety finding.

The FPC has issued certificates for new major import terminals at Cove Point, Md.; Elba Island, Ga.; and Lake Charles, La. The Cove Point terminal began operating in March, 1978, and the Elba Island terminal is expected to begin operating later in 1978. Applications are pending for facilities at Everett, Mass.; Providence, R.I.; Staten Island, N.Y.; West Deptford, N.J.; Port O'Connor, Tex.; Ingleside, Tex.; and Point Conception, Cal. In November, 1977, Western LNG Terminal Associates amended its applications, shifting all its proposed receiving terminal sites to Point Conception, Cal.

HEARINGS

Under 18 CFR 1.4(d), the Commission staff is not allowed to privately discuss a case with persons who are parties to proceedings before the Commission. This

precludes private discussions with intervenors such as states, local governments, and citizen groups. On March 11, 1977, the FPC amended its rules to allow ex parte communications between the staff and intervenors and applicants, but these are limited to requests for data and information. The staff may discuss a case in a technical conference, but only upon notice to all parties.

The limitations on staff contacts do not apply until a formal application has been filed. The staff often discusses possible applications for a year or more before they are filed. The staff justifies such pre-filing conferences on the ground that they ensure the filing of a more complete application, minimize piecemeal staff review of often interconnected issues, and avoid regulatory delays. During this period, however, outside parties have no notice that a project is being planned. They learn of an application only when it is announced in the Federal Register. As a result, they may not have enough time to adequately prepare for hearings.

The time and expense necessary for public participation is further increased because:

"It is the Commission's practice to hold formal hearings under the Natural Gas Act in Washington, D.C. Occasionally the Commission has, upon motion of a party, decided to add local hearing sessions," in communities in which LNG facilities are planned, but most witnesses who appear at them make "statements of position" which are not "evidence of the facts asserted" under the Commission's rules and "cannot be used by the Commission in arriving at its decision." The Commission has said that the purpose of such hearings generally is to allow "local citizens to

express their views by statements of position or to present sworn testimony if they so desire."[2] Such local hearings were held on the Everett, Staten Island, and Racoon Island projects.

THE FPC STAFF

Despite the complex and highly technical issues which must be considered in LNG applications, the primary responsibility for these cases is carried out by only four professionals in the Bureau of Natural Gas (BNG) and five lawyers from the Office of the General Counsel. There is also input from the Office of Pipeline and Producer Regulation (OPPR), including its Environmental Evaluation Branch; the Office of Regulatory Analysis, and the Office of Chief Accountant.

The BNG staff and the FPC lawyers prepare and present evidence considered at formal hearings of LNG applications. The two groups are responsible for developing, analyzing, and presenting data in legal, economic, and technical areas, including safety. BNG shapes the presentation. The five lawyers present witnesses, conduct cross-examinations, and write briefs, but have only a small role in the framing of issues and the selection of witnesses.

The small staff often has unreasonable burdens placed upon it. For example, in the Pacific Indonesia hearing on a proposed facility at Oxnard, California, one attorney wrote briefs on all economic and social issues in 45 days. He addressed questions on maritime transportation contracts and rates; financing and costs of service for the proposed facility; the proper rate treatment and market for imported

LNG; FPC jurisdiction over foreign commerce; and environmental impact and public safety.

THE BUREAU OF NATURAL GAS

The BNG Accident Model

BNG first devoted significant attention to LNG in 1973, when Eascogas applied for certification of an LNG import facility on Staten Island, in New York City. A staff physicist and a consultant statistician developed, with some assistance from the Coast Guard, a general concept of a "maximum, credible shipping accident," and that model, with small modification, is still in use. The BNG has not developed models for other types of LNG facility failure because it feels the danger involved in a "maximum, credible shipping accident" is much greater than in any other. As discussed elsewhere in this report, we do not agree.

The BNG model does not consider:

- Accidents involving trucks at the terminal.
- Accidents involving the terminal itself.
- Sabotage.
- The possibility that the gaseous plume could detonate.

- The possibility that the plume density might vary from point to point. The model's plume dispersion component, based on Coast Guard analysis but later modified by the staff, has never been validated in a wind tunnel nor through large-scale experimentation. The Coast Guard does not endorse these models.

By expressing the risk from a shipping accident in terms of the risk per person per year, the BNG model obscures the total number of possible fatalities and the effect of the density of people and structures. These factors are buried in the BNG calculations. This approach makes it difficult to distinguish between the risks to large and small communities. The risk per person per year could be roughly the same, but the total impact of an accident on a highly populated area would be much greater.

The model of a ship accident is too narrow. It assumes that:

- No more than one LNG tank on a ship will rupture.

- The single rupture will not set in motion the release of flammable or poisonous substances from nearby vessels.

- There will be no secondary fires.

The staff has not analyzed the sensitivity of its model to variations in input and assumptions.

Support from Other Agencies

The Bureau of Natural Gas has relied on the Coast

Guard, the Environmental Protection Agency, the Bureau of Mines, and the National Bureau of Standards for scientific and technical assistance.

The National Bureau of Standards (NBS), a principal source of support, depends in its reviews on plans submitted by applicants and the application of relevant codes and specifications. The NBS review assumes all standards, codes, and regulations are adequate and will be complied with and that the plant will be properly operated.

NBS reviews do not consider plume dispersion, sabotage, or very large spill containment. No explicit fault-tree analysis is made.

The NBS reviews we have read are competent, but far too limited in scope to be a substitute for adequate FPC staff work and procedures. NBS recommends that semi-annual reports be made to FPC after operations begin. While routine operations summaries are probably not needed more than once a year, a system should be set up which requires companies to report any unusual occurrences within 48 hours to the Office of Pipeline Safety Operations. (See Chapter 16.)

Criticism from Other Agencies

BNG's technical work has been criticized by other agencies as inadequate. In one case BNG first favored construction of a terminal facility in the Delaware Valley[3] and then reversed itself after other Federal agencies sharply criticized its draft Environmental Impact Statement (EIS). The Energy Research and Development Administration (ERDA) said the BNG study on vapor cloud plume dispersion

"failed to evaluate the hazard realistically and to consider the characteristics of the terrain."[4] The Nuclear Regulatory Commission (NRC) said the draft EIS "neglected impacts on nearby nuclear power stations and inadequately considered possible alternatives in design and site." The NRC criticized the evaporation rates as "much lower than those reported by the American Petroleum Institute for smaller test LNG spills." It said BNG's risk analysis "obscures the obvious fact that it is safer to conduct LNG traffic in areas of low population than in cities."[5] The Environmental Protection Agency (EPA) said the BNG's final EIS "seriously underestimates the hazards of LNG shipping on the Delaware River" and did not consider the possible effects on a nearby oil refinery nor on the ship traffic to another proposed LNG terminal nearby. EPA said the final EIS ignored local accident histories, low channel depths, the possibility that the LNG ship itself might catch fire, tanker explosions, and the differences between spilled oil and spilled LNG.[6]

The Navy filed major criticisms of the BNG draft EIS on the Oxnard site. It noted that since no ship plans were available the "determination of the safety of the proposed operation. . .with any exactness" is difficult. It expressed the hope that the Commission would be "conservative in evaluating opinions and information not clearly supported by factual data." It pointed out that the Commission's vapor cloud propagation and thermal radiation models appeared to be less conservative than other models, such as the one used in the Coast Guard LNG/LPG Contingency Plan for the Port of Boston. (The Commission's predicted flammable vapor dispersion range was a tenth to a hundredth of other model ranges.)

The Navy also pointed out that by BNG's own figures, "8.5 times as many people could be killed as the result of a major accident at Oxnard. . .(as at). . .Point Conception." It also noted that the possibility of sabotage had not been considered.

In the Pacific Indonesia case BNG rejected a State of California study which concluded that an LNG accident at Oxnard could result in a great number of deaths.[7]

The staff argued that the study should be ignored since it had not been introduced into evidence.

Under the hearing rules the staff could have asked the Administrative Law Judge to reopen the hearing to admit the study as evidence. Instead they argued that he should not, and he didn't. In a matter involving human safety, we have reservations whether the staff's action evidenced disinterested concern for the protection of the public.

Examples of Inadequate Technical Work

On September 17, 1974, the Western LNG Terminal Company applied for a certificate to build receiving, storage, revaporization, and send-out facilities at Point Conception, Los Angeles, and Oxnard, California. The Oxnard and Los Angeles sites are near heavily populated areas. Point Conception is in an area of very low population density. An FPC staff brief recommended, in consonance with the California Coastal Act of 1976, that only one of the three facilities be built initially. It selected Oxnard, contending that safety risks there were "of an acceptable level." Although the final EIS also noted that the facility would be tied to the Oxnard

Municipal Sewer System[8], it did not consider that the site is adjacent to the city's sewer plant where large quantities of chlorine are stored, or that LNG might flow into the system after an accident. Every building in Oxnard is connected to the sewer system, and since natural gas is highly explosive in sewers and houses, a large quantity of LNG or natural gas in the system could cause a disaster.

The final EIS dismissed the possibility of two on-shore tank failures at the same time as "out of the realm of possibility" although for some causes, such as earthquake, flood, high winds, or sabotage, the probability of multiple tank failure is not much less than the probability of a single tank failure.

In the hearing on the Eascogas Staten Island facility BNG concluded that an oil tanker spill was twenty-five times as likely as an LNG spill.[9] They decided this on the basis that LNG tankers were five times more carefully constructed and that LNG ship spill risks could be reduced by another factor of five because LNG tanker crews exercised "extra navigational care and safety precautions."[10] These factors of five were chosen arbitrarily, without consultation with the Coast Guard, for example, and cannot be rigorously supported. In Chapter 6 we discussed many needed improvements in LNG ship design research, training requirements, and operational controls.

BNG has not adopted uniform site selection and facility operation criteria, in spite of a petition from several state governments that they do so. The petition, which asked the Commission for a rule-making proceeding to "promulgate and adopt uniform site selection and facility

operation criteria standards for Liquefied Natural Gas marine storage terminals", was signed by the Attorney General of the State of New Jersey, the Public Advocate of New Jersey, the Attorney General of the State of New York, the Attorney General of the Commonwealth of Pennsylvania, the Attorney General of the State of Delaware, the Township of Woodbridge, New Jersey, and U.S. Representative John M. Murphy. The Commission has failed to rule on the petition.

Without uniform standards, terminal site safety is determined on a case-by-case basis. In the final EIS on the Everett facility, which is already constructed in an urban area, BNG concluded that since the facility has already been built (before FPC certification was required), a discussion of alternatives "would be fruitless to pursue."

In this regard, we are not aware that the FPC staff has ever considered the alternative of using only non-urban sites to receive all LNG imports and developing a gas exchange program using existing pipelines to ensure appropriate distribution of gas supplies. In Chapter 15 we show that non-urban terminals have the capacity to handle the needed quantities.

Under present law the FPC (and its successors in DOE) have no power to require operating LNG terminals to expand to handle new LNG supplies. This prevents the complete consideration of alternative sites for new LNG imports.

For example, in the final EIS for the El Paso Matagorda Bay Project, FPC said that the terminals at Cove Point, Maryland and Elba Island, Georgia "would be well

suited to expansion because more than enough land would be available and disruption to other shipping caused by the additional LNG carrier traffic would be minimal." The possibility of bringing the LNG into Cove Point or Elba Island instead of into Matagorda Bay was rejected, however, because ". . .barriers could exist since El Paso owns neither these terminals nor the gas distribution systems to which they are connected".[11]

Such barriers would be insufficient to bar the use of suitable sites if DOE had the power to require certificated sites to expand to handle new material—as long as expanded use could be carried out economically and with adequate safety.

The nation's ability to pick the best sites for LEG imports, and to avoid storing and transporting large quantities of LEG in densely populated areas, is seriously impaired because already chosen sites cannot be required to serve new customers. This requirement is one that all common carriers must observe.

ADMINISTRATIVE LAW JUDGES

The key figure in LNG safety matters is the Administrative Law Judge (ALJ) who writes the Initial Decision recommending approval or disapproval of an application. None of the safety findings in Initial Decisions on LNG facilities has been questioned in Final Decisions issued by the Commission.

ALJ's rely on the staff for technical assistance. At any stage of a hearing an ALJ may call for further evidence from any parties involved or from the staff, but the record

shows that in the FPC this prerogative is seldom used in LNG cases.

Adequate resolution of complex safety issues requires a process which insures that adequate evaluation and input is obtained from technically qualified persons. ALJ's are not expected to have such a background themselves and our review of published decisions indicates that serious questions exist regarding the adequacy of technical input under the current FPC process.

We have discussed the need for technical input and background with some of the ALJ's. We believe their opinion can best be summarized by a statement in the Initial Decision handed down on June 28, 1977, in the Distrigas hearing. After noting that it had been suggested that "scientists are more able to make decisions, assumedly even in areas outside their expertise, than others," the ALJ responds:

> "Even granting that a number of scientists may begin the effort ahead of the decision-maker due to their previous scientific training, the record, including the scientific evidence, made for decision purposes is explicated in common English and the scientists' advantage, no matter what it may have been at the commencement of the exercise, rapidly fades. Moreover, the decision-maker calls upon all parties to supply that information necessary for a complete record and relies upon the entire record."

Unfortunately, our review of FPC's published Initial Decisions show that adequate information to resolve inconsistencies and to provide a complete record is not always obtained. Many important questions are not raised by any party, and intervenors often do not have the time or money to do the research needed to question an applicant

properly. In an area of new technology such as LNG where there is little previous practical experience, it is difficult to make logical safety findings, even with a clear understanding of the evidence presented. If the evidence is misunderstood or misconstrued, accurate findings are impossible.

The demonstration of safety in LNG cases is usually done on the basis of probabilistic arguments. What may seem obvious, or "common English," to an untrained person may be incorrect or imprecise or both. The uncritical acceptance by the ALJ of the LNG fatality probabilities estimated for the proposed Oxnard terminal illustrates this.

In a report prepared for the Western LNG Co.'s application, Science Applications, Inc. (SAI) stated that: "The probability of electric shock fatalities in electrically wired residences is 1 chance in 1 million per person, per year for the residential population served by electricity. Thus the fatality probability per person, per year, within 5/8th of a mile of the site (Oxnard) due to possible LNG accidents is only 15 percent of that for electric customers throughout the country from electric shock fatalities."[12]

In Chapter 12 we have shown that SAI's fatality probability estimate for persons living within 5/8th of a mile of the proposed site is not supported by the SAI's own analysis. Because neither the FPC staff nor the ALJ realized this, the evidence went unchallenged. What is more, the ALJ, in paraphrasing SAI's estimate in his Initial Decision, misconstrued it. He said that the fatality probability per person, per year, for those within

the 5/8th mile radius "was about 7 times less than the risk to the same person of being electrocuted by faulty wiring when flicking a light switch in his residence." This distorts SAI's accurate estimation of the probability of electrical shock fatality and is completely wrong. Most shock victims in homes are children who are electrocuted while playing with plugs or electric toasters and persons doing their own electrical repairs. We have been unable to find a single case of a person killed "by faulty wiring when flicking a light switch in his residence."

The need for independent analysis by the FPC is illustrated by the following examples. The Initial Decision on the application for the facility at Everett, Mass., which has metal tanks, found that "the possibility of the type of accidental spill which would result in the formation of a vapor cloud capable of catastrophic destruction is extremely remote." The El Paso Alaska Initial Decision found that:

> "In order to achieve the large size vapor cloud necessary to create even measurable risks for people located some distance away, an assumption has to be made that a huge volume of LNG be released instantaneously, but that it be done by force which causes no spark to ignite the escaping vapor. The instantaneous spill can be envisaged as a Dixie cup filled with 10,000 cubic meters (a room about 70 feet wide x 70 feet long x 70 feet deep) suspended over the ocean. A large hand now removes the Dixie cup and the LNG whooshes of a sudden into the ocean. In other words, the risk analysis is not realistic; it is a textbook analysis since only in textbooks can one envisage the removal of the container, such as a ship's hold or the contents of a storage tank, in the manner proposed."

Since the staff did no independent analysis, it did not discover that the most likely mode of failure for many

metal tanks in the event of an earthquake, is tipping the inner tank, breaking the welds which seal the sides to the bottom, and spilling the contents as discussed in Chapter 3. Moreover, there is no evidence that LEG in a large spill would ignite on site, confining most damage there. Spilled LNG, as in Cleveland, may flow into sewers and basements before igniting and exploding. We have also shown in Chapter 9 that sabotage could cause a massive release of fluid. There is no evidence that the sabotage itself would necessarily ignite LEG vapors.

We are not aware that the staff or any ALJ has ever questioned whether any NFPA codes used in LNG facility design might be mistaken or inadequate, as we have shown them to be in Chapter 5.

The danger of sabotage has not been seriously considered by the FPC. The Initial Decision on importation of LNG from Indonesia commenting on the California Public Utility Commission's (CPUC) point that "risk assessment studies have not taken into consideration the possibility of sabotage or terrorist intervention," said:

> "SAI does not believe these risks can be quantified and no evidence was presented by any party, the CPUC or the Commission Staff on the matter. . .Applicants, aided no doubt by the appropriate authorities, will take all practicable measures to safeguard against sabotage and terrorist intervention. In any event, these risks which are probably miniscule, must not be permitted to defeat energy projects which are in the public interest and required by the public convenience and necessity."

We agree that these risks cannot be quantified, but the ALJ presented no argument and cited no evidence to justify his conclusion that the risks are "probably

miniscule." In response to a GAO inquiry about the basis for this and other conclusions in initial decisions, the FPC Chief Administrative Law Judge stated that ". . .our policy has always been that the initial decisions of the Administrative Law Judges speak for themselves."[9] We have not been able to find a logical basis for the assertion that the risks of sabotage are "probably miniscule". In Chapters 6, 7, 8, 9, and 16, we have shown that applicants, aided by appropriate authorities, do not take all practicable measures to safeguard against sabotage and terrorist intervention. To say that "in any event" the risks must not be "permitted to defeat energy projects which are in the public interest and required by public convenience and necessity" seems unreasonable. Since (1) alternative, non-urban sites are available, (2) the risk from sabotage cannot be even approximately quantified, and (3) the consequences are so great, it is unwise to build susceptible facilities in populated areas.

The threat to public safety from LNG ship accidents and from sabotage was similarly discounted in the Initial Decision on the Everett terminal:

> "Giant can openers do not rip open ship bottoms when docked, and if they do, they are not likely to do so without sparks that would ignite the fuel at its source. Nor do forces blow up facilities quietly or with spark-free explosives. . .whether from natural causes or sabotage."

We believe that if the FPC had developed a better system for assessing LNG safety, the problems we have raised would have been addressed and considered, rather than dismissed as impossible or unlikely.

FINDINGS

- The FPC has:

  - allowed LNG facilities to operate in large cities without adequately assessing the threat to the public from such facilities.

  - not sufficiently investigated the possibility that gas exchange programs would minimize the number of urban LNG terminals.

  - not considered the public risks from the trucks and not fully considered those of ships which make or take deliveries at LNG storage sites it licenses.

  - not prepared Environmental Impact Statements and safety analyses on all peakshaving LNG facilities under its jurisdiction.

  - not set uniform criteria for site selection and has failed to rule on a petition by the Attorney General of the State of New Jersey, the Public Advocate of New Jersey, the Attorney General of the State of New York, the Attorney General of the Commonwealth of Pennsylvania, the Attorney General of the State of Delaware, the Township of Woodbridge, New Jersey, and U.S. Representative John M. Murphy for a rule-making proceeding to "promulgate and adopt uniform site selection and facility operation criteria standards for Liquefied Natural Gas marine storage terminals."

- never questioned a safety finding in an Initial Decision.

- held almost all formal hearings in Washington, D.C., making it costly for affected local interests to participate fully. It is important for hearings to be held at a place which is convenient for the public in the area concerned rather than at one that is convenient for the Commission and its applicants. It is the public that will suffer the risk and is paying for the process and the results.

- The first public notice of applications for LNG terminals is the formal notice in the Federal Register, after applicants and the Commission staff may have discussed the proposed application at length. Interested outside parties do not have the opportunity during this period to prepare their positions on the project.

- Many large LEG facilities are not regulated by either the FPC or OPSO.

- The nation's ability to pick the best sites for LEG imports, and to avoid storing and transporting large quantities of LEG in densely populated areas, is seriously impaired because already chosen sites cannot be required to serve new customers. This requirement is one that all common carriers must observe.

CONCLUSIONS

The FPC system for approving LNG projects is clearly inadequate to protect the public health and safety. Some Initial Decisions on LNG projects have been based on safety findings which our research indicates are inaccurate. Where these Initial Decisions have been acted upon by the Commission, none of these safety findings has been questioned by the Commission in its opinions.

Judgments on public safety in an area of new, complex technology involve questions and answers which cannot be found in the published literature. The record indicates that such issues cannot be adequately handled with the level of knowledge, experience, and effort involved in the FPC process. The extent to which there will be any differences in regulation under DOE is unclear. If economic questions are included in the same process as safety questions, as in the case of LNG, fuzzy trade-offs between the two are inevitable.

Improvement in LNG regulation must be considered in the context of the nation's overall approach to energy regulation. In March 1977, GAO issued a report to the Congress on "Energy Policy Decisionmaking, Organization and National Energy Goals" (EMD-77-31, March 24, 1977).

In that report we stated our skepticism as to whether health and safety regulation could any longer be construed as truly "not economic" in nature. In LNG as in other areas, health and safety regulators decisions are likely to affect the cost and timing of facilities and to have significant impact on the options available to energy policy makers. We also pointed out the problems involved

in having regulation focus narrowly on the health and safety aspects of individual energy sources. We supported the idea of bringing together all energy health and safety regulatory functions so that the trade-offs of developing one form of energy as opposed to another could be considered. In the years ahead, such trade-offs will become increasingly important since almost all forms of energy development appear to have some form of adverse environmental and/or health and safety impacts.

In our earlier report, we provided three options for Congressional consideration in the reorganization of Federal energy regulation activities:

- Include energy regulatory functions--both economic and health and safety related--in the Department of Energy. Under this approach, economic and health and safety regulation could be separate entities, but both would fall under a single Assistant Secretary. Statutory provisions should be included to assure maximum insulation of regulatory decisions from the policy process.

- Include only economic regulation in the Department of Energy because of the perceived importance of establishing energy price regulatory policies which are consistent with other energy goals and consolidate health and safety regulation of energy in a separate independent Energy Health and Safety Regulatory Agency (EHSRA). Statutory provisions should be included to assure maximum insulation of economic regulation from the policy process.

- Continue to separate energy regulation—both economic and health and safety related—from energy policy formulation. Should this be done, we believe that the creation of a single energy regulatory agency is desirable. Such an agency could provide a forum for more carefully considering the trade-offs among problems involved in different forms of energy development.

Since our earlier report, the Department of Energy Organization Act transferred FPC's responsibilities to the new Department. No action was taken to consolidate energy health and safety regulatory activities.

The shortcomings in FPC's treatment of LNG safety questions point to the need for a single regulatory agency to consider the complex technical issues in energy health and safety and to balance the health and safety trade-offs among different energy sources.

Given the inadequate consideration of such issues under the administrative law process used by FPC, we believe the current NRC model would more likely ensure adequate and competent technical coverage of health and safety questions. A typical regulatory action in NRC with respect to a construction permit or operating license for a facility involves interaction among the Commissioners, the staff, Advisory Committee on Reactor Safeguards, Atomic Safety and Licensing Board (ASLB), and Atomic Safety and Licensing Appeal Board (ASLAB).

The ASLB and ASLAB work with three-man boards whose members have a variety of legal and technical skills relevant to the safety problems which come before them. No

individual Administrative Law Judge can have such breadth—and he must cover complicated economic issues as well.

With a mandate to adequately protect the public health and safety, EHSRA could assemble a technical staff competent to investigate complicated questions raised by others and to raise important new questions itself. It should be able to develop a higher technical level than the industries it regulates.

RECOMMENDATIONS

TO THE CONGRESS

We recommend that Congress consider creating an Energy Health and Safety Regulatory Agency (EHSRA) which could include the Nuclear Regulatory Commission; the pipeline safety aspects of transporting fuel on land, now handled by the Department of Transportation; the safety aspects of importing energy, now handled in the Department of Energy; and all safety responsibilities carried out in the past by the Federal Power Commission. For reasons discussed in Chapters 7, 8, 16, and 17, additional consideration should be given to including the safety regulation of liquefied energy gases transported by truck and train. (The Nuclear Regulatory Commission already has responsibility for the safe transportation of nuclear materials.) The Department of Transportation would continue to be responsible for all other safety regulation of motor carriers and railroads except those transporting nuclear materials and liquefied energy gases. The Environmental Protection Agency should retain the

responsibility for setting air and water quality standards, including those impacting energy development and use, and waste disposal.

The new agency could be completely independent of the Department of Energy (DOE), or included in DOE with strong statutory provisions to ensure its independence.

The recommendations in Chapters 7, 8, 16, and 17 should be carried out by the Secretary of Transportation and the Interstate Commerce Commission, if liquefied energy gases transportation safety is not included in an Energy Health and Safety Regulatory Agency, or if the agency is not formed.

OTHER RECOMMENDATIONS
TO THE CONGRESS

We also recommend that the Congress:

- enact legislation to require all large LNG and LPG facilities to get certificates of public convenience and necessity from the Federal Energy Regulatory Commission.

- enact legislation that allows the Department of Energy to require certificated sites to serve new customers—as long as the expanded use can be accomplished safely and economically.

NOTE: The following recommendations are intended only if an Energy Health and Safety Regulatory Agency is not formed, or until it is formed. The suggestions should be carried out by EHSRA if it comes in existence.

TO THE SECRETARY OF ENERGY AND
THE FEDERAL ENERGY REGULATORY COMMISSION

We recommend that the Department of Energy and the Federal Energy Regulatory Commission:

- hold most formal hearings for LNG facilities near the site of the proposed facility, rather than in Washington, D.C.

- announce in the Federal Register that they have held discussions on a possible LNG site, the first time such a discussion occurs, so that other interested parties can also talk to them early in the process. Such a notice should also be placed in newspapers in the locality involved.

- consider the public risks from the trucks and ships which make or take deliveries at LNG storage sites in considering applications for such sites.

- require a staff study of the feasibility of using only non-urban sites to receive all LNG imports and developing a gas exchange program using existing pipelines to ensure appropriate distribution of gas supplies.

AGENCY COMMENTS AND OUR EVALUATION

Department of Energy Comments

1. DOE states:

> "The draft report indicates, in several places, that economic considerations have overshadowed safety issues in FPC proceedings. The relative emphasis given to various issues depends, in part, on the project. In all cases, both environmental, including safety, and economic factors have, in the past, been given independent and major weight in FPC proceedings. . ."

GAO response:

Our statement that "safety issues. . .have often been overshadowed by economic considerations", is supported throughout the chapter:

- The FPC, like all Federal agencies, considers safety as part of its responsibilities under the National Environmental Protection Act. The courts have stated, however, that FPC's main responsibility under the Natural Gas Act of 1938, 15 U.S.C. 717 et seq., is economic. (Atlantic Refining Co. v. P.S.C. of N.Y., 360 U.S. 378 (1959).)

- Although the FPC frequently reverses economic findings in its Initial Decisions, it has never even questioned the safety finding in an Initial Decision.

- With regard to the dangers from possible sabotage of the facility, the Initial Decision on LNG from Indonesia says:

> "Applicants, aided no doubt by the appropriate authorities, will take all practicable measures to safeguard against sabotage and terrorist intervention. In any event, these risks. . .must not be permitted to defeat energy projects which are in the public interest and required by the public convenience and necessity."

To say that "in any event these risks. . .must not be permitted to defeat energy projects. . ." is an example of safety issues being overshadowed by economic considerations. The quote is discussed at greater length in the chapter.

- Safety issues are hardly mentioned in FPC Final Decisions. Even Initial Decisions typically devote only a small percentage of their discussion to safety problems.

2. DOE states:

> "Staff does not believe that the publication of notices is appropriate when an LNG site is discussed for the first time with staff (page 23). Notice would be premature because an application for a certificate might never be filed.

GAO response:

The public is paying for the FPC and the gas company. We believe the public has a right to know about any discussions the FPC is having with companies about possible

LNG sites. The fact that "an application for a certificate might never be filed" does not bear on the public's right to know.

3. DOE states:

> "Staff has advocated combined LNG terminal projects in a number of proceedings and has investigated the possibility that gas exchange programs would minimize the number of urban LNG terminals (also page 16). Three terminals have been proposed on the East Coast in urban areas. Since Everett, Massachusetts was the first urban terminal to be built, no exchange program with other LNG terminals was possible. The Providence, Rhode Island terminal is no longer a viable application; and the Staten Island, New York terminal is still in hearing and still under staff investigation."

GAO response:

The type of exchange program we have in mind would not be restricted to exchanging gas between LNG terminals, but rather among all companies in the interstate system. The FPC comment clearly shows that such general applications are not considered in evaluating LNG terminal applications.

4. DOE states:

> "The draft report asserts that the FPC has allowed LNG facilities to operate in large cities without adequately assessing the threat to the public from such facilities. Only one LNG import terminal has been allowed to operate in or near a large city--Everett, Massachusetts. . ."

GAO response:

Only two LNG import terminals are operating in the United States. Only one, Everett, was operating when the FPC sent its comments to GAO. More importantly, our statement was about all LNG facilities—most of which are peakshaving plants—not just about marine terminals. Our statement is true as it stands.

5. DOE states:

> "Staff has testified that the 'maximum credible shipping accident' for an LNG vessel is the rupture of one cargo tank. On numerous occasions the Coast Guard has also testified that the rupture of one cargo tank is the major credible accident for the LNG vessel. Staten Island LNG project (Docket Nos. CP73-47, et. al.). While staff presently believes that the rupture of one cargo tank remains the maximum credible shipping accident, it will continue to assess the probability of shipping accidents. . ."

GAO response:

We believe that LNG shipping is the strongest link in the entire LNG storage and transportation system. BNG's position is that non-shipping accidents are not even worth including in their risk assessment model. The whole report supports our position.

6. DOE states:

> ". . .Staff's general conclusion is that spills from equipment and/or storage tanks spills into diked areas pose little or no significant hazard off-site. . ."

GAO response:

At five of the six sites we examined, more than 50 percent of the fluid in the tanks can vault over the dikes if there is a sudden collapse or major rupture of the tank wall. See Chapter 5.

7. DOE states:

"With respect to safety analyses at specific sites, the draft report notes that the EIS on the Pacific Indonesia LNG Company project (Docket Nos. CP-74-160, et. al.) at Oxnard, California did not consider that the site is adjacent to the city's sewer plant where chlorine is stored or that LNG could flow into the system after an accident (page 10). The staff was aware of the location of the Oxnard sewage plant about 4,000 feet to the northwest of the proposed LNG facility area. The staff was also aware that only sanitary wastes from the LNG terminal would be pumped to the treatment plant through a closed pipeline system. No open sewers are involved. Further, the staff was aware that the LNG storage tanks would be enclosed by individual high-walled concrete dikes and that the perimeter service road around the LNG plant would provide a secondary means of diking. The staff recommended diking around the LNG unloading transfer lines. For these reasons, spills into the sewer system were not considered credible."

GAO response:

The following points are relevant:

- There are many entrances on the site to the closed pipe system leading to the sewer plant.

- An explosion or fire in or above the closed pipe system could lead to further large openings.

- Pleasant Valley Road runs only 4,600 feet from the tanks, and it has open storm sewers connected to the sewer plant and the entire city sewer system.

- The high-walled concrete dikes enclosing the storage tanks will be built to the same standards as the tanks, and thus would be vulnerable to failure from the same manmade or natural events. See Chapters 3 and 9.

- The nominal diking provided by the perimeter service road would have little effect on stopping any flow of LNG. See Chapter 5.

- We have no way to tell what the staff was aware of, but it is a fact that the EIS did not consider the nearby presence of storm sewers or the city sewer plant.

8. DOE states:

". . .the probability of ignition of the cloud approaches unity at a finite distance downstream. . ."

GAO response:

Since every distance is finite, FPC's comment seems true. It isn't, however, since the cloud may disperse below the flammable limit without igniting. More important, however, is the possibility that in a fairly strong onshore wind, the flame front may be blown through a city rather than burn back to the site of the spill. See Chapter 13.

9. DOT states:

> "We oppose the recommendation in the report for inclusion of the safety aspects of transporting energy fuels in a new Energy Health and Safety Regulatory Agency to be established in the Department of Energy (DOE). These safety functions are now carried out in the Department of Transportation (DOT) as part of an overall safety program devoted to the transportation of hazardous materials in general, including transportation by marine vessel. The risks posed by energy fuels are, in many cases, not dissimilar from other hazardous materials regulated by DOT which move in volume in interstate and foreign commerce. To separate and transfer the fuel aspects of the hazardous material program, when there are many benefits of a consolidated hazardous materials program in terms of regulatory and enforcement actions and R&D, would be inimical to an efficient, comprehensive and well coordinated national safety program."

GAO response:

Health and safety problems connected with the transportation of fuels can be considered under the categories of "health and safety", "energy", or "transportation". Because energy is currently one of our most critical problems, we suggest the creation of an Energy Health and Safety Regulatory Agency (EHSRA).

LNG importation and storage is largely regulated by DOE already and most R&D programs in energy--including many for energy transportation--are conducted by DOE or the Nuclear Regulatory Commission.

REFERENCES

1. H.R. Rep. No. 1390, 90th Cong., 2d Sess. 34,35 (1968). Similar language may be found in S. Rep. No. 733, 90th Cong., 1st Sess. 12(1967).

2. September 1, 1977 letter from the Secretary of the Federal Power Commission.

3. Applications to the FPC for an LNG terminal on Racoon Island, Delaware: Tenneco LNG Inc., CP 76-16, and Transco Terminal Co., CP 73-258.

4. ERDA Comments on the Federal Power Commission's Draft Environmental Impact Statement (DEIS), for proposed Racoon Island site, September 8, 1975.

5. NRC comments on the FPC's DEIS for proposed Racoon Island site.

6. Letter dated August 8, 1976, to the FPC from EPA, Region II.

7. Staff brief, p. 29.

8. Final Environmental Impact Statement, Pacific Indonesia Project, FPC Docket 74-160, December 1976.

9. Eascogas Hearing, 37 Tr. 4360.

10. Eascogas Hearing, 37 Tr. 4697 and 4709-10.

11. Final Environmental Impact Statement for the Matagorda Bay Project, FPC Docket CP 77-330, September, 1977.

12. SAI 75615LJ, December 22, 1975: LNG Terminal Risk Assessment for Oxnard.

CHAPTER 19

LNG USE IN JAPAN

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INTRODUCTION

While the United States is shifting from natural gas to coal, Japan, which imports almost all its energy, is moving from coal to LNG. Of all energy sources, only nuclear is projected to grow faster than imported LNG. LNG, which provided only .8 percent of Japan's total energy in 1973, will supply 5.2 percent in 1980 and 7.9 percent in 1985. Meanwhile, the use of coal and naphtha as natural gas feedstocks will drop sharply. By 1979, 44.3 million cubic meters of LNG will be imported annually, two-thirds by electric utilities and about one-third by gas utilities. The number of LNG storage tanks will increase from 46 in 1977 to 58 by 1979, with a total capacity of 3.5 million cubic meters. Appendix XIX gives statistical data on Japan's LNG receiving terminals, importation projects, and long-range energy supply and demand program.

While surveying Japan's facilities for importing, handling, and storing LNG, we visited major LNG import terminals and an LNG shipbuilding yard, and interviewed government and industry officials.

LNG TANKERS

Japan's imported LNG is now carried by foreign-built ships. For example, Cold Gas Trading Ltd. charters seven French-built, 75,000 cubic meter capacity tankers to haul LNG from Brunei. Kawasaki Heavy Industries is currently completing construction of Japan's first LNG carrier, a 128,000 cubic meter Moss Rosenberg design, the type produced by General Dynamics in Quincy, Mass. Kawasaki already builds semi-membrane LPG tankers which typically carry 60,770 cubic meters of propane and 15,188 cubic

meters of butane.

Harbor Safety

Before an LEG carrier over 25,000 gross tons can operate in Japanese ports, the ship's plans and a "Safety Assurance Statement" must be submitted to the Maritime Safety Agency (MSA). On its first trip, the tanker is inspected by MSA officials. Only the vessel's papers are checked on subsequent trips unless officials receive information warranting further examination. Smaller tankers require no inspection.

In some ports, pilots are not legally required. In the others, private harbor pilots, used at the captain's discretion, must be on board all LEG ships above a certain size.

LEG tankers coming into Tokyo Bay are met at the mouth by an escort boat, a fireboat, and tugboats. A 125,000 cubic meter LNG carrier requires three or four 3,000 horsepower tugboats. Smaller tugboats are often used for docking. A moving ship-free pocket system was dropped because as the number of LEG carriers increased, it began to disrupt the normal, congested ship traffic. Once a tanker is docked, the terminal managers decide whether a fireboat remains. Fireboats are equipped with powder and foam. In Tokyo Bay they are privately owned and licensed by MSA. MSA's own fireboats are stationed at Japan's six LNG ports, and operate jointly with the required private fireboats. The agency is responsible for all firefighting in smaller ports, but it lacks enough equipment to protect every harbor.

LPG has occasionally leaked from tankers, the spills in some cases igniting. When a spill does not ignite, safety officials keep traffic away until the LPG disperses. One striking incident occurred off the west coast of Japan in March 1976, when a 550 ton LPG tanker cracked open. Two pressurized tanks separated from the ship and floated away. A man climbed down a rope ladder from a hovering MSA helicopter and opened valves on both tanks so the LPG would evaporate before they could drift ashore.

Unloading Precautions

At the Tokyo Gas Company's Negishi Bay Terminal, an unloading LNG ship is connected to a control air duct that runs parallel to the LNG unloading arm. If the tanker moves more than 2 meters from the dock, this air duct will tear. Emergency cut-off valves at both ends of the unloading arm immediately close and the pump on the tanker stops.

The system seems simple, reliable, and effective, but questions have been raised. The automatic shutdown may put stress on the equipment because of liquid hammering in pipes and valves. Some LNG would be spilled in the shutdown since there would not be time to drain pipes and hoses. After such a shutdown, it would take a long time to resume unloading.

LNG STORAGE TANKS

Aboveground Tanks and Dikes

LNG storage tank systems in Japan are safer in some ways than American systems. For example, the Japanese

require X-ray inspection of all welds in LNG tanks. Each aboveground LNG tank in Japan must be enclosed by a separate dike. (There is no such requirement in the United States.) All Japanese dikes are low, vertical, made of reinforced concrete, and hold at least 80 percent of the tank's capacity. Those at Tokyo Gas Company's Semboku Terminal are typical. They are double walled, three meters high, and enclose an area 110 by 120 meters. An LNG storage tank must be at least 120 meters away from the nearest house. In practice, the distance is often 1 or 2 miles.

At Semboku water sprayers are installed on the dike perimeter to speed the upward diffusion of LNG vapors in case of a spill. High foaming firefighting equipment (designed by Walter Kidde Co. of the U.S.) can fill the dike with foam in 10 minutes. Dry chemical fire extinguishers and fire trucks are stationed in and around the plant. The trucks carry 1,300 liters of air-foam chemical and 1,000 kilograms of dry chemical. This firefighting equipment is more elaborate than at a typical U.S. installation, but still could only extinguish fires from small spills.

Inground Tanks

For greater safety, many Japanese LNG storage tanks are built in the ground. In part, this trend stems from concern over several recent incidents in which flammable liquids leaked from storage tanks.

For example, on December 18, 1974, the wall of a crude oil tank at the Mitsubishi Petroleum Company's Mizashima refinery collapsed and much of the oil escaped

the surrounding dike. The fire which followed caused considerable damage. The tank wall collapse was caused by an undetected oil leak into the soil beneath the side wall of the tank. The oil weakened the soil foundation, and that portion of the sidewall gave way. A ladder on the side of the wall fell against the dike causing a breach.

Japanese engineering companies told us they believe inground tanks are intrinsically safer than aboveground systems because liquid spills are nearly impossible. Moreover, they feel seismic forces will be less on inground tanks.

Inground LNG tanks have proved completely satisfactory in operation and cost about the same in Japan as aboveground tank and dike installations. Inground LPG tanks, however, are considerably more expensive than aboveground LPG installations. Nevertheless, Japanese construction and utility companies told us that inground tanks are likely to be increasingly used to store higher temperature dangerous liquids such as LPG. This prediction was also included in a paper presented by Japanese gas company and construction company officials at the 1976 Winter Annual Meeting in New York of the American Society of Mechanical Engineers.[1]

Most of the underground LNG storage systems in Japan were built by the Ishikawajima-Harima Heavy Industries Company (IHI). The company's first inground tank has been in use since 1970. The tanks range in size from 10,000 to 95,000 cubic meters. IHI's basic system consists of a stainless steel (Austenite, SUS 304) inner tank surrounded by polyurethane foam insulation and an outer wall of reinforced concrete up to 3 meters thick. The 2 mm. to 2.5

mm. inner liner cannot be any thinner because of pressure and thermal contraction.

Reliable welding procedures also require a certain thickness of material. The welds must be able to withstand the cyclic expansion and contraction as LNG is pumped into and out of the tank. If there are two cycles monthly, the welds will have to undergo 720 cycles over the 30 year life of a tank.

There have been no problems with outer wall pressures generated by the expansion of frozen soil. The Japanese have found that as the freezing of the soil progresses, the pressure reaches a maximum and then remains at that level or decreases. It is important, however, to maintain the temperature differential across the wall within 35°F to keep thermal stresses from growing too great. The thermal stress on the outer concrete wall reaches its maximum about six months after the tank is first filled with LNG.

IHI uses three types of bases for its underground tanks, depending on soil conditions. If the soil is impermeable it acts as the tank floor, and the reinforced concrete outer wall is sunk six to eight meters into the impermeable layer. When sand is found above the impermeable soil, a concrete shell is first sunk down into the impermeable layer and then all water is pumped out of the sand. Finally, a stainless steel membrane is laid on top of the compacted sand. The polyurethane insulation between the steel liner and outer concrete shell extends through the sand to the impermeable soil. In sandy soil, the bottom of the tank is made of reinforced concrete. Either the water beneath is continuously pumped out or the soil is heated to prevent freezing by pumping 175°F brine

through tubes installed below the tank. When soil conditions prohibit the tank from being sunk deep enough to keep the maximum liquid level below ground level, the ground level is raised.

IHI inground tanks are sealed at the top by a cone-shaped steel roof which supports a suspended aluminum ceiling. Mineral wool is laid on top of the ceiling for insulation. The initial boil-off rate is less than .2 percent per day. This drops to .15 percent or less a day as the soil around the tank freezes and insulates the tank.

Mitsubishi Heavy Industries (MHI) has developed its own LNG storage systems and has been operating a 75,000 cubic meter experimental tank filled with liquid nitrogen since early 1971. It is also a licensee for the Conch International Methane Ltd. inground frozen soil LNG tank system and the Whessoe Ltd. aboveground double wall system. The MHI inground tank is similar to the one developed by IHI, but uses a much thicker reinforced concrete bottom slab. In addition, the connection between the side wall and the bottom slab has an unusual hinge to reduce any bending moments. IHI tanks are designed to "float" upward or downward to a certain extent. An outside gauge measures the rise and fall.

The inground tanks developed by the Japanese have no similarity to an earlier type which proved unsatisfactory wherever it was used. This type of tank was built by simply excavating a hole in the ground, freezing the sides, and attaching a roof. Invariably, cracks appeared in the sides of the tank when it was filled with LNG. For example, such a tank was built in granite by the Philadelphia Gas Company after Battelle Memorial Institute

tests indicated that only minor cracking would occur. Unfortunately, major cracks developed in a tree-like fashion. The tank had to be pumped out and abandoned.

The Japanese attitude toward handling of LNG involves more than technology. We were told repeatedly that inground LNG storage tanks are "natural". The Japanese say that natural gas comes from under the ground and it is only proper to store it there so that if gas spills, it will go back to its origins. This typical Japanese stress on harmony with nature contains a great deal of technological wisdom.

FINDINGS

- While the United States is shifting from natural gas to coal, Japan is moving from coal to LNG.

- The Japanese handling of LEG differs in several respects from U.S. practices:

  - o A fireboat escorts all large LEG tankers in Tokyo Bay.

  - o All welds in Japanese LNG tanks are inspected with X-rays.

  - o Each aboveground LNG tank is enclosed by a separate, vertical, reinforced concrete dike.

  - o Many Japanese LNG storage tanks are built in the ground.

- Japanese engineering companies told us they believe that inground tanks are intrinsically safer than aboveground systems because liquid spills are nearly impossible.

- Many Japanese engineers believe that seismic forces will be less on inground tanks.

- Inground LNG tanks have proven completely satisfactory in operation and cost about the same in Japan as aboveground tank and dike installations.

- Although inground LPG tanks are considerably more expensive than aboveground installations, many

Japanese gas company and construction company executives believe that inground LPG tanks will be increasingly used.

REFERENCE

1. Experimental Study of LNG Underground Tank, by A. Kobayashi, General Manager, and T. Yamada, Senior Project Engineer, Ishikawojima-Harima Heavy Industries Co., Ltd., and T. Asada, General Manager, Tokyo Gas Co., Ltd. Contributed by the Process Industries Division of the American Society of Mechanical Engineers for presentation at the Winter Annual Meeting, New York, N.Y., December 5, 1976.

CHAPTER 20

OVERALL CONCLUSIONS AND RECOMMENDATIONS

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INTRODUCTION

This chapter draws overall conclusions and recommendations from the other chapters and appendixes. While certain important conclusions and recommendations are also on the chapters, it is not meant to be a general summary of all the previous material.

The burden that the Atomic Energy Act imposes on the Nuclear Regulatory Commission is to "adequately protect the public health and safety". This basic burden of government is implicitly laid upon every agency regulating or approving potentially dangerous activity. Since the risks associated with the large scale use of any dangerous, modern technology cannot be rigorously quantified, the requirement is essentially one of prudence in the face of potential danger and uncertainty. Such prudence must be based on skepticism of material presented by interested parties, and a vigorous, timely, independent investigation of the critical issues. The evidence must be evaluated by people with the time, resources, and training to understand it. Most important, the government must adequately and truthfully inform the public of the benefits and dangers involved in different choices.

Unfortunately, the Federal Government has not acquired sufficient knowledge or competence before making LEG decisions, and thus has been unable to adequately communicate with the public, or to act prudently. It has not adequately protected the public health and safety.

STORAGE FACILITIES

Storage Tanks

Natural Phenomena

Most LEG and naphtha storage tanks have metal walls—double walls for LNG and single walls for LPG and naphtha. They are adequately designed to meet the requirements of the Uniform Building Code (UBC) for the area in which they are built. These standards essentially require that the tanks be able to withstand the largest earthquake, wind, flood, etc., experienced in the area in the last 50, 100, or 200 years. This means that the probability that these "design events" will be exceeded at a particular site in a given year is low, but that it is virtually certain that design events will be exceeded many times during the lifetime of the 100 LEG facilities currently operating. Because there are already many large LEG facilities, it is virtually certain that design events will be exceeded at many places and many times during the lifetime of these facilities.

Because structures have safety margins beyond their required strength, a tank will not necessarily fail when it is subjected to a load greater than UBC standards demand it withstand.

Although all six LEG tanks and dikes we evaluated were adequately designed for the UBC earthquake and the 100-year maximum wind design criteria, tanks at three of the five sites had earthquake safety margins less than 25 percent. Two of these sites (a total of three tanks), the

Distrigas LNG import terminal and the Exxon propane import terminal are next to each other in Boston Harbor.

The outer steel walls of LNG tanks are not made of cryogenic material. Thus, if the inner tank fails for any reason, it is almost certain that the outer tank will rupture from the resulting pressure and thermal shock. Large LEG tanks made of prestressed concrete are usually much more resistant to natural forces than those made of steel.

Because many large LEG tanks with small safety margins will be impacted by winds, floods, or earthquakes greater than those they are required to withstand, it is likely that some of them will fail. The walls of these tanks will probably separate from the bottoms, spilling their contents.

Sabotage

Public utilities and petroleum companies have been targets of sabotage. Many domestic and foreign groups have the weapons, explosives, and ability to sabotage LEG and naphtha facilities. Instructions for the construction and use of appropriate explosives from easily available materials are widely published in the open literature. Recent advances in weaponry will eventually increase the threat to LEG and naphtha facilities.

Security procedures and physical barriers at LEG and naphtha facilities are generally not adequate to deter even an untrained amateur saboteur. Most LEG and naphtha storage tanks are highly vulnerable to sabotage which could lead to complete catastrophic failure of the tank walls and

subsequent massive spilling of the contents. The level of sabotage needed is within the capabilities of terrorists groups.

Dikes

Natural Phenomena and Sabotage

Earthen dikes are normally made of selected, engineered backfill designed for optimum density and slope stability, which make them highly resistant to natural phenomena and sabotage. High, thin, concrete dikes, on the other hand, are often designed to the same building code standards as tanks and are highly vulnerable to sabotage.

Containment

Dikes constructed to National Fire Protection Association safety criteria generally would not contain the surge of liquid from a massive rupture or collapse of a tank wall, or the spigot flows from punctures high up on the tank. We calculated how much LEG could escape from the dikes in six actual facilities. The figures range from 13 to 64 percent in case of a massive rupture or collapse of a tank wall. Five of the facilities could allow more than 54 percent of the fluid to escape. The facility where only 13 percent could escape has a close, high, concrete dike which might be brought down by the same force which destroyed the tank that it contains. For the reasons given in the text we believe these estimates to be conservative, with the possible exception of the facility with the high, concrete dike.

For the same six facilities we calculated that between 0 and 46 percent could arc over the dike from a hole in the tank if there was no friction in the hole. The actual amount would be less, however, since any hole has some friction.

Overall Conclusions

Both natural phenomena and sabotage can lead to the failure of large LEG and naphtha storage tanks and massive spilling of their contents.

Dikes for LEG and naphtha are designed to handle only small spills, and are generally incapable of containing large, rapid ones. The dikes at most LEG facilities could allow more than half the fluid in the tanks they surround to escape containment if the tank walls collapse, or suffer a massive rupture.

Thus, many large LEG storage facilities are a very serious hazard to the surrounding area.

TRANSPORTATION

Ships

Collisions

LNG ships are probably the least vulnerable of all the systems involved in LNG transportation and storage. Nevertheless, if an LNG ship is struck by a sufficiently large vessel going fast enough, a very large spill could result.

Unlike LNG ships, LPG and naphtha ships are not required to have double hulls, and the stress analysis performed is also much less than for LNG ships. Thus, LPG and naphtha ships are much more vulnerable in collisions than LNG ships.

Sabotage

To cause a massive spill from an LNG ship by sabotage, it is probably necessary to use explosives onboard, or to manipulate the ship's controls and valves to cause overpressuring of the tanks.

LPG and naphtha ships with single hulls are much more vulnerable to sabotage. Improvised limpet mines placed on one while it is anchored or alongside a pier could result in a massive fluid release and the sinking of the ship. Onboard explosives could sink the ship even more easily.

Crew Training

Human error is a contributing factor in 85 percent of all marine casualties and operating problems, and LEG ships need particularly skilled operators for safe operation. We do not believe the Coast Guard's contemplated Waterfront Facility Regulations for LNG in Bulk are entirely adequate, and the rules for LNG terminals proposed by the Office of Pipeline Safety Operations cover operations only to a limited extent. Both sets of proposed rules require companies to have training programs, but these would not be reviewed by the agencies. No personnel qualification regulation of LPG waterfront facilities have been proposed.

Operations

The Coast Guard does not require the officers and enlisted personnel who are involved in LEG ship operations to attend any specialized LEG courses. Most Hazardous Material Officers have had little training in the hazards of LEG, and the Coast Guard has not yet even issued a guidance document for the movement and transfer of LPG.

Coast Guard inspections of entering LNG ships do not include the operating condition of ship control equipment.

There are no specific Coast Guard requirements to guide a local Captain of the Port in deciding whether the condition of an LEG ship is serious enough to warrant keeping the ship out of the harbor.

No specific plans or equipment exist to cope with a major LEG spill, or to partially offload and thus lighten an LEG ship that has gone hard aground in inland waters.

Security

The Coast Guard has not used its authority to require adequate security at LEG harbor facilities.

Overall Conclusion

LNG ships are probably the least vulnerable part of the LNG transportation and storage system. LPG and naphtha ships are far more vulnerable to collisions and sabotage. LEG ship crews, terminal staff, and Coast Guard personnel all need more training. The Coast Guard needs to carry out better inspections, give better directions to Captains of

the Port, make much better plans to cope with potential emergencies, and exercise its dormant authority to require adequate security at LEG harbor facilities. To effectively supervise LEG cargo transfer operations in U.S. waters and ports, the Coast Guard will need more money and manpower, revised regulations, and new plans and policies.

Trucks

Accidents

LNG truck trailers have a higher center of gravity than most tank trucks, which makes them particularly susceptible to rolling over; but they have an inner and outer tank with insulation in between and thus are quite resistant to puncture and cargo loss. LPG trucks also have a high center of gravity, although not as high as LNG trucks, but they are single-walled and under pressure, and thus are more vulnerable to cracks and punctures and more likely to explode in fires.

Sabotage and Hijacking

LNG trucks are highly vulnerable to sabotage, and LPG trucks are even more vulnerable. It would also be easy for terrorists to hijack one or many LEG trucks. Nevertheless, LEG trucking companies take no precautions to prevent hijacking or sabotage. The intentional urban release of LEG from one or more trucks by terrorists could cause a catastrophe.

Routing

Interstate Commerce Commission LEG trucking certificates do not restrict truck routes, and LEG trucks move routinely through large cities. Driving LEG trucks on elevated urban highways is particularly dangerous because one might go through the guard rail and split open on the street below. This could fill sewers, highways, tunnels, subways and basements with invisible, odorless explosive gas. The 40 cubic meters of LNG from one truck, vaporized and mixed with air in flammable proportions, are enough to fill 110 miles of 6-foot diameter sewer line, or 15 miles of a 16-foot diameter subway system.

Overall Conclusion

The dangers present in trucking LEG are far greater than those involved in trucking less volatile petroleum products such as fuel oil, naphtha, and gasoline. The trucks are highly vulnerable to sabotage, hijacking, and certain types of accidents. LEG trucking in densely populated areas is very dangerous.

Trains

Accidents

Accidents involving LPG railcars are not infrequent and often lead to deaths and injuries. In September, 1977, the Department of Transportation (DOT) issued regulations requiring all LPG cars to make certain modifications by December 31, 1981, which will make them less susceptible to fires and explosions. After Congressional hearings on a series of derailments of hazardous materials railcars in

early 1978, and recommendations by the National Transportation Safety Board, DOT announced in May, 1978, that it proposes to shorten the retrofit schedule--to require shelf couplers by December 31, 1978, and to require a tank head puncture resistance system and thermal protection by December 31, 1980.

An adequate inspection program for LPG railcars does not exist, and rusted tank cars holding propane under high pressure are currently being used.

Sabotage

Sabotage of LPG railcars or the trains they are part of would not be difficult. The improvements which DOT has mandated for future LPG cars do not significantly increase their resistance to sabotage although they might mitigate the consequences.

Routing

LPG railcars travel through densely populated areas of cities, even cities which prohibit LPG storage. If the contents of one or more of these cars were released in a city by accident or through sabotage, it could lead to a catastrophe.

Overall Conclusion

Although LPG railcars are vulnerable in accidents and to sabotage, and sometimes run in rusted condition, they travel through densely populated areas of cities even cities which prohibit LPG storage. If the contents of one

or more LPG cars were released in a city, it could lead to a catastrophe.

DOT officials believe that the new modifications on railcars are sufficient for their safe operation. We believe restriction of routes is also necessary.

EFFECTS

It is difficult to estimate the effect of a large LEG spill in a city. The only such spill, in Cleveland in 1944, was quite small compared to the quantities stored in urban areas today. Nevertheless, it killed 130 people and injured 225 more. According to the National Fire Protection Association, if the wind had been blowing in the opposite direction the fire "could have destroyed a very large part of the East Side". A spill today could involve 10 to 20 times as much material.

Some insight can be gotten from the June, 1977 spill of naphtha into the sewers of Akron, Ohio. Although naphtha is much less dangerous than LNG or LPG and less than 15 cubic meters was spilled, the incident caused violent explosions more than 8 miles from the point of the spill.

LNG and LPG vapors are highly explosive in confinement, and propane from a pipeline break in Port Hudson, Missouri, in 1970 caused a large detonation in the open air. If LEG spreads across a city in sewers, subways, or other underground conduits, or if a massive burning cloud is blown along by a strong wind, a city may be faced with a very large number of ignitions and explosions across a wide area.

Overall Conclusion

Although the effect of a large spill of LEG in a big city is uncertain, the damage might be much larger than that caused by the Cleveland spill.

LIABILITY AND COMPENSATION

Liability

LNG is imported on ships, each owned or leased by a separate subsidiary corporation, and stored in terminals owned by other subsidiaries. In many cases, the parent firms are wholly-owned subsidiaries of still larger firms. Most of the assets in the system are protected by these corporate chains, and the top corporations, which derive all of the profits, would generally not be liable for the consequences of an accident. The frontline companies most vulnerable to liability are usually the most thinly capitalized. Most of their assets may be the ship or terminal itself, which is unlikely to survive an accident which does extensive offsite damage. The banks and insurance companies which finance these ships and terminals insist that all the companies in the corporate chain co-sign the notes, so that in the event of a catastrophic accident they will be protected by the assets of the whole corporate chain. The public whose lives and property are at risk deserves no less protection.

Insurance

Present and planned liability coverage for LNG import terminals ranges from $50 million to $190 million per

incident. Ten states require proof of liability insurance for LPG facilities, but the maximum required is $100,000 per incident.

The liability of shipowners and bareboat charterers is limited by statute to the post-accident value of the vessel plus any amounts owing for freight, if they can prove that they did not know about the causes of the accident. If injuries or deaths occur, however, the limit is raised to $60 per ton of cargo. For a large LEG ship this would be about $3,500,000.

Recovery

Claimants after a major LNG accident face long, complex, and expensive litigation involving potential complications at every step in the legal process. If the defendant corporation is foreign owned, it and its assets may be out of reach. If the accident resulted from an act of sabotage, or from an "act of God" such as an earthquake, flood, or tornado, the company may not be liable at all. In any case, it is not always possible to prove the primary cause of a major accident, since critical evidence may be destroyed in the accident itself.

Federal Action

No Federal agency considers the question of offsite liability of LNG operations. We believe the Federal Energy Regulatory Commission and the Economic Regulatory Administration have an obligation to do so.

Overall Conclusion

A major LEG accident could cause damage of such severity that injured parties could not be fully compensated under existing arrangements. Present corporate structures and legal limits on liability offer great protection to the parent corporations which reap the profits. This may diminish their incentives for safety.

RESEARCH

Present Results

The Coast Guard has been responsible for some good quality hazard analyses, primarily on the effects of small spills on water. Isolated pieces of research of varying quality have been done by other government and private laboratories around the world. All of the research has been on a very small scale compared to present day hazards.

Among the topics which have been insufficiently explored are: the interaction of spilled LEG with man-made structures such as buildings, subways, sewers, and ships; under what conditions a large LEG cloud ignited on its downwind edge will burn back to its source; under what conditions LNG and LPG clouds can detonate; how far a large LEG could can travel, under varying atmospheric conditions, before reaching its lower flammable limit.

Overall Conclusion

LEG risk assessment studies have not reached a stage where they give confidence in their conclusions. Therefore, safety decisions can not logically be based on them. Federal agencies will have to make timely, prudent decisions with the realization that many important questions cannot presently be answered with confidence.

Future Plans

The Federal Government's present plan is to channel the bulk of LNG safety research through the Department of Energy (DOE). DOE plans to support LNG research in a manner analogous to its support of research in other areas. This is entirely inappropriate because of the number of facilities now under development, under construction, or in use. The research needed for current, temporary technology is different from that which is needed for long-term and not yet perfected technologies. At the same time, the organizations directly responsible for safety have inadequate budgets and personnel to make informed technical judgments.

DOE plans large expenditures to create facilities for very large (1000 cubic meter) experimental spills. This is not an appropriate way to spend LNG safety research funds. It is unlikely that any results can be obtained in this manner soon enough to affect the design of most facilities.

Overall Conclusion

The present plan to channel the bulk of LNG safety research through the Department of Energy is faulty and will not produce timely or useful safety results. Much more thought and resources should be devoted to LPG research.

THE FEDERAL POWER COMMISSION

The level of technical knowledge and experience found at the Federal Power Commission was inadequate to deal with questions of new and high technology such as LNG. In addition, since economic questions were included in the same process as safety questions, fuzzy trade-offs between the two were inevitable. The extent to which procedures will be changed under DOE is unclear. The Initial Decisions on LNG projects have been based on safety findings some of which our research indicates are inaccurate. None has been questioned by the Commission.

Overall Conclusion

The Federal Power Commission's system for approving LNG projects was clearly inadequate to protect the public.

CAPABILITY OF NON-URBAN SITES TO MEET TOTAL U.S. IMPORT REQUIREMENTS OF LEG

Overall Conclusions

Existing and announced non-urban terminals will have the capacity to receive 111 percent of projected LPG imports in 1985.

Non-urban LNG terminals could easily handle all of the LNG imports projected between now and 1990. We have not looked at the capacity of the main gas transmission lines to distribute these quantities.

The nation's ability to pick the best sites for LEG imports, and to avoid storing and transporting large quantities of LEG in densely populated areas, is seriously impaired because already chosen sites cannot be required to serve new customers.

JAPAN

Japan is the world's largest importer of LNG. While the United States is shifting from natural gas to coal, Japan is moving from coal to LNG.

Aboveground Tanks

Japanese LNG storage areas with aboveground tanks are in many ways designed to higher standards than similar installations in the United States. For example, every weld in Japanese LNG tank is inspected with X-rays. Also, each tank is surrounded by a separate, vertical, reinforced concrete dike. Similar low dikes in the United States are usually made of earth and are sloped.

Inground Tanks

In spite of the high quality of Japanese aboveground tanks, many LNG tanks in Japan are built in the ground for greater safety. Japanese engineering companies told us they believe that seismic forces will be less on inground

tanks and that these tanks are intrinsically safer than aboveground systems because liquid spills are nearly impossible.

Overall Conclusion

According to industry officials in Japan, inground tanks have proved completely satisfactory in operation and cost about the same there as aboveground tank and dike installations. If inground tanks, instead of aboveground tanks, were used in the United States, large spills would be far less likely.

FEDERAL, STATE, AND LOCAL REGULATIONS

Almost all state and local regulations for LEG are based on National Fire Protection Association (NFPA) standards some of which we have shown to be inadequate. (See Chapter 5.) The exceptions include somewhat more stringent regulations developed by the New York State Public Service Commission and the New York City Fire Department. Most responsibility for the safety of LEG and naphtha has traditionally been under state and local fire marshals. At public utilities, LEG and naphtha are also regulated by state utility commissions.

Federal safety responsibilities for LEG are shared by many departments and agencies. Federal regulation of LNG has not been well coordinated, and there is little Federal regulation of LPG or naphtha.

In most situations, for a given volume, LPG is more dangerous than LNG, and LNG is more dangerous than naphtha. Many of the regulations imposed by NFPA standards, states,

and localities do not reflect this. Buffer zones for naphtha, for example, are often close to or even greater than those for LPG, and buffer zones for LNG are often substantially less than those for naphtha. The same inconsistencies arise in the requirements for intertank spacing. Dike design requirements are more comprehensive in the NFPA code covering naphtha than in the NFPA standards for LNG and LPG. In addition, since most LEG and naphtha facilities have been designed to meet normal building code standards, design standards for naphtha tanks are essentially as strong as those for LEG tanks.

The requirements for security at LEG and naphtha facilities are so slight as to provide virtually no deterrent to potential saboteurs.

Outside of some specific operating requirements scattered through the various regulations, there are only quite general references to the desirability of operator qualifications and training. New York City certifies LNG plant operators and a few states certify operators at LPG facilities, but there are no comprehensive requirements for the development of formal operating procedures and training programs, or for the review of such procedures by jurisdictional agencies.

Overall Conclusion

The mixture of Federal, state, local, and NFPA codes for LNG, LPG, and naphtha reflect neither the relative dangers from the fuels nor much consistency among themselves. Most of the regulations are based on an uncritical acceptance of NFPA standards.

Federal regulation and inspection of LEG importation, transportation, and storage have not been adequate to ensure the public safety.

GENERAL OVERALL CONCLUSIONS

- No construction of new, large LEG storage facilities - or expansion in size or use of existing ones - should be permitted except in remote areas.

- If any new, large LEG storage facilities are built in other than remote areas, all tanks should either be inground, with the highest level of fluid below ground level, or be built and operated to standards similar to those applied to the construction and operation of nuclear plants.

- Existing LEG facilities in other than remote areas need to be evaluated and any necessary steps taken to protect the public.

- LEG should not be moved through densely populated areas if there is any other way to deliver the material.

- The safest way to move LPG is by pipeline, and railcars are preferable to trucks.

- Dikes for LEG and naphtha are designed to handle only small spills and are incapable of containing large, rapid ones.

- No present or foreseeable equipment can put out a very large LEG fire.

- LEG and naphtha facilities have virtually no protection against saboteurs.

- More careful and comprehensive Federal regulations for LEG storage and transportation are needed, as are more inspectors.

- It is virtually certain that the level of natural phenomena that LEG facilities are designed to withstand will be exceeded at a large number of facilities in the next 50 years. One or more of them will probably fail by the walls lifting from the foundation, spilling the contents.

- At most facilities, most of the fluid released in a large, rapid spill will go over the dike. If this sequence of events happens in a densely populated area, a catastrophe may take place. The same train of events could be started by sabotage.

- A much more equitable system is needed to assign liability and compensate victims after an LEG accident.

- Many energy health and safety responsibilities should be placed in a Federal Energy Health and Safety Regulatory Agency.

GENERAL OVERALL RECOMMENDATIONS

Recommendations to Federal Agencies

1. We recommend that the Secretaries of Transportation and Energy and the Federal Energy Regulatory Commission take whatever steps are necessary to ensure that

- All new, large LEG storage facilities are built in remote areas.

- No existing, large LEG storage facilities in other than remote areas are expanded in size or in use.

2. If, despite our recommendation, new, large LEG storage facilities are built in other than remote areas, or existing ones are expanded in size or use, we recommend that:

- All storage tanks be in the ground with the highest level of fluid below ground level, or

- All storage tanks be built and operated to standards similar to those applied to the construction and operation of nuclear plants.

3. We recommend that the Secretary of Energy evaluate each existing, large LEG storage facility and recommend to the President and the Congress the actions necessary to protect the public from the hazards associated with them.

CHAPTER 21

GAO TREATMENT OF AGENCY AND COMPANY COMMENTS

INTRODUCTION

Because of the wide interest in this report, it has undergone several reviews to ensure its accuracy and objectivity.

Prior to furnishing the draft of this report to concerned Federal agencies and the LEG industry, we asked a group of past and present leaders in industry, labor, science, law, consumer affairs, security, and government to comment on the material developed before GAO's findings, conclusions, and recommendations were prepared. Their comments were received in writing and at an all-day meeting.

Eight Federal agencies which have jurisdiction or a direct interest in LEG safety received a complete draft of the report. At the same time, we sent to companies and private organizations those chapters of the report in which they were mentioned, minus GAO's findings, conclusions, and recommendations.

We received more than 500 pages of comments from companies, organizations, and Federal agencies. The official comments received from six Federal agencies are reprinted in Volume 3 of this report. The comments from private organizations and companies are available for public review at the U.S. General Accounting Office, 441 G Street, N.W., Washington, DC.

Many changes have been made in the report since the initial draft - some as a result of the comments, some as a result of further staff work.

Most of the Federal agency comments with which we disagreed are answered at the back of the appropriate chapters. We did not have time to comment on every such industry comment, but many industry comments were similar to those received from agencies.

Where comments correctly disputed the accuracy of specific statements, we made the appropriate corrections. The suggestions we adopted are not commented upon. General comments on more general issues—such as the report's procedures, motivation, tone, presentation, use of certain types of analyses—are discussed in this chapter.

THE REVIEW PROCESS

Several companies objected to our removal of preliminary findings, conclusions, and recommendations from the chapters they were sent. Others asked to review the entire draft, not just the portions they were mentioned in. We also received requests for copies from many state and local agencies and private organizations which were not mentioned in, and not sent, the draft.

GAO recognized the wide public interest in this study, but it is GAO's policy to send to private organizations only those parts of studies in which they are discussed. The purpose of sending those parts is to allow companies to review the accuracy of statements made about them. Federal agencies, which are required by law to respond to GAO recommendations, are always sent the entire report.

MOTIVATION OF THE REPORT

Many comments complained that we had singled out LEG for scrutiny. They named other dangerous substances which are used in much greater quantities than LEG, such as gasoline and fuel oil, and others which may be more hazardous, such as chlorine.

There are other hazardous materials used, stored, and transported in the United States, and we do not mean to imply that LEG is the only one worthy of public attention. We chose LEG for examination because of its widespread and possibly growing use, and its storage and transportation in very large quantities in urban areas. GAO has examined the storage and transportation of other hazardous materials in the past—for example, nuclear materials—and may do similar studies in the future.

Although LEG is very dangerous, we believe it can be used in a way that does not pose undue risk to the public. Our recommendations are pointed toward making its use adequately safe. Many of our conclusions and recommendations may be applicable to other hazardous materials.

LEG BENEFITS

Some comments suggested that we failed to adequately bring out the benefits of LEG. They correctly point out that liquefying energy gases makes overseas imports possible and often makes storage and transportation cheaper. They also point out that its use may increase and that a moratorium on LEG could impose hardships on parts of the country.

This report was not intended to evaluate the advantages and disadvantages of LEG as an energy source. Rather, because LEG use is substantial and may greatly increase, we believe it is important to examine the adequacy of current practices for handling LEG.

TONE

Some comments criticized the report for being "unobjective" and for attempting to "discredit the industry." We have attempted to present the material in the report in a logical clear manner without inflammatory language. We demanded that the consultants who worked on the report have the highest qualifications and have no financial or intellectual stake in the results. We believe that we have carefully backed up our findings and conclusions, even conducting our own basic research where necessary.

THE LEG SAFETY RECORD

Some comments accuse GAO of ignoring the "excellent" safety record of the LNG industry. They say that, since the Cleveland accident in 1944, there has been no major accident, either at storage facilities or in land or sea transportation. They also claim that the Cleveland accident is no longer relevant because advances in cryogenic technology and engineering practices make it "impossible" for such an accident to re-occur.

Since no cause for the Cleveland catastrophe was ever officially determined, it is impossible to say whether the cause has been eliminated by the somewhat higher percentage of nickel in the tank steel and the other changes made. However, the same assurances of safety that were given

before the Cleveland accident are given now, and many of the same design assumptions are still being made. Most important, although the quantities spilled in Cleveland are much smaller than those at storage sites today, the accident illustrates the kind of phenomena that can take place in an urban spill. And very large quantities of LEG are still stored in urban areas.

The LNG safety record has been less than perfect since Cleveland. Although no other catastrophes have occurred, accidents—including uncontrolled spills of material—have happened at LNG storage facilities around the world and from ships and trucks. There have also been many serious accidents in all aspects of the much older and more widespread LPG industry. Some of the ones that happened in the United States are recounted in the chapters on truck and train transportation, but accidents have also occurred at storage facilities and on ships.

USE OF NUCLEAR ANALOGY

In Chapter 3 we examined the extent to which typical LEG facilities meet the requirements of the Uniform Building Code (UBC), the least stringent code to which buildings are built, and the requirements for nuclear plants, the most stringent criteria applied to commercial buildings. Many commentators condemned this juxtaposition, saying that the short-term dangers from an LEG spill are much less than the short- and long-term effects of a nuclear accident. Some comments also suggested that reevaluations of nuclear standards have implied that they may be overly stringent.

It is not obvious to us that the risk to the public from a remotely located nuclear power plant is less than

that from a large LEG installation in an urban area, and we are not aware of any analysis which would lead to this conclusion. This study does not address the issue of whether nuclear standards need to be more or less stringent but, as we conclude in the report, it makes little sense to allow LEG facilities in urban areas to use much weaker standards than nuclear facilities in rural areas.

A few companies pointed out that the UBC is the minimum level earthquake and wind loading required for many industrial facilities which store other types of hazardous materials. They also suggested that experience with LNG storage tanks shows that large LEG tanks designed to the UBC standards can be safely built in urban areas.

Chapter 3 shows that many LEG tanks will experience natural forces greater than the UBC standards require, and some of these have very low safety factors.

Only in the last several years have many large LNG tanks been built, and some have had serious operating problems. A few have been closed because of them.

LPG storage tanks have also had serious problems as indicated by the following examples. In 1977, the wall of a 50,000 cubic meter propane storage tank in Qatar, designed by Shell International, suddenly collapsed. The fluid went over the dikes. The resultant explosion killed many people and destroyed the natural gas liquids facility in which it was located.

At the Rhone-Alpes Refinery, one of France's most modern, eight butane and propane storage tanks exploded. The original explosion was caused when the vapor from a

leaking butane tank was ignited by a truck passing on a road 175 yards from the tank. Eleven people died and another 70 were injured.

We believe that this report supports the need for substantial strengthening of the design and operation standards for LEG facilities, and for site-by-site evaluations of existing LEG facilities in urban areas to determine actions needed to adequately protect the public.

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