Cryogenics

Liquefied Natural Gas

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CRYOGENIC TECHNOLOGY

A. While the techniques of liquefying and handling natural gas are a relatively recent development, they are rooted in cryogenic technology which began over 100 years ago. This technology was continually refined and improved upon through the efforts of suppliers of liquefied gases to meet the ever expanding industrial needs of our society. Research laboratories have also aided the development of this technology by developing methods of producing low temperatures for their experimental projects.

Recently a new thrust in the advance of cryogenic technology has developed under the influence of the space efforts. Liquid oxygen and liquid hydrogen are widely used as missile fuels. The criticality of manned rockets and ballistic missiles has placed high demands on the integrity and safety of liquefied gas systems.

Interest in LNG was first shown by the British Government in 1917 and various patents for transportation, liquefaction, storage and delivery of LNG were issued during the years 1920-1940. During the period 1940-1944 several LNG plants were constructed throughout the country.

B. One of the above plants was a plant constructed in 1941 in Cleveland, Ohio, and in which a storage tank failed in 1944 resulting in a disastrous fire. A contributing factor in this disaster was the lack of suitable diking around the tank, the liquid natural gas flooding a large area in all directions and later igniting.

The Bureau of Mines report of investigation on the tank failure indicated that the most probable cause for such failure was that the 3.5 percent nickel steel used for the inner shell may not have been suitable for the tank. (Later research showed that 3.5 percent nickel steel had low impact resistance at the service temperature of LNG.) The general conclusion of the Bureau of Mines report was: "Regardless of the cause of the disaster of the liquefaction, storage and regasification plant of the East Ohio Gas Company, the application of the system for liquefying and storing large quantities of natural gas is not invalidated, provided proper precautions are observed".

Since the disaster in Cleveland in 1944, many LNG plants have been constructed throughout the country. The designs of such plants and the technologies involved have been greatly disciplined by concepts of safety.

C. At present there are two (2) liquefied natural gas (LNG) storage plants undergoing construction in New York City. These construction projects were authorized by the Board of Standards & Appeals and that agency fixed the responsibility for the design of the fire protection features of the plants with the New York Fire Department. The first LNG plant to undergo construction is located in the Greenpoint section of Brooklyn, while the other plant is located in the Gulfport section of Staten Island.

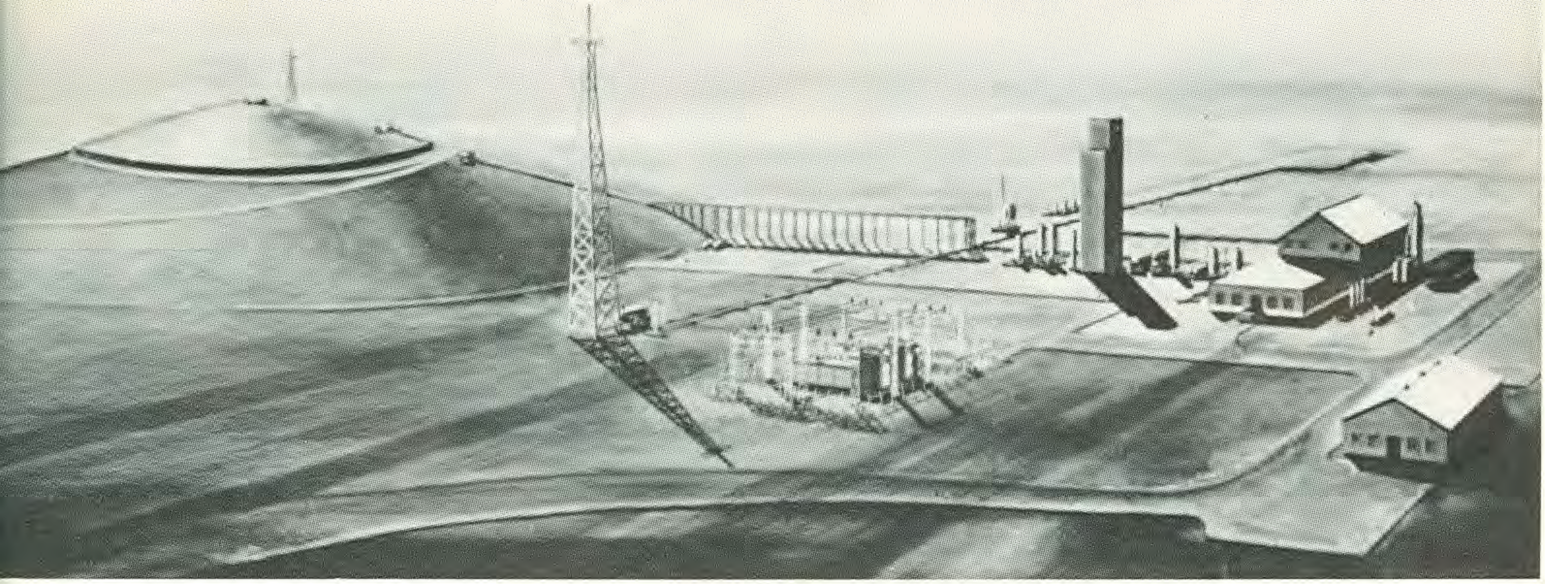
Before any specific comment is made relative to the above two plants, it is believed that background information relative to the science of cryogenics, physical properties of LNG and the theory of LNG plant operation should be presented for a fuller appreciation of the fire protection problems presented in the design, construction and operation of the LNG plants.

D. Cryogenics or low temperature physics is the science that is concerned with the behavior of matter at very low temperatures. The word cryogenics is derived from the Greek word "Kryos" which means cold and usually includes those temperatures below −250°F.

To liquefy natural gas, a temperature of below −258°F at atmospheric pressure is required. Because of this factor, liquefied natural gas will be seldom viewed in this phase. However, it can be described as an energy packed liquid fuel that is basically colorless, tasteless and odorless. The gas has a specific gravity of 0.5 to 0.6 as compared to 1.0 for air and is the only hydrocarbon vapor which is lighter than air and will disperse rapidly. The specific gravity of the liquid is 0.45 as compared to 1.0 for water.

Natural gas is composed of varying proportions of methane, ethane, nitrogen, carbon dioxide, water, acid gases, sulphur, propane and butane. (The greatest proportion is methane.)

LNG does not burn; it is only the vapor rising from the liquid that can burn and only when the gas-air mixture is within a ratio of 5 to 15% gas. In the atmosphere a pool of LNG will immediately begin to vaporize and the area of potential flammability will be defined by the cloud of vapor surrounding the spill. To ignite this vapor it will require a source of ignition with a temperature of approximately 1170°F. Outside the vapor cloud the gas will be too dispersed to ignite by any means. Explosions can only occur if three (3) conditions exist simultaneously; the proper gas-air mixture must be present, the gas-air



Above is an artist's rendering of the LNG Plant now being constructed in Staten Island. Attention is called to the earth berm which has been required to be built around the tank. The berm provides effective protection against failure of the LNG storage container.

mixture must be confined and sufficient ignition energy must be introduced.

Increased recognition of the great savings in storage volume obtained by the liquefaction of natural gas (six hundred and twenty cubic feet of gas is converted into one cubic foot of liquid in the cryogenic process) has lead impetus to the development of the modern LNG plant.

E. A LNG plant is one in which natural gas is liquefied and stored for later regasification and use. There are four (4) basic interrelated processes involved in the overall operation of such plants, i.e., purification, liquefaction, storage and vaporization.

Although the incoming natural gas is clean by all standards, it must be passed through a purification process in order to remove certain constituents which would solidify and freeze up the equipment in the gas stream. For the purposes of this article it is sufficient to state that the feed gas is purified and prepared for liquefaction through the use of amine processes or molecular sieves. The major impurities that are removed are CO2 and traces of sulphur compounds with water being removed through a dehydration unit. The "heavy ends", propane and butane, are also removed in the purification process.

The purified natural gas is liquefied normally through a process which involves a compressing of the gas to a high pressure and then subjecting it to a series of cooling processes. Eventually the feed gas is flashed into liquid storage at –258°F by reducing the stream to atmospheric pressure.

The liquefied gas is then stored in the storage tank which can be any one of the four types which have been developed up to this time, namely, above-ground metallic containers, above-ground cylindrical prestressed concrete containers, below-ground cylindrical prestressed concrete containers and below-ground in ground containers.

Within any of the above cryogenic storage containers a continuous boil-off activity takes place which corresponds to water boiling in a pan. This is one of the most important safety factors in the entire cryogenic technology. The fact that there is always some LNG being converted to gas within the storage container creates a slight positive pressure above the liquid level in the container. For this reason, it is absolutely impossible for air to get into the storage container and, since air is not present, it would be impossible for the material to ignite from the presence of an improbable spark within the container.

Vaporization or regasification involves the changing of the stored natural gas from a liquid to a gaseous state by the addition of heat and is the final step in the operation of a LNG storage facility. The steps involved in this regasification operation are the pumping of LNG from the storage unit, vaporizing the liquid to gas, controlling process flow, pressure and temperature and finally odorizing the send out stream. This odorization is required because liquefaction processes remove any odors present in the incoming gas stream.

FIRE HAZARD EVALUATION AND FIRE PROTECTION PROGRAMMING

A. The two LNG plants currently under construction in New York City were evaluated with the purpose of identifying the potential emergency situations that could develop when the two plants are in operation. The situations envisioned are as follows:

1. Failure of the LNG storage container shell or bottom resulting in the escape of gas in the liquid phase.
2. Failure of LNG storage container roof resulting in the escape of gas in the gas phase.
3. Failure of the liquid piping or piping system component resulting in the escape of gas in the liquid phase.
4. Failure of gas piping or piping system component resulting in the escape of gas in the gas phase.
5. Normal operation of system components such as relief valves or bursting discs resulting in the escape of gas or liquid.

B. After making an evaluation of the possible sources and types of rupture, spill or leak, a projection was made as to the existing hazard in the event of fire and the following considerations were developed:

1. The main hazard would be one of thermal exposures to the adjacent surroundings.
2. That the severity of the thermal exposure would be heavily influenced by the amount of fuel available to a fire. This availability of fuel was related to the rate and duration of a rupture, spill or leak in the possible areas of occurrence and provisions were built into the fire protection package for isolating

valves, gas and liquid venting, and dumping of fuel and the confining of liquid to a designated area in the event of rupture, spill or leak of LNG.

C. In developing fire detection and extinguishing systems for these plants it was theorized that:

1. Automatic dry chemical extinguishing systems (sodium bicarbonate) would be necessary for immediate control of fires in selected areas of hazard. This would reduce the chance of an impinging fire developing (fire hitting metal parts of tank, equipment or process piping) and becoming a source of reignition after the initial fire was extinguished.
2. In manual fighting, the use of conventional hose lines (all purpose nozzles) coupled with an emergency shut-down and isolation system would be the best approach. It is recognized that fire fighting tactics used in LP gas fires and emergencies would be applicable to these situations.

D. The overall fire protection planning goals for the LNG plants can be summarized as follows: To provide a means for limiting the LNG spread from a rupture of the tank to the smallest possible area; to provide a means for reducing the rate and duration of leaks; to provide means for immediate fire and gas detection sensing systems keyed to the automatic shut-down of the plant and to provide adequate means for automatic and manual fire fighting and control.

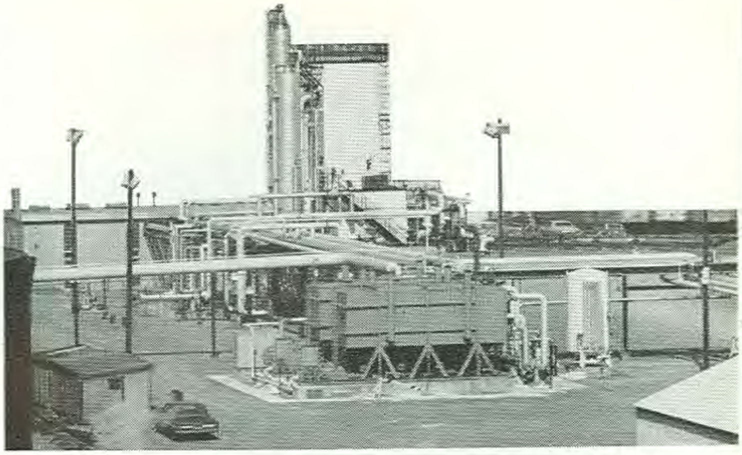
It is believed that a review of the design features of the plants and their fire protection programs, as indicated in the following portions of this article, will indicate that they more than meet the criteria for a fire safe operation.

BROOKLYN UNION LNG PLANT

The liquefied natural gas storage plant being constructed by the Brooklyn Union Gas Company is located at 438 Varick Avenue in the Greenpoint section of Brooklyn and is within the administrative districts of the 11th Division, 36th Battalion and Ladder Co. 146.

A. LNG STORAGE TANK DESIGN

1. The storage tank is a vertical cylindrical double shell tank 118′ in diameter, 91′ high and will contain 7,350,000 gallons of LNG stored at a temperature of −260°F under a pressure of .5 PSI. This liquid storage represents approximately 600,000,000 cubic feet of gas at standard conditions. The inner shell of the tank is made of 9% high nickel steel and the outer tank shell is constructed of carbon steel with perlite insulation being provided between the two tank shells; also, a dry nitrogen atmopshere is required between the inner and outer shells of the tank. The tank supports are fireproofed and also protected against temperatures of −260°F.
2. All butt welds made in the construction of the tank were required to be x-rayed and provisions were made for air space or electric heating under the foundation of the tank so that no soil upheaving occurs due to freezing underneath. The tanks, piping and equipment are electrically grounded and provided with protection against lightning. In areas of possible hazard all electrical equipment is required to be explosion proof.
3. Dual sets of relief valves were required at the tanks and selected locations in the process piping between stop valves. Such relief devices are required to be connected to a "flare stack" equipped with flash arrestors, or other suitable devices, so that vapors can be burned off harmlessly in the event of a gas leak.



Above is the Brooklyn Union Gas Co. complex containing LNG. This plant, also under construction, is slated to be completed shortly.

4. Shut-off valves, which operate automatically in the event of emergency or fire and which can be operated manually in case of necessity, are provided at the tank, on the outside of protective dikes and at points in the processing piping which isolate the various systems of the plants from each other.

B. CONTAINING DIKES

The tank is surrounded by a main dike of earth 20′ high with a 63′ wide base. The dike has an area of 284 feet square and will have the capability of containing 150% of the storage tank capacity. If the entire LNG content of the storage tank was emptied into the dike, the liquid level of the LNG would be 14′ high, or, a distance of 6′ from the top of the dike. The dike is constructed to be liquid tight with no openings for pipes and underground channels, conduits, ducts or sewers permitted under the dike area.

Within the main dike is a drain or catch basin for collecting possible LNG spills (the ground area within the dike is sloped towards the basin) and a pump is provided for pumping the liquid spill back into the process equipment of the plant for regasification.

The main dike is enclosed by a second earthen dike that has the capability of containing 125% of the storage tank capacity and no underground channels, conduits, ducts or sewers are permitted under the secondary dike area.

C. PIPING AND VALVE DESIGN

All connections to be welded and x-rayed with any gasketing materials to be of thermal resistance design. The type of construction to be suitable for the temperature and pressures involved. (Cryogenic piping to be in the processing area) and the piping in the process area to be tested at two (2) times the maximum operating pressure or 100 PSI, whichever is greater.

D. EXPOSURE PROTECTION AND WATER SUPPLY

1. A primary vertical water curtain can be set up at approximately 200 feet from the center line of the tank and will be fed on the four sides of the tank by a salt water distribution system automatically activated by fire sensing devices.

   A secondary water curtain is available outside of the primary water curtain by the installation of coarse flat spray monitor nozzles on hydrants surrounding the tank and process equipment.
2. The water supply for the water protective curtains outlined above is supplied from Newton Creek

through automatic fire pumps. The system can be augmented through the use of fire boats, the super pumper system and conventional land unit pumpers. A requirement of this Division was that facilities for the setting up of a water curtain to protect a fire boat must be provided. This protection consists of 5—100 gpm spray heads or nozzles 50′ apart at the foot of Lombardy Street where the fire boat berth for fire fighting is located. Water curtain protection was also required for the control house and the salt water pump house.

3. The water supply for manual fire fighting as required in the plant vicinity is provided by the city water distribution system in the area which has been tested and found to be capable of providing the required fire flows. All dead ends in the system in the area were minimized by the requirement that they be cross connected wherever possible.
4. Further exposure protection was built into the system by the requirements that the tank must be at least 325 feet from adjacent buildings of the plant; that the tank must be at least 690 feet from the Gas Company property line; that the tank must be at least 750 feet from residential occupancies and that the tank must be at least 1400 feet from critical occupancies, such as, schools, hospitals and theaters. A radiation study was conducted which was the basis for accepting these distance factors.

E. DRY CHEMICAL SYSTEMS

Automatic sodium bicarbonate fire extinguishing systems with a minimum flow rate of .035 lbs. per square foot per second have been required to protect the following areas of hazard:

1. Regasification and cold box areas.
2. Tank roof vents and blow-offs.
3. Secondary dike area containing piping from LNG pump and blower.
4. Catch basin in the main dike area.

These systems to be of fixed piping protected against mechanical, heat or cold damage and to be activated automatically by heat sensing devices.

The systems to be augmented by a standby dry powder mobile truck with turret nozzle for separate use, and for connection into any fixed system.

The flow rate of .035 lbs. per square foot per second for dry chemical discharge was decided upon after an analysis of reports relative to fire extinguishing tests with dry chemical powder (sodium bicarbonate) conducted by the Bureau of Mines and the LNG industry. The Department's required rate of discharge is approximately three (3) times that recommended by fire safety experts in the LNG industry.

F. FIRE SAFETY INSTRUMENTATION SYSTEMS

1. A Davis combustible gas analyzer will continuously check the atmosphere for hydrocarbon vapors. Eight (8) detector heads are located at various points throughout the plant. These analyzers are not tied into any automatic shut-down circuits.
2. Ultra-violet detection devices which activate the dry chemical systems, activate the fire pumps for the water curtains, automatically shut down plant operation, are connected to Central Office (ADT).
3. The LNG storage tank is equipped with pressure, temperature, liquid level and flow rate sensing devices on closed electrical circuits which automatically shut down operations in the event of unusual readings. Pneumatic circuits were acceptable in lieu of closed electrical circuits.

TEXAS EASTERN LNG STORAGE FACILITIES - STATEN ISLAND

This facility is located at the foot of River Road, Prall's River, Staten Island, and is within the administrative districts of the 8th Division, 22nd Battalion, Engine Co. 166. The plant will have a storage capacity of about 3.5 times that of the LNG plant in Brooklyn and differs in tank construction from that plant. The process is an automated one, operating under one plant attendant per shift with possible additional personnel as required.

A. LNG STORAGE TANK DESIGN

1. The tank is a reinforced concrete tank, post stressed with steel wires after pouring and attaining 90% of 28 day strength. This stressing has been done vertically and circumferentially to assure that the concrete will remain in compression during all phases of tank operation.
2. The tank is 267′ inside diameter x 106′7″ high (liquid storage level of 61′ high) and is surrounded by a man-built earth berm to a height of 66′7″ above grade. This earth berm is sloping earth fill around the tank which provides the safety features and insulating characteristics of in ground storage facilities. This earth berm will provide a safeguard against the spreading of LNG throughout the area as a result of tank failure and is approximately 15′ wide at its top and slopes off at 1½ to 1 slope. Access roads will be provided to the top of the berm.
3. LNG is to be stored in this tank at -260°F and the tank has a capacity of 25,000,000 gallons of LNG. All fill lines, vent lines, and product withdrawal lines are through the top of the tank. This design feature conforms to the concept of not having the integrity of the walls of the concrete tank being violated by pipes or other appurtenances.
4. Heating cables are installed below the tank to guard against any frost heaving of the soil under the tank foundations. The roof, walls and floor of the tank are insulated with urethane foam. The walls and floor will have a laminated metallic plastic liner held in place by aluminum lattice and trussed to prevent leakage of LNG.

B. EXPOSURE PROTECTION

1. A survey of the area revealed that there were two possible areas of exposure in the event of an LNG fire involving the storage tank. A Consolidated Edison plant is approximately 500′ distance from the storage tank and the Gulfport tank farm is approximately 1265′ from the storage tank.

   At the request of this Division, a study was made by an expert in the field of radiant heat on the exposure problem to the Con Edison and Gulfport property. The study was made on the premise that the entire content of the tank was involved in fire and was permitted to burn out. (A period of 45 hours is involved). The report reached the conclusion that little exposure problems existed as the maximum temperature that would reach the Gulfport tank farms is approximately 165°F and the maximum temperature reaching the Con Edison facility is approximately 340°F with wind conditions of approximately 60 mph.
2. All of the buildings comprising the complex are of incombustible construction and fire loading is limited to a building which will be used as an office, warehouse and garage. This building will be protected by an exterior sprinkler system and the Compressor Building will be protected in the same manner.

C. WATER SUPPLY

1. The source of water will be unlimited (Arthur Kill) and will be made available through a yard hydrant system fed by a fire pump rated at 7500 gpm at 100 psi. The fire pump can be augmented by a fire boat and the super pumper system. Seventeen (17) fire hydrants are in the yard hydrant system and spaced 250′ apart.
2. In making a determination as to the amount of water needed for fire fighting purposes, it was recognized that a fire involving the contents of the tank would not be susceptible to extinguishment through the use of water. It was felt that water would be required to control any possible relatively small LNG fires occurring from breaks in the process equipment, to extinguish brush fires on the plant site, to extinguish motor vehicle fires at the plant site, to provide water supply for the outside sprinklers protecting the Compressor Building and the office, warehouse and garage building, and to provide for exposure protection to the LNG storage tank from any fire involving the Long Island Pipeline which runs underground approximately 225′ from the tank.

D. DRY CHEMICAL SYSTEMS

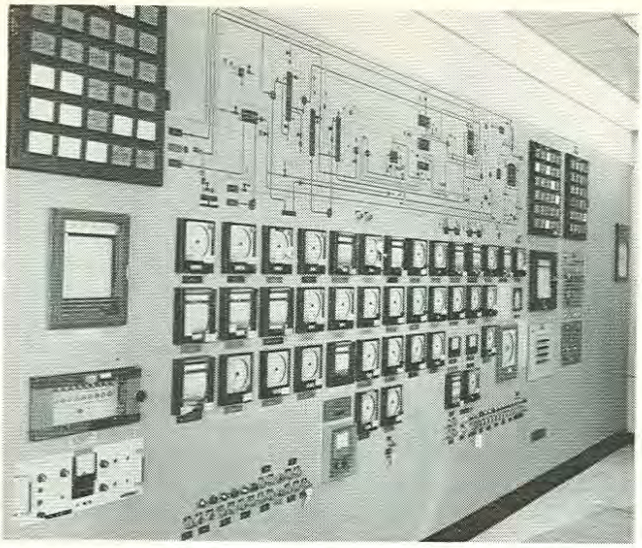
1. Automatic sodium bicarbonate fire extinguishing systems have been required to protect the following areas of hazard:
   a. Storage tank pumps (an area of 3880 sq. ft. surrounding the pumps).
   b. Gas compressors (an area of 2500 sq. ft. surrounding the compressors).
   c. Storage tank roof vent (an area of 135 sq. ft. surrounding the vent).
   d. Vaporizer booster pumps (an area of 900 sq. ft. surrounding the pumps).
   e. Liquefaction unit (an area of 6300 sq. ft. surrounding the unit).
2. These systems will be augmented by a dry chemical truck of at least 4000# capacity and 150 lb. wheeled dry chemical units.
3. The flow rate of .035 lbs. per second per sq. ft. of sodium bicarbonate, as required in the Brooklyn Union LNG plant, has been made a requirement in this plant.

   NOTE: As the process system design has not yet been finalized, some minor changes may be made in areas to be protected by dry chemical powder. However, the coverage, as outlined above, will remain substantially the same.

E. FIRE SAFETY INSTRUMENTATION

1. Tank instrumentation will include sensors for measuring temperature, earth pressure, concrete strain, vertical rod strain, prestress wire strain and floor-wall radial movement.
2. Fire detection heads will be placed at strategic locations in the plant area. All fire indicators will be wired to a panel in the control room and a visual and audible alarm will indicate the position of a fire. Any fire detected by these heads will cause the plant to automatically shut down.
3. Combustible Gas Alarm System.

   A combustible gas alarm system will be installed throughout the plant. The system will be pre-set below the lower explosive limit. Escaping gas will cause a visual signal on the control panel which will indicate the exact position of the head registering the combustible gas. Audible alarms will sound inside and outside of the building. At present, it is proposed to have the gas detector heads installed in the Compressor Room to automatically shut down the plant when they sense a gas leak.



Above is a typical control panel which illustrates the numerous and complicated systems that are installed in the interest of fire safety.

4. Remote controls for the fire extinguishing systems are located inside the control room of the compressor house making it possible to operate any system from this point.

F. PRESSURE RELIEF DEVICES

1. The storage tank shall be provided with both pressure and vacuum vents provided in dual sets with each set sized for total relief. The vacuum vents shall be so arranged that during inbreathing only methane or nitrogen shall be admitted to the tank.
2. All relief devices (other than the tank) to discharge to a continuously operating flare stack with flash arrestor or other suitable safeguard.

G. PIPING AND VALVES

All piping and valves shall be of suitable construction for temperatures and pressures involved and shall be tested hydrostatically to two times the operating pressure or 100 psi, whichever is greater. All joints shall be welded and x-rayed.

Blocking valves that are automatically operated and which can be operated manually, if necessary, are required to be installed at:

1. The natural gas feed line to the liquefaction plant.
2. The natural gas feed line to the derime heater (moisture removal equipment).
3. The liquefied natural gas fill line from cold box to tank (at cold box).
4. The liquefied natural gas fill line to tank (at tank).
5. The liquefied natural gas withdrawal lines to pumps from tank (at pumps and at tank).
6. The liquefied natural gas feed line to vaporizer from tank (at vaporizer).
7. The natural gas vapor boil off line from tank (at tank).
8. Outlet valve from vaporizer to distribution line.
9. Discharge side of refrigerant compressor.

   The inclusion of these valves will provide a means for the reduction of the source of fuel for fire in the event of leaks and will provide a more meaningful opportunity to pre-fire plan or potential leaks in the system.

Because of the complicated and extensive nature of this article, it will be carried in two issues. The second part will appear in the next issue of W.N.Y.F.