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SUMMARY

This bibliography provides brief summaries of literature related to LNG safety and environmental control, organized alphabetically by author.

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Alger, A. S., Corlett, R. C., Gordon, A. S. and Williams, F. A., Some Aspects of Structures of Turbulent Pool Fires. WSS/C1 76-46, October 1976.

Results are reported on the burning of JP-5 and methanol pools 305 cm. in dia. Measurements made include radiant energy fluxes outside and within the fire, temperatures and chemical compositions within the fire and rates of weight loss of the pool. Results emphasize structural differences between JP-5 and methanol fires and importance of radiant feedback of energy to the pool surface in controlling rates of burning.

Allan, D., Atallah, S., Drake, E., Hinckley, R. and Mathias, S., Technology and Current Practices for Processing, Transferring and Storing Liquefied Natural Gas. Department of Transportation/OST, Office of Pipeline Safety, Washington, DC, (prepared by Arthur D. Little, Inc., Report No. C-76971) December 1974.

Current state-of-the-art safety information related to the design, location, construction, operation and maintenance of facilities required for liquefaction, transfer, storage, and revaporization of natural gas is assembled and summarized. A detailed review of codes, standards and practices pertaining to LNG installations is presented along with an evaluation of present trends in LNG safety requirements. LNG safety research programs completed or in progress are described and key research results summarized. Finally a methodology for quantitative assessment of risks associated with LNG facilities is outlined.

Almgren, D. W. and Smith, J. L., Jr., "The Inception of Nucleate Boiling With Liquid Nitrogen." Journal of Engineering for Industry. pp. 1211-1216, November 1969.

The phenomena of patchwise boiling are discussed, and the significant parameters restricting the growth of a boiling patch are analytically determined to be: a high nucleate boiling heat-transfer coefficient; a low total heat flux; the absence of cavities with a trapped liquid vapor interface outside the boiling patch; an appropriate value of wall thermal conductivity; a high vapor enthalpy per bubble.

American Gas Association, LNG Fact Book. Planning and Analysis Group, AGA Arlington, VA 22209, 1977.

This report summarizes the American Gas Association view of LNG importation and its advantages. Issues and project status at the time of publication are also reviewed.

An Economic Analysis of Imported LNG in Selected End Use Markets. Prepared for the American Gas Association by Booz Allen and Hamilton, Inc., May 1978.

Economics of LNG usage in space heating, with and without advanced equipment, and in industrial applications is reviewed.

An Experimental Study of the Mitigation of Flammable Vapor Dispersion and Fire Hazards Immediately Following LNG Spills on Land. A report by University Engineers, Inc., to the American Gas Association, February 1974.

A series of fire control, fire extinguishment and vapor dispersion tests were conducted under the high boil-off rates which occur immediately following an LNG spill on land. Correlations of the results provide fire control and extinguishment times with dry chemical agents and high expansion foams. The magnitude of the reduction in downwind concentrations of methane vapors by the application of high expansion foam on the spill was also determined.

Analysis of Risk in the Water Transportation of Hazardous Materials. U.S. Coast Guard Report, CG-D-39-76. NTIS No. AD/A025298, January 1976.

This report assesses the utility and feasibility of using risk analysis to assist in management decisions regarding the regulation of water transportation of bulk hazardous materials. A number of risk analysis studies were surveyed. Barge transportation on inland waterways was chosen for special study, and a probabilistic model of risk was selected. It was concluded that the greatest utility of the methodology lies in answering specific questions with output of a specific predetermined nature.

Andersen, W. H., Garfinkle, D. R., Carpenter, G. E. and Brown, R. E., "Energy Absorption Near and Below the Burning Surface of Hydrocarbon Pools." Paper presented at the 1969 Meeting, Central States Section, The Combustion Institute, March 18-19, 1969.

The burning behavior of a liquid fuel pool is discussed in terms of the heat feedback from the flame that is transported into and through the fuel via conduction and radiation. It is shown that the radiant flux contribution to the total heat flux input is greatest for benzene, and decreases consecutively for gasoline, kerosene, and alcohol.

Anderson, P. J., "Recent Developments in Regulations for LNG Storage in the United States." CONF-790985-1, 1979.

The paper reports on the ongoing debate for a new version of the principal standard for LNG facilities: NFPA-59A. A target date for final approval was set for November 1979.

Anderson, R. P. and Armstrong, D. R., "Experimental Studies of Vapor Explosions." 3rd International Conference on Liquefied Natural Gas, paper 3 of Session VI, Chicago, 1972.

Small scale experiments with molten salts and molten metals, injected into water, are described. In some cases ensuing reactions can turn into vapor explosions.

Anderson, R. P. and Armstrong, D. R., "Experimental Study of Vapor Explosions." Paper presented at the Third International Conference and Exhibition on Liquefied Natural Gas, September 24-28, 1972, Washington, DC.

Present knowledge about various aspects of vapor explosions is summarized. Particular emphasis is placed on methods of evaluating the destructive kinetic energy release from a specified accident. A theoretical method of calculating the maximum destructive energy is outlined.

Andrews, G. E. and Bradley, D., "The Burning Velocity of Methane-Air Mixtures." Combustion and Flame. 19:275-288, 1972.

Results are presented for the variation of burning velocity with equivalence ratio for methane-air mixtures at one atmosphere pressure. Values were determined by the bomb-hot wire and corrected density ratio techniques, for combustion during the pre-pressure period. The former of these methods gives a maximum burning velocity of 45 ± 2 cm/sec, at an equivalence ratio of 1.07.

Anspach, G., Baseler, R. and Glasfeld, R., "A Floating LNG Receiving Terminal." Chem. Eng. Progr. 75(10):86-91, 1979.

The paper presents the floating LNG terminal as a practical alternative to land-based storage and regasification facilities. Lower cost and independence of seismic restraints are its prime advantages. However, so far no such terminal has been designed or ordered.

Anthony, E. J., "Some Aspects of Unconfined Gas and Vapor Cloud Explosions," Journal of Hazardous Materials. 1:284-301, 1975-77.

A critical review is presented of experimental and theoretical work on unconfined vapor explosions with emphasis on modeling studies.

Arnoni, Y. G., "The Marriage of LNG and Offshore Facilities." Chem. Eng. Progr. 75(10):60-65, 1979.

The article deals with the advantages and problems of an LNG offshore facility on technical, economic and sociological grounds. Even though no such facilities have been built, several are in the planning and engineering phase.

Arthur D. Little, Inc., A Report on LNG Safety Research, Vol. I. to A.G.A., A.G.A. Project I U-2-1, A.G.A. Catalog No. M19711, January 31, 1971.

It is concluded that smaller releases are rather rare and usually not damaging; probability is low that a large spill will occur from currently constructed facilities; spills from containers may have acceptable probability but some additional protection should be provided; risk of transfer line failure requires higher level of protection; further consideration should be given to hazards involved with LNG transport.

Atallah, S. and Allen, D. S., "Safe Separation Distances From Liquid Fuel Spill Fires." Paper presented at Central States Section, Combustion Institute Meeting on Disaster Hazards, Houston, TX, April 1970.

This paper critically reviews the methods generally used to calculate safe separation distances from liquid fuel spill fires. Correlations for predicting flame height and other radiative properties are reviewed. Distances at which the thermal radiation flux falls below the minimum level needed to ignite cellulosic materials are calculated and the results are presented in convenient graphical form.

Atallah, S. and Raj, P., "Thermal Radiation From LNG Spill Fires." Paper P-3 presented at the Cryogenic Engineering Conference, Atlanta, GA, August 10, 1973.

This paper reviews the present state of knowledge relating to thermal radiation from LNG fires. Utilizing data from recent AGA-sponsored LNG fires in seven 6-ft, six 20-ft, and one 80-ft diameter pools, equations were derived for predicting LNG flame height and the angle of tilt of LNG flames in the presence of wind. A model for predicting the thermal radiative flux at various locations away from an LNG fire is presented.

Bailey, F. B., "Status of United States Codes and Regulations Affecting Land Based LNG Facilities." 1978 Operating Section Proceedings, American Gas Association, Montreal, Quebec, May 1978.

This report summarizes current safety and non-safety regulations, and activities concerning regulations. NEPA59A versions and applications are listed.

Baitis, A. E., Bales, S. L. and Meyers, W. G., Prediction of Lifetime Extreme Accelerations for Design of LNG Cargo Tanks. U.S. Coast Guard Report CG-D-89-74. NTIS No. AD/779635, March 1974.

A procedure is developed to predict the extreme accelerations needed for design of the cargo tanks in LNG vessels. The validity of the prediction tool is discussed. Comparisons are made with accelerations measured in model and full scale experiments.

The results of a pilot study on a single, large typical LNG ship are presented. Acceleration response variations due to changes in ship load conditions and changes due to longitudinal, lateral and vertical locations are examined.

Becker, H. and Liang, D., "Viable Length of Vertical Tree Turbulent Diffusion Flames." Combustion and Flame. 32:11-137, 1978.

The authors of this paper propose and review correlations for the visible length of turbulent diffusion flames. This paper may be useful for determining the magnitude of thermal radiation from LNG pool fires.

Beer, J. M., "Methods for Calculating Radiative Heat Transfer from Flames in Combustors and Furnaces." Heat Transfer in Flames. Chapter 2, John Wiley and Sons, 1974.

Recent advances in methods for predicting radiative heat flux distribution in furnaces and combustors are reviewed with special reference to the zone method of analysis and the flux methods. Recent experimental studies specially designed to test these prediction procedures under sufficiently severe conditions are discussed.

Bellus, F., Cochard, H., Vincent, R. and Mauger, J., Controlling the Hazards from LNG Spills on the Ground LNG Firefighting Methods and Their Effects Application to Gaz de France Terminals. Gaz de France, DOE-Tr-18.

Three basic areas are examined in this paper. A mathematical model to calculate vapor dispersion from accidental LNG spills on land is described. This model is used to investigate various types of impounding areas and their minimization of methane cloud travel. A method to calculate water spray rates for the protection of LNG tank walls from the energy radiated by an adjacent fire is described and a numerical example is given. The authors describe the details of design and construction of the new 80,000 m³ LNG tank at the Fos Terminal.

Bellus, F., Vincent, R., Cochard, H. and Mauger, J., "Controlling the Hazards from LNG Spills on Land." Fifth International Conference on LNG, Session III, paper 5, Institute of Gas Technology (in French), 1977.

A new mathematical model is described which allows the calculation of vapor dispersion from accidental spills of LNG on land.

Benedick, W. B., "High-Exposure Initiation of Methane-Air Detonations." Combustion and Flame. 35:89-93, 1979.

The detonation limits of a stoichiometric methane-air mixture have been determined under "free-field" and "confined" conditions. Such a mixture is generally more difficult to detonate than an LNG vapor cloud.

Bennett, C. P., "Marine Transportation of LNG at Intermediate Temperature." Chartered Mechanical Engineer. 26(3):63-66, 1979.

The paper details advantages of transporting LNG at intermediate temperatures in pressure vessels.

Bensesh, M. E., "The Use of Gas Hydrates in Improving the Load Factor of Gas Supply Systems." U.S. Patent 2,090,163 (to Chicago By-Products Corp), 1942.

This method recommended using excess natural gas, during low demand periods, for hydrate formation and storage. The natural gas would be regenerated for peak demand.

Berger, E., "LNG Plants on Floating Structures - Intermediate Reports on an Extensive Test Program." Chemical Economy and Engineering Review. 10(10):22-29, 1978.

The paper reports on progress in designing floating LNG liquefaction plants which could be used for marginal offshore gas fields where sub-surface pipelines are not economical.

Bernert, R. E., "Technical Aspects of Ambient Vaporizers and Superheaters." Applications of Cryogenic Technology. Vol. 6. Proc. Cryo 173 Conf. 6th Los Angeles, CA, October 2-4, 1973, pp. 85-93, 1974.

This paper discusses aspects governing the performance of ambient water and air cryogenic vaporizers and superheaters. This paper also includes some design limits due to ice and frost formation.

Beychok, M. R., "How Accurate are Dispersion Predictions?" Hydrocarbon Processing. pp. 113-116, October, 1979.

This paper cautions the reader against assuming that generalized dispersion models have a fixed accuracy in all applications. Examples of the variability are shown.

Bijl, P., Vet, P. N., "Noval Approach Required for LNG Peakshaving Plant in the Netherlands." Oil and Gas Journal. pp. 81-85, November 28, 1977.

This article describes a unique peakshaving facility which produces both LNG and liquid nitrogen, LN₂. Because of the high N₂ content of the gas in the Netherlands, a slightly modified expander liquefaction cycle was designed which allowed separation of LN₂ from the LNG.

Bingham, G. E., Gillespie, J. H. and McQuaid, J. H., Small Battery-Powered Infrared Absorption Sensor for Methane, Ethane, and Other Hydrocarbons. UCID-17968-79-1, pp. 23-42 Lawrence Livermore Laboratory 1979.

The concept for a portable gas sensor capable of measuring LNG vapor concentrations is described. It is based on infrared absorption by hydrocarbons between 3 and 4 μ m.

Biro, P., "Fire Protection for LNG Storage, Transportation and Distribution Facilities." gwf-gas/erdgas. 118(8):344-346, 1977 (in German).

The requirements for fire protection of LNG facilities are described. Specifically, liquefaction plants, storage facilities, LNG terminals and LNG tankers are addressed.

Blackshear, P. L., ed., Heat Transfer in Fire: Thermophysics, Social Aspects, Economic Impact. John Wiley & Sons, 1974.

The book, in five parts, considers social and economic aspects of fires; geometric parameters for classifying full-scale fires; heat and mass transfer in gaseous and condensed phases; radiative heat transfer associated with fire problems, and radiative transfer parameters.

Blinov, V. I. and Khudyakov, G. N., "Certain Laws Governing Diffusion Burning of Liquids." Doklady Akademii Nauk U.S.S.R. 113:1094-1098, 1957.

An investigation of the burning of gasoline, diesel oil, solar oil and a number of other petroleum products in containers having different diameters enabled the authors to determine some important relationships for diffusion of burning liquids.

Board, S. J., Farmer, C. L. and Poole, D. H., "Fragmentation in Thermal Explosions." International Journal of Heat and Mass Transfer. 17:331-339, 1974.

Experiments involving explosions between molten tin and water are described. Results indicate that thermal explosions usually involve several distinct interactions; a small disturbance can escalate by successive growth and collapse cycles; vapor collapse is the main cause of dispersion in many thermal explosions, and the jet penetration hypothesis can account for both the time scales and energy transfer rates.

Boni, A. A., Wilson, C. W., Chapman, M. and Cook, J. L., "A Study of Detonation in Methane/Air Clouds." Acta Astron. 5:1153-1169, 1978.

A numerical simulation of the detonation in unconfined, gaseous mixtures of methane/oxygen/nitrogen is attempted. Results show that initiation of such detonations requires very large trigger charges (10 to 1000 t of tetryl).

Booth, S. H. and Vance, R. W. (ed.), Applications of Cryogenic Technology, Vol. 8. Scholium International, inc., New York, 1976.

This text presents papers comparing Cryogenic Applications Symposia on Liquefied Natural Gas (LNG) presented at CRYO '75 and CRYO '76, conferences of the Cryogenic Society of America.

Bowman, B. R., "Dispersion Model Comparisons." Report B, Liquefied Gaseous Fuels Safety and Environmental Control Assessment Program: A Status Report. DOE/EV-0036, Department of Energy, Washington DC, 1979.

Various mathematical models for the dispersion process following an LNG spill are evaluated. Deficiencies are pointed out and needs for further work are outlined.

Bowman, B. R., Sutton, S. B. and Comfort, W. J., "The Impact of LNG Spills on the Environment: A Comparison of Dispersion Models and Experimental Models." Proceedings of the 25th annual technical meeting of the Institute of Environmental Sciences, Seattle, WA, April 1979.

A Gaussian and Three-Dimensional Navier-Stokes model for LNG spills and subsequent dispersion are compared. Data including hydrocarbon concentrations from three 5-m LNG spill tests are used to evaluate the models.

Boyle, G. J., "Vapor Production From LNG Spills on Water." American Gas Association Distribution Conference, May 1973.

The results indicate that LNG spilled onto water will spread outward with a rate that decreases with time; vapor production will equal the discharge rate as long as the discharge is occurring; with a batch spill it is necessary to take into account the LNG which evaporates to calculate the maximum pool and the peak vapor production rate; the dispersion plume from a large LNG spill on water will be wide and shallow.

Boyle, G. J. and Kneebone, A., Laboratory Investigation into the Characteristics of LNG Spills on Water, Evaporation, Spreading and Vapor Dispersion. Re 6Z32, Shell Research Limited, Released by the American Petroleum Institute, March 1973.

This is a laboratory and small-scale wind tunnel investigation of the characteristics of LNG spills on water. One characteristic investigated, that has not been studied by others, is the appreciable incorporation of water in the vapor cloud.

Bradley, D. and Mitcheson, A., "The Venting of Gaseous Explosions in Spherical Vessels I, II." Combustion and Flame. 32:221-237, 1978.

The authors present various theoretical analyses of the pressure rise in partially confined reactive systems. The results of these investigations are then compared with experimental data and recommendations are made for proper venting procedures.

Briscoe, F. and Vaughn, G. J., "LNG/Water Vapor Explosions--Estimates of Pressures and Yields." Paper presented at the Gastech 78 LNG/LPG Conference, Monte Carlo, November 1978.

The essentials for the occurrence of LNG vapor explosions are discussed. The maximum possible yields and pressures in such explosions are determined by various theoretical approaches.

Briscoe, F. and Fog, G. F., A Guide to the Use of BKWAVE - A Computer Program for the Calculation of One-Dimensional Shock Wave Propagation from Explosions. United Kingdom Energy Authority, SRO-R-104, Calceth Warrington, U.K., May 1978.

This report is a description of a computer code, BKWAVE, which can calculate the shock wave resulting from an explosion of known strength. The reaction is assumed to be over instantaneously.

Britter, R. E., "The Spread of a Negatively Buoyant Plume in a Calm Environment." Atm. Envir. 13:1241-1247, 1979.

The paper presents the results of a laboratory experiment to study the spread of a negatively buoyant plume in a calm environment including semi-empirical relation for the cloud leading edge. Under conditions where the effects of wall frictions and ambient wind can be neglected, most or all mixing occurs at the cloud leading edge.

Brown, L. E. and Romine, L. M., "Liquefied Gas Fires: Which Foam?" Hydrocarbon Proc. 58(9):321-332, 1979.

Six different types of foam were evaluated for their effectiveness in controlling liquefied gas fires. Medium and high expansion foams proved to be most efficient.

Brown, L. E., Martinsen, W. E., Muhlenkamp, S. P. and Puckett, G. L., Small Scale Tests on Control Methods for Some Liquefied Natural Gas Hazards. Final Report, prepared by University Engineers, Inc., Norman, Oklahoma, for the U.S. Coast Guard, Report No. CG-D-95-86. NTIS No. AD/A033522, May 1976.

A report of results of small scale (100 ft²) tests of some liquefied natural gas (LNG) hazard control methods and concepts. Tests of water spray screens showed that the concept is practical and effective for small LNG spills. Tests of water spray screens to reduce radiant heating of exposures demonstrated no practical value.

Brown, T. T. and Hubbard, J. K., Application of Gas Turbine/Compressors in LNG Plants. 1979.

This paper discusses key considerations associated with selection of Gas Turbine Driven LNG Turbo Compressors. Use of gas driven versus steam driven compressors is compared.

Browning, R. L., "Estimating Loss Probabilities." Chemical Engineering. pp. 135-140. December 15, 1969.

This article presents a technique for analyzing industrial risks. Methods for obtaining the loss incident frequencies are described and the relative probabilities of loss incidents are included.

Brzustowski, T. A., "A New Criterion for the Length of a Gaseous Turbulent Diffusion Flame." Combustion Science and Technology. 6:313-319, 1973.

The flame tip is identified with the point on the axis of maximum fuel concentrations where the fuel has been diluted to the lean flammability limit. Flame-length equations are derived using the new criterion, together with data from the literature on entrainment of air into flames, transverse concentration profiles in turbulent jets, and flammability limits.

Brzustowski, T. A., "The Hydrocarbon Turbulent Diffusion Flame in Subsonic Cross-Flow." AIAA Paper 77-222, January 1977.

The flame is modeled as a bent-over initially vertical circular jet with top-hat profiles of composition, temperature, and velocity. The hydrocarbon pyrolyzes in a zero-order reaction and the pyrolysis products are oxidized at a rate proportional to the rate of entrainment of air into the flame.

Buch, E., "Utilizing the Cold of LNG for Power Generation." Energie. 29:182-183, 1977 (in German).

When vaporizing LNG, it would be economical to take advantage of the low temperature of the LNG as a heat sink in a closed gas turbine cycle. Such a scheme could recover 14% of the total LNG energy, which otherwise could be lost in the vaporization process.

Buchholz, C. D. and Senkowski, E., "Unique Design and Operating Features of Philadelphia Electric Company's LNG Plant." Paper presented to Seminar and Study Tour on LNG Peakshaving, Washington DC, March 5-9, 1979.

The design and operating experience of the West Conshohocken LNG Plant is reviewed. The plant utilized a nitrogen expansion cycle for liquefaction, a double-walled, double-roofed above ground storage tank, and submerged combustion vaporizers.

Bull, D. C., Ellsworth, J. E., Hooper, G. and Quinn, C. P., "A Study of Spherical Detonation in Mixtures of Methane and Oxygen Diluted by Nitrogen." J. Phys. D: Apply. Phys. 9:1991-2000, 1976.

Experiments are described which examine the behavior of spherically propagating detonation waves in methane/oxygen/nitrogen mixtures. Such tests have a bearing on the safety question of LNG.

Bull, D. C., Ellsworth, J. E. and Hooper, G., "Susceptibility of Methane-Ethane Mixtures to Gaseous Detonation in Air." Combustion and Flame. 34:327-330, 1979.

Experiments are described which determine the detonation limits of methane-ethane-air mixtures. The presence of even small amounts of the heavier hydrocarbons has a significant effect on these limits.

Burgess, D., Biordi, J. and Murphy, J., Hazards of Spillage of LNG into Water. PMSRC Report No. 4177, U.S. Department of the Interior, Bureau of Mines, Pittsburgh, PA, 1972.

These are reports of experimental investigations of LNG spills on water. The pool spread, evaporation rate, vapor gravity spread, downwind drift and dispersion were studied in spill sizes up to 0.5 m³. In unconfined spills coherent ice flow formation was not observed. In several cases small scale physical explosions were observed but no attempt was made to study the initiation or burning of the cloud.

Burgess, D. S. and Hertzberg, M., "Radiation From Pool Flames." Heat Transfer in Flames. Chapter 27, John Wiley & Sons, 1974.

Some radiation data from pool flames is summarized and our understanding of the problem is reviewed. Spectral data yield a 1500± K temperature for hydrocarbon pool fires, which is consistent with the 40 percent maximum in the fraction of combustion energy radiated, and with limited flame temperatures for the mixing limited systems. A revised correlation of mass burning rate with $\Delta H_C/\Delta H_V$ is presented, and derived fundamentally.

Burgess, D. S., Murphy, J. N. and Zabetakis, M. G., Hazards Associated with the Spillage of Liquefied Natural Gas on Water. Report RI 7448, U.S. Department of the Interior, Bureau of Mines, November 1970.

The hazard of spilling LNG onto water is discussed. After spillage, the initial vaporization rate of LNG was determined to be 0.037 lb/ft² sec. If the LNG was confined, this rate was modified by the formation of ice on the water surface. Using a 2000-gallon LNG sample, the maximum diameter (in feet) of the spreading pool was calculated at $6.3 w_o^{1/3}$ where w_o is the weight of LNG in pounds.

Burgess, D. S., Murphy, J. N. and Zabetakis, M. G., Hazards of LNG Spillage in Marine Transportation Final Report. NTIS No. A0/70578, for USCG, Office of Research Development, February 1970.

The hazard of spilling LNG onto water is discussed. After spillage onto water, the initial vaporization rate of LNG was determined to be $0.037 \text{ lb/ft}^2 \text{ sec}$. If the LNG was confined, this rate was modified by the formation of ice on the water surface. Using a 2000-gal LNG sample, the maximum diameter (in feet) of the spreading pool was calculated at $6.3 W_0^{1/3}$ where W_0 is the weight of LNG in pounds.

Burgess, D. S., Murphy, J. N., Zabetakis, M. G. and Perlee, H. E., "Volume of Flammable Mixture Resulting from the Atmospheric Dispersion of a Leak or Spill." Application of Cryogenic Technology, Vol. 8. Combustion Institute 15th Symposium on Combustion, 1976.

The paper discusses atmospheric dispersion of flammable vapors, the structure of gas clouds and the explosion potential of flammable mixtures.

Burgess, D. S., Strasser, A. and Gumer, J., "Diffusive Burning of Liquid Fuels in Open Trays." Fire Research Abstracts and Reviews. 3(3):177-192, 1961.

The paper describes the effects of fuel temperature and wind on burning rate, discusses the problem of cryogenic fuels, and suggests that burning rate may be predicted from heats of vaporization and combustion of the fuel. Data on methanol, LNG, liquid hydrogen, amine fuels, and typical hydrocarbons are included.

Burgess, D. S. and Zabetakis, M. G., Detonation of a Flammable Cloud Following Propane Pipeline Break: The December 9, 1970 Explosion in Port Hudson, Missouri. Report RI 7752, U.S. Department of the Interior, Bureau of Mines, 1973.

This report summarizes the incidents that preceded the December 9, 1970, propane-air explosion in Port Hudson, MO. Both near- and far-field damage indicated that this explosion may be attributed to the detonation of propane in air with an energy release equivalent to that from about 50 tons of detonating TNT.

Burgess, D. and Zabetakis, M. G., Fire and Explosion Hazards Associated With Liquefied Natural Gas. Report RI 6099, U.S. Department of the Interior, Bureau of Mines, 1962.

Factors that should be considered in evaluating the fire and explosion hazards relating to any fuel are discussed. These factors are utilized in the design of experiments to evaluate the hazards associated with LNG as compared to those hazards associated with other fuels.

Buschmann, C. H., "Experiments on the Dispersion of Heavy Gases and Abatement of Chlorine Clouds." Proceedings of the Fourth International Symposium on Transport of Hazardous Cargoes by Sea and Inland Waterway, Jacksonville, FL, October 26-30, 1975, Report No. AD/A023505, pp. 475-488, October 1975.

The experiments comprised four different parts: dispersion of heavy gases offer an instantaneous release; penetration of heavy gases in buildings during the passage of a gas-cloud; influence of a chlorine-cloud on motorized traffic, and suppression and abatement of chlorine-clouds.

Bush, S. H., "Pressure Vessel Reliability." Journal of Pressure Vessel Technology. 97(J):54-70, February 1975.

An informative review pertaining to United States pressure vessels is made and compared to data available from Germany. An attempt to understand the apparent differences in reliability of these two countries on the bases of the ASME codes covering materials, design, and construction, on operating procedures, and on differences in reporting techniques. Some attention is given to failure modes to possibly understand the low incidence of operational failures in the United States.

Byram, G. M., "Scaling Laws for Modeling Mass Fires." Pyrodynamics. 4:271-284, 1966.

The paper is concerned with the development of scaling laws necessary for modeling and is restricted to the stationary mass fire.

Byram, G. M. and Nelson, R. M., Jr., "Buoyancy Characteristics of a Fire Heat Source." Fire Technology. 10(1):68-79, 1974.

Buoyancy production rates for a pure heat source and for a fire heat source of burning woody fuels show that fire may be regarded as a pure source yielding heated air rather than heated combustion products.

Byram, G. M. and Nelson, R.M., Jr., "The Modeling of Pulsating Fires." Fire Technology. 6(2):102-110, 1970.

The authors present scaling relationships for modeling pulsating fires. Data gathered from various sizes of pulsating fires compared favorably with the predicted relationships between fire diameter and pulsation frequency.

Cahn, R. P., Johnston, P. H. and Plumstead, J. A., "Transportation of Natural Gas Hydrate." U.S. Patent 3,514,274 (to Esso Research and Engineering Co.), 1970.

Natural gas was combined at 25 to 40°F and >80 psia with a slurry of propane hydrate in propane. This mixture was cooled to -40°F to give methane hydrate slurry in propane. Treating this product with propane gas at 25-40°F and <80 psia regenerated methane and propane hydrate.

Carne, M., Thomas, J. R. and Hutchinson, E. A., Buxton Bund-Fire Tests. The Gas Council, December, 1971.

Ignition and burnout tests were conducted on LNG contained within walls of clay or pulverized fuel ash. The test objective was to establish whether walls of this construction would be damaged by a combination of cold LNG and flame radiation. Results showed no damage to the walls apart from a superficial calcining of the turf and slight spalling of the concrete covering. Flame radiation agreed reasonably well with predicted values.

Cermak, J. E., "Applications of Fluid Mechanics to Wind Engineering - A Freeman Scholar Lecture." Journal of Fluids Engineering. 97:9-38, March 1975.

The objectives of this review are to establish an initial subject-matter base for wind engineering, to demonstrate current capabilities and deficiencies of this base for an engineering treatment of wind-effect problems, and to indicate areas of research needed to broaden and strengthen the subject-matter base.

Chan, S. T. and Gresho, P. M., A Comparison of Hydrostatic and Nonhydrostatic Models as Applied to the Prediction of LNG Vapor Spread and Dispersion. UCID-18097, Lawrence Livermore Laboratory, March 1979.

Two mathematical models are described and after numerical implementation, results of a series of computations for LNG vapor dispersion are compared. Conclusions are drawn on how to further develop the less elaborate model into a more cost-effective code.

Chan, S. T., Gresho, P. M. and Lee, R. L., Simulation of LNG Vapor Spread and Dispersion by Finite Element Methods. UCRL-82441, Lawrence Livermore Laboratory, July 1979.

Two finite element models are described: one based on solving the time-dependent, two-dimensional conservation equations of mass, momentum, and energy, with buoyancy effects included via the Boussinesq approximation; the other based on solving the otherwise identical set of equations except using the hydrostatic assumption, and applied these models to predict some aspects of the vapor dispersion phenomena associated with LNG spills.

Chatterjee, N., Gaumer, L. S. and Geist, J. M., "Operational Flexibility of LNG Plants Using the Propane Precooled Multicomponent Refrigerant MCR Process." LNGS - International Conference on LNG, Duesseldorf, Germany, August 29-September 1, 1977.

This paper discusses the operation of the MCR liquefaction process over a wide range of conditions. A computer program which models the process is described.

Chatterjee, N. and Geist, J. M., Spontaneous Stratification in LNG Tanks Containing Nitrogen. ASME Publication 76-WA/PID-6, December 5, 1976.

LNG containing significant concentrations of nitrogen can stratify spontaneously during weathering in storage tanks. Mixing of stratified layers leads to an increase in boil-off rates, commonly referred to as "rollover". LNG storage tanks can be designed and operated safely if stratification and associated problems are taken into account.

Chatterjee, N. and Geist, J. M., "The Effects of Stratification on Boil-off Rates in LNG Tanks." Paper presented at the A.G.A. Distribution Conference, Atlanta, GA, May 8-10, 1972.

The addition of LNG to a partially filled tank containing liquid of a different density may lead to the temporary formation of stratified layers. The physical phenomena associated with the mixing of stratified layers of LNG have been simulated on the computer. One method for mitigating potential hazards associated with stratification is by limiting the density and the temperature difference between fresh liquid and LNG in the tanks.

Chippett, S. and Gray, W. A., "The Size and Optical Property of Soot Particles." Combustion and Flame. 31:149-159, 1978.

This paper presents the results of an experimental investigation to determine the spectral transmissivity and size distribution of soot aggregates. Measured attenuation and light scattering were found to be in best agreement with theoretical results when the complex refractive index, $\bar{n}$, was taken to be $1.9-0.35i$.

Chiu, Chen-Hwa, "Evaluate Separation for LNG Plants." Hydrocarbon Processing. pp. 266-272, September 1978.

Energy losses from various processes involved in separation of LNG components during liquefaction are discussed. Losses due to compression and liquefaction were cited to show areas for improvement in energy use.

Clapp, M. B. and Litziner, L. F., "Marine Terminals for LNG, Ethylene, and LPG." A paper presented at the 68th National AIChE Meeting, Houston, Texas, February 28 - March 4, 1971.

The design and economics of marine terminals for LNG, Ethylene, and LPG are discussed. Some discussion of safety features is included.

Closner, J. J. and Parker, R.O., "A Careful Accident Assessment Key to LNG Storage Safety." Oil and Gas Journal. pp. 47-51, February 6, 1978.

This article discusses potential accidents and related hazards associated with LNG storage facilities. A list of mitigating measures which would prevent an accident or reduce its consequences is included.

Closner, J. J. and Parker, R. O., "Safety of Storage Designs Compared." Oil and Gas Journal. pp. 121-125, February 13, 1978.

Eight different types of LNG storage designs are compared with respect to the likelihood and potential consequences of a spill or accident.

Cole, R. S. and Mouldsley, T. J., "The Use of the Atmospheric Acoustic Sounder to Track Methane Gas Plumes." Atm. Envir. 13:1437-1441, 1979.

The usefulness of the acoustic sounder as a method of tracking elevated methane plumes is explored.

Colgate, S. A. and Sigurgeirsson, T., "Dynamic Mixing of Water and Lava." Nature. 244:552-555, August 31, 1973.

It is suggested that lava eruptions under the ocean might result in vapor explosions, similar to those which have been observed when liquid metals or LNG come into contact with water. Violent mixing of water and lava are believed to be the cause of such explosions.

Colton, J. W., Pretreatment of Raw Natural Gas Prior to Liquefaction. U.S. Patent 4,150,962, 1979.

A process for pre-treating raw wellhead gas is described that reduces the liquefaction refrigeration power requirements by expanding the gas through an expansion turbine, which in turn drives the liquefaction compressor.

Connors, T. G., "LNG Primer." Hazardous Chemicals--Spills and Waterborne Transportation. AIChE Symp. Ser. 194, 76, pp. 62-69 1980.

The paper gives a brief description of the cargo operations of an LNG tanker and outlines the basic types of LNG containment and insulation systems.

Corlett, R. C., "Gas Fires With Pool-Like Boundary Conditions: Further Results of Interpretation." Combustion and Flame. 14:351-360, 1970.

A circular, upward-facing burner, supplying uniform flux of fuel gas from a water-cooled surface, preserves the essential features of a pool fire. Addition of up to 2% methyl bromide to several fuels had no effect on heat transfer. At high fuel supply rates, the data tend to correlate independently of the air requirement of the fuel; at low supply rates, the data tend to correlate independently of volumetric supply rate.

Corlett, R. C. and Fu, T. M., "Some Recent Experiments With Pool Fires." Pyrodynamics. 4:253-269, 1966.

Steady burning rates of methanol, ethanol and acetone in thin-walled stainless steel burners of 0.6 to 30 cm diameter have been studied. Radiation levels were estimated and are found consistent with results of earlier experiments with water-cooled gas burners. Measured water absorption rates are in reasonable agreement with those inferred from burning rate data on the basis of heat and mass transfer similarity.

Crawford, D. B. and Eschenbrenner, G. P., "Heat Transfer Equipment for LNG." Chemical Engineering Progress. September 1972.

This article describes liquefaction heat exchangers and vaporizers for LNG facilities. Advantages, disadvantages, and relative costs for each type are included.

Creighton, J. R., A Two Reaction Model of Methane Combustion for Rapid Numerical Calculations. UCRL-79669, Rev 1, Lawrence Livermore Laboratory, September 28, 1977.

Inclusion of chemical kinetics in the computational schemes for multi-dimensional thermo-hydrodynamic codes (involving flame propagation) results in prohibitively expensive computational time. The author of this report attempts to develop a simplified flame propagation model (of possible use in Lagrangian-Eulerian hybrid codes) which yields acceptable values of flame velocity, temperature and pressure.

Crouch, W. W. and Hillver, J. C., "What Happens When LNG Spills?" Chem. Tech. 2(4):210-215, 1972.

Authors try to assuage certain exaggerated fears about the safety hazards of LNG spills. They stress, however, the need for more information on the behavior of large spills.

Culbertson, L. and Emery, W. B., "Liquefaction Plant Experience at Lenai." Presented at the 3rd International LNG Conference and Exhibition, Washington, DC, September 24-28, 1972.

This paper reviews the more significant problems encountered and solutions employed in the operation of the Alaska to Japan LNG project. This is a follow-up to earlier papers describing design and startup at the Kenai plant.

Dailey, W. V. and Long, E. V., "Remote Sensing of Combustible and Toxic Gases." Analysis Instrumentation, Vol. 17. pp. 89-96, Pro. 1979 Symposium Measurement Technology for the 80's. Instru. Soc. Am., 1979.

Remote sensing systems with central control readout for detecting and monitoring levels of combustible gas (as, e.g., contained in LNG) are described. Detailed specifications are listed. The systems can be obtained from the Mine Safety Appliance Company.

Davenport, J. A., "A Survey of Vapor Cloud Incidents." Loss Prevention. 11:39-49, A CEP Technical Manual, 1977.

The paper gives a survey of open-air, unconfined vapor cloud explosions which have occurred during the last 25 years. The survey is taken from the viewpoint of a major insurance company and is primarily concerned with the property loss (in \$) in the various types of accidents. LNG accidents represent only a minor fraction of all reported cases.

Deaton, W. M. and Frost, E. M., "Gas Hydrate Composition and Equilibrium Data." Proc. Natural Gas Department, American Gas Association. pp. 49-56, 1946.

Phase diagrams as well as equilibrium data were presented.

DeFrondeville, B., "Reliability and Safety of LNG Shipping: Lessons from Experience." Paper presented to the Annual Meeting of the Society of Naval Architects and Marine Engineers, New York, New York, November 10-12, 1977.

This paper reviews LNG shipping experience in Europe, Japan, and the United States. The review concentrates on reliability and safety aspects. The safety/reliability record for liquefaction/loading ports and receiving are also summarized.

Del Tatto, D. L., "LNG Satellite Peakshaving." Presented at the AGA Distribution Conference, Houston, Texas, May 6-9, 1968.

This paper presented by an engineer from Chicago Bridge and Iron describes one of the first LNG satellite operations in the U.S. Both primary liquefaction and peakshaving plant and the satellite peakshaving facility are discussed.

Department of Transportation, "Liquefied Natural Gas Facilities; Federal Safety Standards: Development of New Standards." Federal Register. pp. 8142-8182, Thursday, February 8, 1979.

The notice proposed establishment of a set of comprehensive safety standards governing design, site selection and construction of LNG facilities used in pipeline gas transportation or interstate or foreign commerce. Implications of the regulations and comments are also discussed.

Department of Transportation, "Liquefied Natural Gas Facilities; Federal Safety Standards; Final Rule and Proposed Rule Making." Federal Register. pp. 9184-9237, February 1980.

The final rule establishing a set of comprehensive safety standards governing the design and construction of liquefied natural gas facilities is given. A proposed rule establishing safety standards governing operation and maintenance is also described.

Department of Transportation, "Liquefied Natural Gas Facilities, (LNG); Federal Safety Standards: Development of New Standards," Federal Register, pp. 70776-70800, Thursday, April 21, 1977.

The article sets forth proposed safety standards for LNG facilities. The proposed rules are based largely on National Fire Protection Association Rules (NFPA 59A 1975) and an Arthur D. Little Report summarizing LNG Technology.

Desgroseilliers, G. J. Radiation from Burning Hydrocarbon Clouds. M.S. Thesis, MIT Department of Mechanical Engineers, p. 88, 1978.

Radiation test data from the combustion of methane, ethane and propane are reported. Tests are of small scale with the vapors initially contained in soap bubbles. A newly-developed mathematical model agrees fairly well with the experimental results.

Devanna, L. and Doulames, G., "Planning is the Key to LNG Tank Purging, Entry and Inspection." Oil and Gas Journal. pp. 74-82, September 8, 1975.

Procedures used by the Lowell Gas Co. to purge a one billion cu-ft tank out of service are described in detail. The article includes a drawing showing the piping, valves, and fittings on the tank which are used for purging.

Diller, D. E., "LNG Thermophysical Properties Data and Custody Transfer Measurements." American Gas Association Monthly. March 1979.

Measurement research for custody transfer discussed along with the economic reason for pursuing these studies. Publications in Thermophysical properties of LNG are referenced.

Di Napoli, R. N., "Design Needs for Base-load LNG Storage, Regasification." Oil and Gas Journal. pp. 67-70, October 22, 1970.

Design of base-load storage and vaporization equipment and facilities is described. The article contains particularly good information on the operation and control of sendout pumps and seawater vaporizers.

DiNapoli, R. N., "LNG Peakshaving Plants Require Careful Cost Estimating." Pipeline and Gas Journal. pp. 28-36, May 1978.

The paper reports a dearth of data on the costs of LNG peakshaving plant construction probably due to the competitive nature of the LNG construction industry. Generalized costs of peakshaving and satellite facilities are presented.

Dincer, A. K., Drake, E. M. and Reid, R. C., "Boiling of Liquid Nitrogen and Methane on Water. The Effect of Initial Water Temperature." Int J. Heat Mass Transfer. pp. 176-177, 1977.

This note reports on the results of studies carried out in a vessel equipped to measure the temperature-time history at a number of locations in the bulk water phase as different cryogenes were spilled on the surface. It is concluded that if the initial water temperature is low, heat transfer to the cryogen occurs through a growing ice shield, with little effect on the underlying water. If the water is initially warm, ice forms more slowly and cool surface water is mixed through the bulk.

Drake, E. M., "LNG Rollover--Update." Hydrocarbon Processing. 55:119-122, January, 1976.

The article considers LNG density, effects preceding rollover, rollover time prediction, heat storage, and discusses three documented cases of rollover.

Drake, E. M., Geist, J. M. and Smith, K. A., "Prevent LNG Rollover." Hydrocarbon Processing. 52:87-90, March 1973.

Studies were undertaken of basic mechanisms involved in LNG "roll-over", to predict when they may occur and to evaluate effectiveness of possible preventive measures. Such measures include mixing during filling, limiting variations in LNG composition and lowering tank set point pressure.

Drake, E. M., Jeje, A. A. and Reid, R. C., "Transient Boiling of Liquefied Cryogens on a Water Surface. I - Nitrogen, Methane, and Ethane." International Journal of Heat Mass Transfer. 18:1361-1368, 1975.

The results of an experimental study of the transient boiling rates of pure liquefied nitrogen, methane, and ethane in water are discussed. Nitrogen boiled with the lowest heat flux rate and the highest vapor superheat. For nitrogen, the heat flux rate was found to be proportional to the square root of the liquid head. The heat flux rate for ethane was the lowest and that for methane was intermediate.

Drake, E. M., Jeje, A. A. and Reid, R. C., "Transient Boiling of Liquefied Cryogens on a Water Surface. II - Light Hydrocarbon Mixtures." International Journal of Heat Mass Transfer. 18:1369-1375, 1975.

Light hydrocarbon mixtures similar to liquefied natural gas were boiled on a water surface. The rate of vaporization was measured and the heat fluxes were found to be much higher than that measured for pure liquid methane. Like methane, the rate of vaporization increased during the course of the experiment unless a continuous thick ice layer formed. No significant vapor superheat was noted.

Drake, E. M. and Reid, R. C., "How LNG Boils on Soils." Hydrocarbon Processing. 54(5):191-194, May 1975.

Implications of the paper are that: boil rates of LNG on compacted soils are influenced by soil type, moisture content and LNG composition; reduction in boiling rates can be obtained by sealing the dike surface; dikes of crushed rock or stone will have higher evaporation rates than compacted soil dikes; more studies are needed to assess insulating or sealing materials under LNG spill conditions and on LNG foaming behavior.

Drake, E. M. and Reid, R. C., "The Importation of Liquefied Natural Gas." Sci. Am. 236(4):22-29, 1977.

Arguments in favor and against large-scale importation of LNG are discussed, with the safety question receiving primary attention. On balance, LNG appears to be a relatively safe and promising alternative energy source.

Drake, E. M. and Wesson, H. R., "Review of LNG Spill Vapor Dispersion and Fire Hazard Estimation and Control Methods." Proceedings of A.G.A. Transmission Conference, Las Vegas, NV, May 1976.

This paper reviews techniques presently being used by the LNG industry for evaluating potential LNG vapor dispersion and fire hazards and will describe practical methods for reducing the severity of LNG spill accidents.

Duckham, H. E., "LNG Import Terminal Design Considerations." Cryogenics and Industrial Gases. pp. 41-48, September/October 1972.

This article describes the many processes and mechanical parameters involved in the design of an LNG import terminal. Included are discussions on facilities location, transfer lines, insulation, storage tanks, vapor handling systems, and LNG vaporizers.

Duffy, A. R., Gideon, D. N. and Putnam, A. A., Comparison of Dispersion From LNG Spills over Land and Water. Prepared by Battelle Columbus Laboratories for the American Gas Association, Project SI-3-7, September 4, 1974.

This study examines and compares the available data on dispersion from land and water spills, and explains similarities and differences in results on the basis of differences in experimental techniques and test conditions, and possible differences in pertinent phenomena.

Duffy, A. R., Gideon, D. N., Putnam, A. A. and Bearint, D. E., LNG Safety Program - Phase I - Potential LNG Spills. Report by Battelle Columbus Laboratories and University Engineers, Inc., to the American Gas Association, February 25, 1971.

The report presents data on known spills of LNG or other cryogenes, a discussion and analysis of problem areas, and a discussion of consequences of spills including downwind dispersion, radiation from fires, and reactions with water. Conclusions are summarized and recommendations made for future research.

Dunn, W. A. and Tullier, P. M., Spill Risk Analysis Program Phase II Methodology Development and Demonstration. NTIS No. AD/785026, August 1974.

This report describes research and results in the development and demonstration of systematic methods of assessing the effectiveness of either proposed or recently implemented merchant marine safety regulations. The methods have been designed primarily to assist Coast Guard regulatory decision-makers in their selection of alternative means of reducing marine transportation casualties and spills of hazardous or polluting materials.

Durr, C. A. and Crawford, D. B., "LNG Terminal Design." Hydrocarbon Processing. November 1973.

This article discusses the special problems associated with design of an LNG terminal. Particular attention is given to the transfer line and the vapor handling and pressure control system.

Durr, C. A., "Process Techniques and Hardware Uses Outlined for LNG Regasification." Oil and Gas Journal. May 13, 1974.

The following components of an LNG terminal are discussed by a process engineer from M. W. Kellogg: LNG unloading, storage, vapor handling, sendout pumps, vaporizers, power generation, nitrogen system, and heat recovery.

Ecosystems, Inc., Expected Behavior of an LNG Release Under Specified Conditions. Report to Federal Power Commission, August 17, 1973.

The report comprised an assessment of hypothetical LNG spill situations in the Staten Island area. Results were calculated using methods of the Esso Research and Engineering Company. Three tasks described are analyses of a 100,000 m³ spill over water, analyses of evaporation and dispersion following an LNG tank roof failure, and a description of the New York Harbor climate.

Edeskuty, F. J., Critical Review and Assessment of Problems in Hydrogen Energy Delivery Systems. Initial Report, Los Alamos Scientific Laboratory LA-74-PR Progress Report UC-41, August, 1978.

A preliminary risk assessment for the transport of gaseous hydrogen by pipeline and liquid by tank trucks is presented. Metal embrittlement by liquid hydrogen is discussed and regulations are reviewed.

Edwards, J. G., "A Combustible Gas Detection System for an LNG Terminal." Analysis Instrumentation, Vol. 17. Proc. 1979 Symposium on Measurement Technology for the 80's. Instr. Soc. Am., pp. 84-88, 1979.

For reasons of personnel safety and plant integrity, combustible gas detection systems are required in all LNG facilities. Practical guidelines are given for the reliable operation of such systems.

Edwards, R. M., "The Application of Sub-X Heat Exchanger for Vaporization of Liquid Natural Gas." American Society of Mechanical Engineers publication, 8 pp., September 1967.

The basic design and development of the Sub-X heat exchanger for vaporization of liquefied natural gas is presented in this paper. Detailed drawings and discussions are included.

Eichhoff, H. E. and Grethe, K., "A Flame Zone Model for Turbulent Hydrocarbon Diffusion Flames." Combustion and Flame. 35(2):267-275, August 1979.

The authors present a flame zone model which corrects the deficiency of two previous models (called the flame sheet and equilibrium models) by more correctly accounting for the intermediate reaction species. Comparison with experiment supported their model.

Eichler, T. V. and Napadensky, H. S. Accidental Vapor Phase Explosions on Transportation Routes Near Nuclear Power Plants. U.S. Nuclear Regulatory Commission, NUREG/CR-0075, 1977.

A review of vapor cloud explosion literature is used to develop a method to estimate TNT equivalency for accidental blasts as a tool for calculating exclusion distances for hazardous materials near nuclear plants.

Enger, T., "Explosive Boiling of Liquefied Gases on Water." Conference Proceedings on LNG Importation and Terminal Safety, Boston, MA, June 13-14, 1972.

Explosive boiling of a liquefied gas mixture such as LNG on ambient water can only be produced when the methane content is less than 40 mole percent. The potential hazard of having explosive boiling from an LNG spill is negligible during commercial transportation of LNG. In addition, energy estimates show that the potential damage from explosive boiling of a liquefied gas is minimal.

Enger, T. and Hartman, D. E., "Mechanics of the LNG-Water Interaction." Paper presented at the American Gas Association Distribution Conference, Atlanta, GA, May 8, 1972.

Shell Pipe Line Labs has conducted research since 1970 on rapid phase transformation which can occur when LNG is spilled onto water. "Explosive" LNG-water interaction results because of rapid phase transformation and violent expansion of a thin layer of superheated LNG at the interface between the LNG and water. It is stated that "explosions occur only when LNG is in a weathered state, i.e., when the methane content of LNG is less than 40 mole percent."

Enger, T. and Hartman, D. E., "Rapid Phase Transformation During LNG Spillage on Water." Paper presented at the Third International Conference and Exhibition on LNG, Washington, DC, September 24-28, 1972.

It is shown that "explosions" can only occur with "aged" LNG which contains less than 40 mole percent methane. The "explosive" interaction between a liquefied gas and water is caused by the rapid phase transformation and violent expansion of a thin layer of superheated liquefied gas at the liquefied gas-water interface.

Enger, T., Hartman, D. E. and Seymour, E. V., "Explosive Boiling of Liquefied Hydrocarbon/Water Systems." Paper presented at the Cryogenic Engineering Conference, National Bureau of Standards, Boulder, CO, August 9-11, 1972.

The conditions which produce "explosions" when LNG is spilled on water at ambient temperature have been isolated and verified experimentally. It has been shown that "explosions" can only occur with "aged" LNG which less than 40 mole percent methane. Contact between water and LNG with more than 40 mole percent methane produces normal vaporization.

Enger, T., Hartman, D. E. and Seymour, E. V., "Explosive Boiling of Liquefied Hydrocarbon/Water Systems." Adv. Cryo. Eng. 18:32-41, 1973.

The mechanism of LNG/water interactions, and the conditions under which they can occur, are described. The explosive boiling, which has been observed, is explained as a result of superheating of the liquefied gas.

England, W. G., Teuscher, L. H., Hauser, L. E. and Freeman, B. E., "Atmospheric Dispersion of Liquefied Natural Gas Vapor Clouds Using Sigmet, a Three Dimensional Hydrodynamic Computer Model." Proceedings of the 1978 Heat Transfer and Fluid Mechanics Institute, Washington State University, Pullman, Washington, June 26-28, 1978.

The SIGMET dispersion model is presented in the form that it is applied to LNG vapor dispersion problems. Model results are presented for examples of plume behavior and to verify model predictions. Model numerical methods are also described.

Ermak, D. L. and Bowman, B. R., "Average Dispersion of a Liquefied Natural Gas Vapor Plume." UCID-17968-79-1, pp. 1-10, Lawrence Livermore Laboratory, 1979.

The theoretical predictions for the vapor spread from an LNG spill are compared with experimental data obtained in a China Lake test. Agreement is fair. Prevailing winds are shown to have a significant influence but are hard to model.

Escudier, M. P., "Aerodynamics of a Burning Turbulent Gas Jet in a Crossflow." Combustion Science and Technology. 4:293-301, 1972.

The study extends the entrainment theory for weak plumes by including into its framework the influences of radiative thermal-energy transfer, large density variations, and thermal-energy generation through chemical reaction. Thermal radiation is found to be of secondary importance to plume dynamics. Calculations show that a plume's motion is not significantly influenced by buoyancy forces until well downstream of the reaction zone.

Evaluation of LNG Vapor Control Methods. Report to the American Gas Association by Arthur D. Little, Inc., Cambridge, Massachusetts, October 1974.

It is shown that, for the high spill rates, the maximum downwind hazard zone is not significantly affected by shutdown of the leak in the 10-minute period specified in the NFPA Code. To be effective in reducing downwind hazards shutdown of the leak should be accomplished as soon as possible, preferably under 2 minutes.

Fannelop, T. K. and Waldman, G. D., "The Dynamics of Oil Slicks - Or 'Creeping Crude'." AIAA Paper No. 71-14 presented at the AIAA 9th Aerospace Sciences Meeting, New York, New York, January 25-27, 1971.

The spread of an oil slick into calm water is considered from a theoretical viewpoint. The equations of motion are derived for the gravity-inertial and gravity-viscous flow regimes. For both two-dimensional and radial slicks, similarity solutions are obtained for the two flow regimes which give adequate agreement with available experimental data.

Farley, M., "The LNG Plant Design Engineer." LNG/Cryogenics. pp. 25-27, February/March 1973.

This article, through interviews with six individuals involved in LNG plant design activities, provides a brief overview of some of the problems they have had to cope with on various projects.

"Fast LNG-leak Detector Developed." Oil and Gas Journal. pp. 52, December 19, 1977.

A new device developed and patented by the Direction of Studies and New Techniques of Gaz de France is claimed to provide fast detection and location of leaks in large storage tanks. The location for the detector, at the bottom of the annular space between the walls and next to the internal tank, was determined following tests made on a reduced model tank.

Fauske, H., "The Role of Nucleation in Vapor Explosions." Transactions of the American Nuclear Society. 15:813-815, 1972.

The paper suggests a possible mechanism for vapor explosion and examines the validity of the mechanism in light of available experimental facts.

Fay, C., Desgroseillier, G., and Lewis, D., "Radiation from Burning Hydrocarbon Clouds." Combustion Science and Technology. 20, 1979.

This paper is a report of a series of experiments performed at M.I.T. Small scale fireballs were created in the laboratory and the time-dependent thermal emission was measured by a radiometer. Various correlations concerning fireball parameters (diameter, temperature, etc.) are presented.

Fay, J. A., Scale Effects in LNG Hazard Analysis and Testing. Progress Report for period 12/1/76 to 8/21/77. ERDA Contract No. EE 77-S-02-4204.

The effect of LNG spill size on the physical parameters in hazard analysis has been investigated. Measurements of radiant heat envisions have been made.

Fay, J. A., "Unusual Fire Hazard of LNG Tanker Spills." Combustion Science and Technology. 7:47-49, 1973.

This report gives theoretical expressions for the pool spread and evaporation rate of liquefied natural gas spilled on water, the gravitational spread, and the heating and downwind spread of the vapor cloud. It does not treat the diffusion or mixing of the vapor with air.

Fay, J. A. and Lewis, D. H., Jr., "The Inflammability and Dispersion of LNG Vapor Clouds." Proceedings of the Fourth International Symposium on Transport of Hazardous Cargoes by Sea and Inland Waterway, Jacksonville, FL, October 26-30, 1975, NTIS No. AD/A023505, pp. 489-498, October 1975.

The paper considers the statistical properties of LNG vapor concentration, the mean vapor concentration in dispersing cloud and downwind distances for two flammability conditions.

Fay, J. A. and Lewis, D. H., "Unsteady Burning of Unconfined Fuel Vapor Clouds." 16th International Symposium on Combustion, 1976.

The problem of fireball hazards associated with LNG and LPG spills is investigated. A derivation of fireball maximum radius, height above surface and time required, are obtained by phenomenological, empirical and dimensional (with some physical and mathematical) analysis. Experimental corroboration is included.

Feirabend, C. E., "Design Considerations for LNG Production Facilities in Arctic Regions." 1978 Operating Section Preceedings, American Gas Association, Montreal, Quebec, May 1978.

Operational and engineering design responses to extremes of temperature and windspeed in arctic regions are considered.

Feldbauer, G. F., Heigl, J. J. and McQueen, W. et al., Spills of LNG on Water - Vaporization and Downwind Drift of Combustible Mixtures. Report No. EE61E-72, Esso Research and Engineering Company, May 24, 1972.

A total of seventeen LNG spill tests, ranging in size from about 250 to 2500 gallons, were carried out under a variety of weather conditions. The main thrust of the experimental work was aimed at measuring the parameters required to predict downwind concentrations. The aim of the experimental work was to measure the plume shape and other information which would permit the data on these variables to be extrapolated.

Felske, J. D. and Tien, C. L., "Calculation of the Emissivity of Luminous Flames." Combustion Science and Technology. 7:25-31, 1973.

A simple analytical basis for determining the total emissivity of luminous flames is developed. The analysis considers flames whose dominant emitting species are water vapor, carbon dioxide and soot particles. Calculations are made to illustrate the relative importance of gas and soot emission under typical flame conditions.

Filstead, C. G., "The Design and Operation of LNG Ships with Regard to Safety." Shipping World and Shipbuilder. pp. 259-262, February 1972.

This article summarizes the safety features and operating procedures of LNG ships particularly the Methane Princess and Methane Progress.

Findlater, A. E. and Prew, L. R., "Operational Experience with LNG Ships." LNG 5 - International Conference on Liquefied Natural Gas, 5th Proceedings, Session IV Paper 5, 16 pp., Duesseldorf, Germany, August 29-September 1, 1977.

Some of the experience gained during the initial years of operation of the shipping phase of the Shell Bruenei/Japan LNG scheme are presented in this paper. The operational planning required for the successful commissioning and operation of a fleet of gas carriers and the wide range of disciplines and expertise involved is also included in this paper.

Fortson, R. M., Holmboe, E. L., Brown, F. B., Kirkland, J. T., Tullier, P. M. and Dayton, R. B., Maritime Accidental Spill Risk Analysis Phase I: Methodology Development and Planning. NTIS No. AD/761362, January 1973.

This report develops a methodological approach and task plan for assessing alternative methods of reducing the potential risk caused by the spill of hazardous cargo as the result of vessel collisions and groundings. In addition to developing the overall study approach, a very preliminary analysis of ship/barge accidents in U.S. territorial waters and port traffic was done to identify types of accidents to be examined in the next phase of the study effort.

Fourth International Conference on Liquefied Natural Gas. Papers, Place of Nations, Algiers, Algeria, June 24-27, 1974.

This book is a collection of papers presented at the conference. The papers have been divided into 8 sessions according to their subject matter.

Fowles, G. R., "Vapor Phase Explosions: Elementary Detonations?" Science. 204:168-169, 1979.

A new theory is outlined which would explain a vapor explosion as an elementary detonation. It predicts the energy resulting from a superheated liqueried methane vapor explosion as 95 J/g.

Garforth, A. and Pallis, C., "Luminar Burning Velocity of Stoichiometric Methane-Air; Pressure and Temperature Dependence." Combustion and Flame. 31:69-83, 1978.

The authors of this paper determine the flame velocity in a stoichiometric methane-air mixture (for initial various temperatures and pressure) experimentally and analytically, with resulting good agreement between the two.

Garland, F. and Atkinson, G., The Interaction of Liquid Hydrocarbon With Water. U.S. Coast Guard, Office of Research and Development, NTIS No. AD/753561, October 1971.

This is an investigation of the phenomena reported in a Bureau of Mines report which studied the hazards of LNG. During the investigation, LNG was dropped onto a variety of liquid samples. Explosions did not occur when pure water was used as the sample, but water contaminated with n-hexane or toluene gave an explosion every time. Peak explosion pressures are given for a variety of experimental conditions.

Gaydon, A. G. and Wolfhard, H. G., Flames - Their Structure, Radiation and Temperature. Chapman & Hall Ltd., London, 1960.

The book includes information concerning premixed flames, flow patterns and shapes, burning velocity; propagation, diffusion, stability, carbon in flames, radiation, temperature, ionization, combustion processes of rocket fuels, and recent progress on some flame problems.

Georgakis, C., Congalidis, J. and Williams, G. C., "Model for non-instantaneous LNG and Gasoline Spills." Fuel. 58:113-120, February 1979.

A predictive model for non-instantaneous spills is presented which is applied to holes in storage vessels for gasoline and LNG. Effects of spill size and shape and combustion are discussed and results are compared to those for instantaneous spills.

Germes, A. E., "A New Model for LNG Tank Rollover." Paper presented at the Cryogenics Engineering Conference, Kingston, Ontario, July 1975.

A dynamic model is presented which can give very accurate rollover predictions and is a potentially powerful tool in rollover prevention strategies. The excellent agreement between the predictions of the model and observations for the La Spezia rollover indicate that the model is valid. Uncertainties in the model transport coefficients indicate that further validation of the model would be desirable. The model has been computerized.

Germes, A. E., "Forced Plumes and Mixing of Liquids in Tanks." Journal of Fluid Mechanics. 71:601-623, 1975.

A mathematical model for the mixing of two miscible liquids of different density is presented, from which the tank stratification can be computed.

Germes, A. E. and Drake, E. M., "Gravity Spreading and Atmospheric Dispersion of LNG Vapor Clouds." Proceedings of the Fourth International Symposium on Transport of Hazardous Cargoes by Sea and Inland Waterway. Jacksonville, FL, October 26-30, 1975, NTIS No. AD/A023505, pp. 519-539, October 1975.

The paper presents methods for estimating the extent and location of flammable vapors as a function of spill and weather conditions, assuming that ignition does not occur. Models allow the width of the vapor cloud to be computed at the point of ignition for consequence analysis.

Gibson, G. H., "Consider Safety, Reliability, Cost in Selecting Type of LNG Storage." Oil and Gas Journal. pp. 65-69, February 8, 1971.

Several types of LNG storage are compared with respect to safety and cost.

Gideon, D. N. and Putnam, A. A., "Dispersion Hazard from Spills of LNG on Land and on Water." Cryogenics. 17, January 1977.

This report analyzes the pertinent published data on dispersion of vapors from LNG spills on land and water. Correlation of these data is based on the commonly used relationships from dispersion theory. The report has emphasized peak concentration rather than average or 'maximum average' concentrations and for instantaneous spills. The peak concentrations of major interest to safety, are related to the peak vaporization rates.

Gideon, D. N., Putnam, A. A. and Duffy, A. R., Comparison of Dispersion from LNG Spills Over Land and Water. Report to the American Gas Association by Battelle Columbus Laboratories, Project IS-3-7, A.G.A. Catalog No. M19877, September 4, 1974.

The report discusses dispersion variables, spill characteristics on water, a description of LNG programs, and provides comparisons of dispersion data.

Gideon, D. N., Putnam, A. A. and Duffy, A. R., "Safety Aspects of LNG Spills on Land." Advances in Cryogenic Engineering. 21:377-386. Paper presented at 1975 Cryogenic Engineering Conference held at Queen's University, Kingston, Ontario, July 22-25, 1975.

The paper provides information concerning experimental spills of LNG. Instrumentation and procedures, the dispersion hazard, the radiation hazard, and fire control and vapor suppression are discussed.

Gifford, F. A., Jr., "Use of Routine Meteorological Observations for Estimating Atmospheric Dispersion." Nuclear Safety. 2(4):47-51, June 1961.

The article considers vertical dispersion of a cloud or plume and gives estimates of the lateral spread as well as wind speed and direction.

Goldfeder, L. B., "Control Valves for LNG Facilities." Pipeline and Gas Journal. pp. 58-74, January 1972.

The types, applications and materials of construction of control valves for LNG are reviewed.

Goodwin, R. D., The Thermophysical Properties of Methane, from 90 to 500 K at Pressures to 700 Bar. NBS Tech. Note 653, 1974.

An extensive tabulation of the thermophysical property data for Methane is presented. The temperatures covered range from 90 to 500 K and the pressure up to 700 bars.

Green, K. A., Tiffin, D. L., Luks, K. D., and Kohn J. P., "Solubility of Hydrocarbons in LNG, NGL." Hydrocar. Process. 58(5):251-253, 1979.

Experiments are described to verify correlations for multicomponent solid-liquid-vapor behavior of realistic natural gas systems. The resulting test data are in essential agreement with correlations derived earlier.

Griffis, K. A. and Smith, K. A., "Convection Patterns in Stratified LNG Tanks - Cells Due to Lateral Heating." Paper presented at the 3rd Conference on Natural Gas Research and Technology, Dallas, TX, March 6-8, 1974.

The paper treats the subject of layer formation due to a uniform lateral heat flux, such as exists at an LNG tank wall. Experimentally, a water sugar system has been used to model the methane-higher hydrocarbon system. Preliminary results indicate that convective layers will be relatively thin for cases which are germane to LNG storage.

Guise, A. B., "How to Fight Natural Gas Fires." Hydrocarbon Processing. 54:76-79, August 1975.

The following recommendations are made for coping with natural gas fires: 1) assume all fires to be impinging, 2) use potassium bicarbonate-base dry chemical, 3) use multipurpose dry chemical where water is not available, 4) use high velocity concentrated streams, and 5) use protective clothing and face shields.

Gullberg, R. W., "NWNG's Newport LNG Facility First User of CRYEX Purification." Pipeline and Gas J. 206(13):40-48, 1979.

A new concept for removing carbon dioxide from a gas stream is incorporated into Northwest Natural Gas Co.'s LNG peakshaving facility on Yaquina Bay, 114 miles southwest of Portland, Oregon.

Guthrie, J. K. and Gregory, E. J., "Design of Baseload Evaporators for LNG."

The design and operation of an open rack vaporizer and an indirect fired vaporizer are discussed.

Haines, G. H. and Thompson, J., "Offshore Gas Liquefaction Without Offshore LNG Plants." Oil & Gas J. 78:87-91 February 18, 1980.

It is proposed to liquefy natural gas with liquid nitrogen stored aboard a tanker moored to an offshore drilling platform. At the shore-based terminal, the liquid nitrogen in turn is produced with some of the "cold" derived from vaporizing the LNG. It is claimed that such an operation is well within existing technology and is also economical.

Hale, D., "LNG Projects Develop Overseas, Only Regulations Develop in U.S." Pipeline and Gas Journal. pp. 17-21, June 1979.

The article provides an industry summary of LNG activities in 1978 and includes a list of foreign and U.S. LNG facilities.

Hale, D., "Peakshaving Capabilities Ready for 1979 - 1980 Winter Season." Pipeline and Gas J. 206(13):22-25, 1979.

U.S. peakshaving capabilities will be at a record high for the 1979-1980 winter seasons as underground gas storage capacity and withdrawal/send-out capacity reach new peaks and LNG peakshaving capacity reaches an all-time high; new peakshaving capacity is about 70 billion ft³/day.

Hall, A. R., "Pool Burning." Oxidation and Combustion Reviews. 6:169-225, Elsevier Scientific Publishing Company, 1973.

This review of literature includes: influence on the burning characteristics; temperature distribution in the liquid and the phenomena of hot zone formation and boilover; prevailing concepts of heat transfer from the flame to the liquid; effect of water as a dispersed phase, and as a substrate, on burning.

Hall, D. J., Barrett, C. F. and Ralph, M. O., Experiments on a Model of an Escape of Heavy Gas. LR 217 (AP), Warren Spring Laboratory. Department of Industry, Hertfordshire, United Kingdom, 1976.

The report describes model experiments on a release of a heavy explosive gas, propane or butane, into the atmosphere at ground level. Both long and short term releases are considered and the validity of the model is discussed. A method of extrapolating the experimental results to full scale is provided.

Hall, R. J., "CARS Spectra of Combustion Gases." Combustion and Flame. 35(1):47-60, May 1979.

The author presents a theoretical basis for obtaining species concentration and temperatures in turbulent, sooty flames using Coherent-Anti-Stokes Raman Spectroscopy (CARS). Comparisons of theory and experiment are presented.

Hall, S. F., A Simple Homogeneous Equilibrium Critical Discharge Model Applied to Multi-Component, Two Phase Systems. Safety and Reliability Directorate (U.K.), Report SRO R 127, May 4, 1978.

Two models of two phase critical discharge from reservoirs are presented which are applicable for spill calculations from breaches in storage tanks or piping.

Halverson, G., "Automatic Continuous LNG Level-Gauging and Temperature Measuring System." Proceedings of the 1st Biennial Symposium on Cryogenic Instrumentation, Vol. 1, 1976.

This paper describes a system which is being used to make accurate measurements of the liquid level and temperature profile in LNG storage tanks.

Handman, S. E., "Pros and Cons of LNG Safety." Pipeline Industry. pp. 39-42, September, 1979.

This paper reviews types of existing LNG facilities, agencies which have jurisdiction over the facilities, and risks associated with LNG facilities versus risks associated with other human activities.

Hankel, C. C., LaFare, I. V. and Litzinger, L. F., "Purging LNG Tanks Into and Out of Service Considerations and Experience." Paper presented to the AGA Transmission Conference, Minneapolis, Minnesota, May 6-8, 1974.

This paper discusses detailed procedures used by Chicago Bridge & Iron for purging LNG tanks into and out of service.

Hankinson, R. W. and Thomson, G. W., "Calculate Liquid Densities Accurately." Hydrocarbon Processing. pp. 277-282, September, 1979.

Liquid density calculation methods are compared on 3000 compounds; results on 190 of these are presented. The Costald - Corresponding States Liquid Density method was found to be more accurate than the Yen-Woods or modified Rackett Equation (SDR) methods.

Hardee, H. C., Lee, D. O. and Benedick, W. B., "Thermal Hazards from LNG Fireballs." Combustion Sci. and Techn. 17:189-197, 1978.

LNG fireballs can pose serious burn hazards in their vicinity. Third degree burns from a very large LNG fireball (several 10^7 kg) could occur out to several kilometers from its center.

Harsha, P. T., LNG Safety Program Topical Report: Dispersion Modeling. Report RDA-TR-1100-003, by R&D Associates for the American Gas Association, July 1976.

A variety of techniques exist for near-field LNG dispersion phenomena; Gaussian plume models are inappropriate; hydrostatic models are appropriate; three-dimensional numerical models have been demonstrated; a general LNG vapor dispersion model should incorporate sophisticated state-of-the-art turbulence models.

Haselden, G. G., "Developments in Gas Liquefaction and Separation." Int. J. Refrig. 2(6):207-210, November, 1978.

Some of the most interesting papers presented to the Gas Liquefaction and Separation Commission of the IIR are reviewed. A novel LNG peak-load storage plant was described in which the excess cooling capacity available during most of the year is used to produce low cost liquid oxygen and nitrogen. On a larger scale, design studies were reported showing the advantages to be gained by cooling natural gas before admitting it to very long transmission pipelines. For duties above 100×10^9 m³/year, piping LNG is recommended.

Haselden, G. G., "The Achievements and Potential of LNG for Energy Storage and Transport." Inst. Chem. Eng. Sym. 44:7-13, 1976.

The paper presents a brief general overview on present LNG technology, highlighting those features that make LNG transport economically attractive.

Hashemi, H. T., Lott, J. L., Wesson, W., D. and Wesson, H. R., "Effect of Barometric Pressure Changes on Rate of Boiloff in a Storage Tank of Saturated Liquids." 1978 Operating Section Proceedings, American Gas Association, Montreal, Quebec, May 1978.

An analytical model for prediction of boiloff variations due to atmospheric pressure changes in atmospheric storage tanks is presented. LNG examples are shown although the model can be applied to various other cryogenic gases.

Hashemi, H. T. and Wesson, H. R., "Cut LNG Storage Costs." Hydrocarbon Processing. pp. 117-120, August 1971.

Better, more precise designs can be made using a new mathematical model which more closely predicts actual boil-off rates. LNG losses and storage costs are reduced.

Havens, J. A., A Description and Assessment of the SIGMET LNG Vapor Dispersion Model, U.S. Coast Guard Report, CG-M-3-79, 1979.

The mathematical model SIGMET, which has been developed to predict dispersion of LNG vapor clouds from large spills on water, is described in great detail. The particular features of the model are discussed and evaluated. Conclusions and recommendations for further improvement of the model are given.

Havens, J. A., Predictability of LNG Vapor Dispersion From Catastrophic Spills Onto Water: An Assessment. Report prepared by the University of Arkansas for the Cargo and Hazardous Materials Division, Office of Merchant Marine Safety, U.S. Coast Guard, April 1977.

The author has reviewed various mathematical models and the methodology described by SAI and believes that such techniques hold the most promise for accurate prediction of vapor dispersion from catastrophic spills on water. A program designed to evaluate the accuracy of the SAI model or other models should now be considered high priority.

Heat Transfer at the Air-Ground Interface With Special Reference to Airfield Pavements. Report Prepared by the Massachusetts Institute of Technology, Department of Civil and Sanitary Engineering, Soil Engineering Division, Technical Report No. 63, January 1961.

The variables which affect the transfer of heat at the air-earth interface were studied as a part of an investigation to improve techniques for predicting subsurface temperatures. The investigation demonstrates that certain readily obtainable measurements may be utilized to predict the amounts of heat flow at the ground surface due to various atmospheric phenomena.

Henry, R. E., Gabor, J. D., Winsch, I. O. and Spleha, E. A. et al., "Large Scale Vapor Explosions." Argonne National Laboratory, Argonne, IL. Paper presented at the Fast Reactor Safety Meeting, Beverly Hills, CA, April 2-4, 1974.

Experimental results with Freon-22 and water show that the interface temperature homogeneous nucleation model accurately predicts the necessary temperature conditions for the onset of large scale vapor explosions. Test results for many different contact modes revealed that the magnitudes of explosions were highly dependent upon contact mode.

Hertzberg, M., "The Theory of Free Ambient Fire. The Convectively Mixed Combustion of Fuel Reservoirs." Combustion and Flame. 21:195-209, 1973.

The theory of fuel-reservoir fires is extended and amplified into a quantitative formulation that includes all the significant physical processes: mass diffusion, heat conduction, convective mixing, convective heat transport, and radiative heat transport. The predictions are compared with the data for 3 fuels (gasoline, liquid hydrogen, and methanol), and the comparison gives reasonable agreement.

Hertzberg, M., Cashdollar, K., Litton, C. and Kansa, E., "The Diffusion Flame in Free Convection. Buoyancy-Induced Flows, Oscillations, Radiative Balance and Large-Scale Limiting Rates." Paper presented at the Central States Section, Combustion Institute Meeting on Fluid Mechanics of Combustion Processes, Cleveland, OH, March 29-30, 1977.

Early studies of flame oscillations are reviewed and new data are presented for the fundamental infrared flicker frequencies of methanol pool flames and other diffusion flames. Measured frequencies decrease monotonically with increasing size, in good agreement with independent data obtained photographically and acoustically.

Heskestad, G., Kung, H. C. and Todtenkopf, N. F., "Air Entrainment into Water Sprays and Spray Curtains." ASME Winter Annual Meeting, New York, New York, 1976.

Theoretically derived volumes of entrained air were found to agree with experimental values to within 17%. While no explicit reference is made to LNG, the results are sufficiently general to apply to the vapor stage of an LNG spill.

Hindle, W., Arctic Islands LNG. Presented to the Americal Gas Association Transmission Conference, Montreal, Quebec, May 8-10, 1978.

Trans Canada has begun the study and design of an LNG project which would transport LNG from the high Arctic Islands to Quebec. The type of ship that would be used, an icebreaking LNG carrier, is described.

Hoehne, V. O. and Luce, R. G., "The Effect of Velocity, Temperature, and Molecular Weight on Flammability Limits in Wind-Blown Jets of Hydrocarbon Gases." Proceedings, Division of Refining. API, 50:1057-1081, 1970.

Various diameter jets of methane, ethane, butane, and heptane gas were directed perpendicular to the wind stream in a wind tunnel. Measurements were made to define the flammable zone caused by the jet-wind interaction. The application of the test results to practical process plant vent spacing to minimize hazards during windy atmospheric conditions is illustrated.

Holman, O. B., "LNG Peakshaving Plant Design Features and Operating Experiences." Paper presented to Seminar and Study Tour on LNG Peakshaving, Washington DC, March 5-9, 1979.

This paper reviews the design features and operating experiences of the Philadelphia Gas Works Richmond Peakshaving Plant. The plant uses a cascade liquefaction process, a prestressed concrete type design for storage and running film vaporizers.

Hottel, H. C. and Sarofim, A. F., Radiative Transfer. Chapter 6, McGraw-Hill Book Company, 1967.

Chapter 6 deals with gas emissivities and absorptivities.

Hoult, D. P., "The Fire Hazard of LNG Spilled on Waters." Proceedings on LNG Importation and Terminal Safety. NTIS No. AD/754326, Boston, MA, June 13-14, 1972.

The paper considers the rate of evaporation of LNG spilled on water, the negatively buoyant plume, heat transfer to the plume, the buoyant puff, and concludes that there is no single rule whereby the fire hazard of an LNG spill may be estimated.

Howard, J. L., and Andersen, P. G., "Barge-Mounted Gas Liquefaction and Storage Plant." Chem. Eng. Progr. 75(10):76-81, 1979.

The design and operation of a floating LNG facility for liquefaction, storage and export of natural gas are described. This new plant was to be built in modules by shipyards in highly industrialized areas and to be towed to Iran for installation near Kangan.

Howard, M. A., "Second Generating Peakshaving Plant Benefits from Experience." Pipeline and Gas Journal. November 1978.

Northern Natural Gas has two peakshaving plants, one built in 1975 and other in 1978. This article discusses the lessons learned at the first facility and the various design changes in the second facility that resulted.

Humbert-Basset, R. and Montet, A., "Dispersion dans l'Atmosphere d'un Nuage Gazeux Forme par Epondage de G.N.L. sur le Sol." Paper presented at the Third International Conference on LNG, September 1972.

An experimental study conducted by GAZ de FRANCE at the test station of NANTES is described. To investigate the hazards occurring from spillage, measurements of evaporation rates of LNG on various soils were made. In addition, measurements were made of the extent that clouds generated from spillage in diked areas up to 200 m². A mathematical model was utilized in the extensive study of the hazards problem.

Jamison, L. R., "United States Codes and Regulations Affecting the Marine Aspects of LNG Movements." 1978 Operating Section Proceedings, American Gas Association, Montreal, Quebec, May 1978.

This paper presents a collection of regulations which influence marine movement of LNG. Agencies regulating this transport are the U.S. Coast Guard, Intergovernmental Marine Consultative Organization, and the Republic of Liberia Bureau of Marine Affairs.

The Japan Gas Association, A Study of Dispersion of Evaporated Gas and Ignition of LNG Pool Resulted From Continuous Spillage of LNG Conducted During 1975. April 1976.

LNG spill tests were conducted for continuous releases to determine the characteristics of evaporation, dispersion, and ignition of pool fires. Tests were concerned mainly with the vapor cloud dispersion and the resultant cloud dimensions and character.

Jaquette, D. L., Possibilities and Probabilities in Assessment of the Hazards of the Importation of Liquefied Natural Gas. Rand Corporation. Study P-5411, AD/A019353, 1975.

Currently prevailing assessment of the safety hazards of LNG spills is criticized. The unknowns of such spills are listed and the need for more definitive information is stressed.

Javelle, B. and Raynaud, J., "Structural Problems in Methane Carriers." Shipping World and Shipbuilder. pp. 831-833, September 1975.

The authors briefly discuss stress calculations for LNG ships. They include fatigue, lamellar teaming, crack propagation, and liquid motions.

Jeje, A. A. and Reid, R. C., "Boiling of Liquefied Hydrocarbons on Water." Paper presented at the Third Conference on Natural Gas Research and Technology, Dallas, TX, sponsored by the American Gas Association, March 1974.

The cryogens studied were liquid nitrogen, methane, ethane, and several typical LNG compositions. In general, boiling fluxes increased slightly as the initial water temperature was lowered and as more cryogen was spilled. For LNG mixtures, significant foaming resulted and it is also suspected that ice is rapidly formed and remelted by eddy circulation in the upper layer of water.

Jeje, A. A. and Reid, R. C., Transient Pool Boiling of Cryogenic Liquids on Water.

Boiling rates of LNG and LPG on water are determined as a function of water temperature and liquefied gas composition.

Jensen, D. E. and Jones, G. A., "Reaction Rate Coefficients for Flame Calculations." Combustion and Flame. 34:1-34, 1978.

Current functional forms for chemical reaction rates and corresponding uncertainty factors are presented.

Jensen, D. E., Spalding, D. B., Tatchell, D. G. and Wilson, A. S., "Computation of Structures of Flames with Recirculating Flow and Radial Pressure Gradients." Combustion and Flame. 34(3):300-326, April 1979.

The authors present a technique for modeling steady-state, axis symmetric, highly-turbulent chemically reacting flow from a rocket engine. This technique has many features relevant to LNG pool fire modeling.

Kato, D., "Ultra Low-Temperature LNG Compressors." Fifth International Conference on LNG, Session II, paper 10, Institute of Gas Technology, 1977.

Special compressors for recompression of LNG boil-offs in storage facilities are described.

Katz, D. L., "LNG-Water Explosions." NTIS No. AD/775005, 1973.

The "limit of superheat" is identified as the cause of LNG-water explosions. However, theoretical support for this argumentation is mainly speculative.

Katz, D. L., "Superheat-Limit Explosions." Chemical Engineering Progress. 68:68-69, May 1972.

The rapidity of this superheat-limit event as compared to nucleated bubble growth in a partially superheated liquid provides an explanation for vapor explosions discussed in the literature.

Katz, D. L. and Sliepcevich, C. M., "LNG/Water Explosions: Cause and Effect." Hydrocarbon Processing. 50:240-244, November 1971; also NTIS No. AD/775005.

The paper discusses the limit of superheat, the methane-water system, LNG mixtures, massive LNG spills, and considers other systems such as liquid methane poured into pure pentane in the absence of water.

Katz, D. L. and West, H. H., "LNG Shipping and Storage." Paper Presented to the Engineering Foundation Conference on Risk/Benefit Methodology and Application, Asilomar, California, September 21-26, 1975.

This article gives an overview of the history and development of the LNG industry with emphasis on storage and shipping. Potential hazards associated with LNG are discussed briefly.

Kaustinen, O. M., "Polar Gas Project." Presented to the American Gas Association Transmission Conference, Montreal, Quebec, May 8-10, 1978.

Some of the alternative methods of moving natural gas from Canada's Arctic Islands are discussed.

Kee, R. J. and Miller, J. A., "A Split-Operator, Finite Difference Solution for Axisymmetric, Laminar-Jet Diffusion Flames." AIAA Journal. 16(2), February, 1978.

An economical numerical solution of a vertical diffusion flame is presented. The complete chemical kinetics of the problem are included. Discussions of possible numerical treatment of the thermo-hydrodynamics and the "stiff" chemical kinetics are presented. "Majorant" splitting (as opposed to ADI methods) and the Gear-Hindmarsh "stiff" equation methods are utilized in the paper.

Kee, R. J., The Computational Nature of Combustion Modeling, Sandia Laboratories, SAND78-8245, Albuquerque, New Mexico, July 1978.

The report presents a fundamental approach to computations for combustion systems. Specific problems and numerical algorithms are presented.

Keeny, R. L., Kulkarni, R. B. and Nair, K., "Assessing the Risk of an LNG Terminal." Technology Review. pp. 65-71, October 1978.

The report presents a description of LNG risk analysis methods for an import terminal using as its example the risk study prepared for the proposed Elapsed Natural Gas Co. Matagordo Bay Terminal.

Kelley, C. S., Radiative Transfer Between Flame Burning Zone and Unburned Fuel. EATR-4555, Edgewood Arsenal, Maryland, NTIS No. AD/732405, October, 1971.

An assessment of the complex role of radiative heat transfer in the interaction of fuel and flame is presented. The thermo-physical properties of the fuel are included in the analysis.

King, W. S., On the Fluid Mechanics and Heat Transfer of Liquefied Natural Gas Spills. RAND Corp., P5396, 1975.

A new mathematical model for the interaction between LNG and water is proposed. However, no details are supplied on the analytical and numerical details for practical use of the model.

Kletz, T. A., "Consider Vapor Cloud Dangers When You Build a Plant." Hydro-Carb. Proc. 10:205-212, 1979.

A catalog of 15 items is presented which should be considered when building a facility in which vapor cloud explosions could occur (such as in an LNG plant).

Kneebone, A. and Prew, L. R., "Shipboard Jettison Tests of LNG Onto the Sea." Paper presented at the Fourth International Conference on LNG, Session 5, Paper 5, 1974.

The first part of the paper describes the procedures and results of a series of jettison tests carried out on board ship and discusses the operational safety aspects of such discharges. The second part is concerned with the environmental hazards associated with the release of large quantities of LNG to the sea in terms of the extent of vapor cloud formed; its characteristics and rate of dispersal.

Kogarko, S. M., "Detonation of Methane-Air Mixtures and the Detonation Limits of Hydrocarbon-Air Mixtures in a Large Diameter Pipe." Soviet Physics. 3, 1958.

A review is made of the Russian literature on methane-air detonation. The author describes his work using tubes with diameters up to 0.305 meter and lengths to 12.2 meters. Gas mixtures were initiated with 50/50 amatol explosive charges. The author concludes that the limits and the possibility of a detonation vary with the diameter.

Lancaster, John F., "What Causes Equipment to Fail?" Hydrocarbon Processing, pp. 74-76, January 1975.

This article deals with four main causes of service failure in process equipment. They are: fatigue, general corrosion, stress corrosion cracking and manufacturing defects. Comments and suggestions for reducing each type of failure are included.

Lawrence, G. H., "Comments of the American Gas Association on Delegation of Functions by the Secretary of Energy to the Administrator of the ERA and FERC." American Gas Association, November 15, 1978.

The American Gas Association requests revision of the delegation due to confusing and inconsistent language, a failure to correct jurisdictional overlaps, and the increasing cost of regulations.

Lee, R. H. C. and Happel, J., "Thermal Radiation and Methane Gas," I&EC Fundamentals, 3:167-176, May 1964.

The infrared absorption of methane in three wavelength regions (2.37, 3.31, and 7.65 microns) has been determined at various temperatures and optical depths. The semi-empirical expressions for the band absorption so obtained are used to calculate the total and band emissivities of methane from 0.01 to 2.0 ft-atm. and from 500° to 3750°R.

Lees, F. P., "Some Data on the Failure Modes of Instruments in the Chemical Plant Environment." Chem. Engineer, 277:418-421, September 1973.

Failure mode data are given based on a previously presented survey of failure rate data for 9500 instruments in chemical works.

Lehto, D. L. and Larson, R. A., Long Range Propagation of Spherical Shock-waves From Explosions in Air. NOLTR 69-88, NTIS No. AD/698121, U.S. Naval Ordnance Laboratory, White Oak, Maryland, July 22, 1969.

Hydrocode calculations for spherical shock propagation using the artificial-viscosity method are carried out to 0.2 psi overpressure for a nuclear explosion and for a TNT explosion. An ideal-gas integration from the literature is used to extend the results to 1.6×10^{-4} psi. Below 1.0 psi, 1 kiloton nuclear is equivalent to 0.7 kilotons of TNT.

Leonard, D. A., and Caputo, E., Technical Report: Remote Sensing of LNG Spill Vapor Dispersion Using Raman LIDAR. UCRL-13984, Computer Genetics Corp., Wakefield, MA, 1979.

The feasibility of using a Raman LIDAR scheme for the measurement of LNG vapor concentration has been demonstrated. The report describes the test apparatus and discusses the quality of the obtained results.

Lester, T. W. and Wittig, S. S. K., "Soot Nucleation Kinetics in Pre-mixed Methane Combustion." Presented at the 16th International Symposium on Combustion, 1976.

This paper is an investigation of the early chemical kinetics of soot formation in fuel rich methane flames.

Levine, A. D., Theoretical Models of LNG Dispersion Studies (Phase III - LNG Safety Program), Part I: Modeling of LNG Spills. AGA Project IS-129-1, Technical Report TLN-1, October 17, 1975.

A series of theoretical models relating to the growth and evaporation of cryogenic pools is reviewed, and new ones added in order to allow for complete empirical correlation. Agreement with all experimental results is quite good although the scaling law is somewhat questionable. Continuous spills are modeled using harmonic function analysis with adequate results.

Levine, A. D., Theoretical Models for LNG Dispersion Studies. Report on A.G.A Project IS-129-1, 1975.

Progress reports survey basic relations of detonation phenomena used to emphasize the importance of kinetics and induction time for the initiation process. Current knowledge of explosives in open air gas mixtures suggest that induction time may be very important in correlating experiments with theory.

Levy, M.M., "The Cove Point LNG Terminal: Its First Year of Operation." Paper presented to Seminar and Study Tour on LNG Peakshaving, Washington DC, March 5-9, 1979.

The design and operating experience of the Cove Point LNG terminal is reviewed.

Lewis, D. H., The Dispersion and Ignitability of LNG Vapor Clouds. M.S. Thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts, June 1974.

The flammability of vapor clouds resulting from instantaneous spills of LNG is determined quantitatively using statistical methods. A new physical theory on the vapor dispersion process is presented and compared to available experimental data. Numerical predictions of distance to various flammability limits are presented graphically.

Lind, C. D., Explosion Hazards Associated With Spills of Large Quantities of Hazardous Materials - Phase I. U.S. Coast Guard Report CG-D-30-75. NTIS No. AD/A001242. October 1974.

This report documents the results of a program to quantify the explosion hazards associated with spills of material such as LNG, LPG, or ethylene. The results are: a phenomenological description of a spill; an examination of the detonation properties of methane; a qualitative theory of non-ideal explosions; a plan for Phase II of the study.

Lind, C. D. and Whitson, J. C., Explosive Hazards Associated with Spills of Large Quantities of Hazardous Materials. Phase II. U.S. Coast Guard Report CG-D-85-77. NTIS No. AD/A047585, 1977.

Tests have been conducted to investigate the burning behavior of LNG type materials. No detonations have been observed in any of these tests.

Lind, C. D. and Strehlow, R. A., "Unconfined Vapor Cloud Explosion Study." NTIS No. AD/A023505, presented at the Fourth International Symposium on Transport of Hazardous Cargoes by Sea and Inland Waterways, Jacksonville, FL, October 26-30, 1975.

Five-meter radius hemispherical bag tests of ignition of 10% methane/propane-air mixture were conducted. Results indicated that ignition of fuels in this amount does not produce a detonation or damaging pressure waves.

Lind, C. D. and Whitson, J. D., "China Lake Spill Tests." Report L, Liquefied Gaseous Fuels Safety and Environmental Control Assessment Program: A Status Report. DOE/EV-0036, Department of Energy, Washington, DC, 1979.

The 1978 LNG spill tests at China Lake are briefly described. No data analysis is included.

Liquid Natural Gas, Characteristics and Burning Behavior. Conch Methane Services, Ltd., Villers House, Strand/London, W.C. 2, England.

A synopsis of a comprehensive engineering report prepared for Conch Methane Services Ltd., based on large-scale field tests conducted near Lake Charles, Louisiana, plus laboratory data from the Bureau of Mines and available information in the literature. Field tests measured the levels of radiation by use of thermopiles; and extinguishment trials, using various extinguishment media, were conducted in conjunction with burning tests.

LNG Safety Program - Interim Final Report. (Draft) R&D Associates Report RDA-TR-1100-006 to the American Gas Association, September 30, 1976.

This program represents a comprehensive LNG safety study and includes the following tasks: LNG spread and boiloff rates. subscale land experiments performed in a wind tunnel, dispersion modeling, radiation and detonation studies, and a field test program definition which represents a major focal point of all other tasks. Emphasis is placed on scaling, instrumentation, and data analysis methodologies.

LNG Safety Program - Interim Report on Phase II Work. A.G.A. Project IS-3-1, Report to the American Gas Association by Battelle Columbus Laboratories, July 1, 1974.

Models for dispersion and radiation were developed, which fit data for 80-ft spills and will predict the hazard for spills into dikes up to 400 to 500 ft dia. Experiments verified reduction of dispersion hazards by insulated dike floors and high dikes. Predictions are given of downwind distances of travel of flammable vapors and radiation intensities on targets near fires on soil, and in low dikes up to 500 ft in dia.

LNG Terminal Risk Assessment Study for Los Angeles. Report by Science Applications, Inc., for Western LNG Terminal Company, December 22, 1975.

Science Applications, Inc., concludes on the basis of this study that LNG risks to populated areas near the Los Angeles Harbor site are extremely low. The physical characteristics of LNG, the design of the facility and tankship and the planned operating rules account for the low risk values.

LNG Wind Tunnel Simulation and Instrumentation Assessments. Report RDA-TR-105700-003, Draft by R&D Associates for the U.S. Energy Research and Development Administration, April 1977.

Information is presented on LNG flame radiation, test site criteria, wind tunnel modeling, and test instrumentation.

Love, T. J., Hood, J. D., Shahrokhi, F. and Tsai, Y. W., "A Method for the Prediction of Radiative Heat Transfer From Flames." ASME Publication 67-HT-47 presented at the ASME-AIChE Heat Transfer Conference and Exhibit, Seattle, WA, August 6-9, 1967.

This paper presents a method, based on the transport equation, to predict the radiative heat flux from methanol and acetone flames of arbitrary size and geometry. Predicted and measured values of the radiative flux were compared for several larger flames and found to be in good agreement for free-burning flames of acetone and methanol.

Mackay, D. and Matsugu, R. S., "Evaporation Rates of Liquid Hydrocarbon Spills on Land and Water." The Canadian Journal of Chemical Engineering. 51:434-439, August 1973.

Experiments on the evaporation of cumene, water and gasoline are described and the evaporation mass transfer coefficient correlated with the windspeed, liquid pool size and the vapor phase Schmidt Number. Comparison of the correlation with flat plate mass transfer correlations shows satisfactory agreement and suggests that turbulent transfer occurs, the rate being enhanced by liquid surface roughness.

Maezawa, M., Experiments on Fire Hazards of Liquefied Flammable Gases. Osaka Gas Company, Ltd., May 1973.

Part I discusses the fire properties of liquefied flammable gases. Part II presents the results of an experiment in fire extinguishing. Part III is concerned with a dispersion experiment. Briefly, the flame temperature of each liquefied gas is 700 to 800°C compared to gasoline at 1100°C. LNG burning rates are much larger than gasoline. Radiation energy is also larger than gasoline.

Magnussen, B. F. and Huertager, "Mathematical Modeling of Turbulent Combustion with Special Emphasis on Soot Formation and Combustion." Presented at the 16th International Symposium on Combustion, pp. 719-729, 1976.

This paper presents a mathematical model of turbulent diffusion and/or premixed flames. Methods for thermal radiation and soot formation predictions are also presented. Soot formation is analyzed as a two-step process (nucleation site formation and soot particle formation). Thermal radiation is evaluated using a two-flux equation.

Maher, J. B. and Van Gelder, L. R. "Rollover and Thermal Overfill in Flat Bottom LNG Tanks." Pipeline and Gas Journal. 199:46-48, September 1972.

Conclusions are that high venting incidents involve thermal overfill; surface layer phenomena occurs in flat bottom LNG tanks filled through bottom with a liquid of saturation pressure greater than pressure capability of the tank; bottom filled tanks should provide venting over entire fill time consistent with degree of thermal overfill; if top layer is continually agitated during filling, thermal overfill will not occur.

Markstein, G. H., "Scaling of Radiative Characteristics of Turbulent Diffusion Flames." Paper presented at the 16th International Symposium on Combustion, 1977.

It is shown that radiative properties of gaseous-fuel turbulent diffusion flames can be scaled successfully over a fairly wide range of fuel flow rates. In addition, radiometric scans were found to provide quantitative information on flame length and diameters and their scaling properties. The work was part of a program to develop a generally applicable model of fire radiation.

Martinsen, W. E., S. P. Muhlenkamp, J. Olson, "Disperse LNG Vapors With Water." Hydrocarbon Processing. 56(7):261-266, July 1977.

This paper discusses the potential for enhancing LNG vapor cloud dispersion by water sprays into the cloud. Experiments showed increased mixing due mainly to mechanical turbulence induced by the watery sprays and a resultant decrease in the distance a vapor cloud spreads before reaching the lower flammability limit.

Masliyah, J. H. and Steward, F. R., "Radiative Heat Transfer From a Turbulent Diffusion Buoyant Flame With Mixing Controlled Combustion." Combustion and Flame. 13:613-625, 1969.

A mathematical model of a turbulent buoyant diffusion flame is postulated. The radiative interchange between the flame and a plane surrounding its base is determined. From this radiative distribution, it is possible to determine the radiative heat flux to the liquid fuel which is vaporizing to feed the flame. A graphical solution is presented which yields the rate of burning of a liquid fuel of given physical properties in a fixed diameter fuel source.

Mathiesen, T. C., Flatseth, H. H., Solberg, D. M. and Tueit, O. J., "Risk Management in Marine Transportation of LNG," 1979.

Measures are being described for dealing systematically with LNG hazards as they might occur in marine transportation. The measures are largely based on reliability engineering results.

May, W. G. and McQueen, W., "Radiation From Large LNG Fires." Combustion Science and Technology. 7(2):51-56, 1973.

Radiation from flames of burning LNG were measured in a burning pool contained in a trench. Burning rates over the range of 13,500 to 40,000 BBL/D of LNG were studied. Measured flux varied from 60 to 480 Btu/hr/ft² at ground level and 300 to 600 feet from the flame center and from elevated points. An inverse square law of radiation versus distance held fairly well.

May, W. G., McQueen, W. and Whipp, R. H., "Dispersion of LNG Spills." Hydro-carbon Processing. 52:105-109, May 1973.

The paper discusses data analysis of plume shape and plume dispersion characteristics. Correlations show that dispersion of LNG vapors can be predicted from observed facts and controlled conditions.

May, W. G., McQueen, W. and Whipp, R. H., "Spills of LNG on Water." Paper presented at the American Gas Association Distribution Conference, Washington, DC, May 14, 1973.

The conclusions reached cover: effect of variables on flow rate; inequality of downwind flow rate and evaporation rate; effect of density on plume shape; dependence of plume density on air humidity; effect of plume heating; weather effects; predictions of downwind plume travel.

May, W. G., McQueen, W. and Whipp, R. H., "Spills of LNG on Water." Proc. Div. of Refining, API, pp. 626-653, 1973.

The vapor dispersion from large LNG spills on water was experimentally determined. The tests, carried out by Exxon, were intended to verify and extend results obtained earlier in the Bureau of Mines and Gaz de France tests.

May, W. G., and Perumal, P. V. K., The Spreading and Evaporation of LNG on Water. ASME paper 74 - WA/PID-15, 1974.

The paper proposes a semi-empirical relationship for estimating the total evaporation from a LNG spill on water. Correlations are based on LNG spread rate, maximum pool diameter and evaporation rate per unit area.

McCarthy, D., A Comparison of Mathematical Models for the Prediction of LNG Densities. NBSIR 77-867, National Bureau of Standards, October 1977.

Four mathematical models of the equation of state for LNG like mixtures are compared using experimental data optimized for each model. The objective of predicting LNG densities to within $\pm 0.1\%$ could not be assessed due to discrepancies in the input data. Model listings are included.

McNaughton, D. J. and Berkowitz, C. M., "Overview of U.S. Research Activities in the Dispersion of Dense Gases." Symposium Schwere Gase (Heavy Gas), Battelle-Institute, Frankfurt, F6 R, September 3-4, 1979.

This paper presents an overview of U.S. research in heavy gases particularly LNG. Topics include mathematical modeling, experiments, and facility controls available to decrease gas release or increase gas cloud dilution. Recommendations or further research are included.

Meinen, E., "LNG Storage in Prestressed Concrete Safety Walls - 1." Oil and Gas Journal. May 14, 1979.

The concrete safety wall incorporated in the design of the Maasvlakte LNG plant in the Netherlands is described. The properties of steel and concrete at cryogenic temperatures are reviewed.

Meinen, E., "LNG Enclosure Design - 2." Oil and Gas Journal. May 21, 1979.

The design, testing and construction steps for the retaining wall and the tank foundation of the Maasvlakte LNG plant are outlined. Analytical procedures and test results are described.

Mellor, G. L. and Yamada, T., "A Hierarchy of Turbulence Closure Models for Planetary Boundary Layers." Journal of the Atmospheric Sciences. pp. 1791-1806, October 1974.

Turbulence models centered on hypotheses by Rotta and Kolmogoroff are complex. In the present paper, we consider systematic simplifications based on the observation that parameters governing the degree of anisotropy are small. Discussion is focused on density stratified flow due to temperature.

Meroney, R. N., Neff, D. E. and Cermak, J. E., "Wind Tunnel Modeling of LNG Spills." 1978 Operating Section Proceedings, American Gas Association, Montreal, Quebec, May 1978.

The author's report scales of spill conditions that may be successfully simulated in Colorado State University wind tunnels. Simulations of 1974 AGA LNG load spill experiments and uses of wind tunnels in experimental design are also discussed.

Miller, B., "Possibilities in Hydrate Storage of Natural Gas." Gas Age. 97:37-40, May 1942.

The formation of methane and LNG hydrates was reviewed. Data concerning hydrate storage, properties and decomposition pressures were discussed. Refrigeration and heat requirements for hydrate storage and regeneration were also presented.

Miller, R. C. and Hiza, M. J., "Experimental Molar Volumes for Some LNG-Related Saturated Liquid Mixtures." Fluid Phase Equilibria. 2:49-57, 1978.

Saturated (orthobaric) liquid molar volumes are reported for some methane-rich mixtures containing ethane, propane, isobutane, normal butane and nitrogen at temperatures between 100 and 115 K. These data were obtained with a gas-expansion system calibrated against pure methane orthobaric liquid molar volumes. Comparisons are shown between the experimental molar volumes and the results of some recent calculational methods.

MITRE Corp., A Summary of Accidents Related to Non-Nuclear Energy. EPA 600/9-77-012, PB-271506, 1977.

This report is an executive summary of a more extensive EPA study on accidents, in non-nuclear energy. LNG accidents are covered rather briefly, since only a few accidents have occurred in this category.

Modak, A. T., "Thermal Radiation From Pool Fires." Paper presented at Western States Section, The Combustion Institute Meeting, La Jolla, CA, October 18-20, 1976.

This analysis computes: radiative energy fluxes to surfaces located external to the fire in any arbitrary orientation; variations of radiative heat flux along the fuel surface; total radiative heat transfer from flames to fuel surface; forward radiative heat transfer from fire to virgin fuel bed external to the fire; angular distribution of radiative flux emitted by the pool fire; total radiative power output of the fire.

Montoya-Lirola, C., "Manufacture of Gels, Especially Liquid Fuels, and Their Subsequent Reversible Liquefaction." Chem. Abstr. 76:27001g, Span. 362, 146 (to Gelsa S. A.), 1970.

LNG could be gelled by generating a mixture of 20 percent water containing 2.5% of a vegetable albuminoid, saponin or viscous resinous gum with 80% LNG.

Morton, B. R., "Modeling Fire Plumes." Paper presented at the Tenth International Symposium on Combustion, Cambridge, UK, August 17-21, 1964.

Theoretical treatments for turbulent diffusion flames and for the strongly heated regions of fire plumes in a still environment may be based on those developed for weakly buoyant plumes. A discussion is given of some of the modifications that are needed, and the effects of large variations in density on the plume dynamics are aspects of heat transfer by radiation are presented separately.

Mullen, F. et al., Thermal Radiation and Overpressures from Instantaneous LNG Release into the Atmosphere - Phase II. TRW Systems Group Report No. 08072-9, to A.G.A., A.G.A. Catalog No. M60015, May 1969.

This report considers the fluid mechanics and thermochemistry of thermal radiation; boil-off, LNG vapor/air mixture dispersion experiments, and blast of overpressure; dike design; and a discussion of the flame program and vapor cloud studies.

Multhauf, L. G., Frank, A. M. and Koopman, R. P., Remote Measurement of LNG Vapor Dispersion Using LIDAR. UCID-17968-79-1, pp. 15-22 Lawrence Livermore Laboratory, 1979.

This is essentially an abbreviated version of Lawrence Livermore Laboratory report UCID-18237.

Multhauf, L. G., Frank, A. M. and Koopman, R. P., Remote Sensing for Diagnosing Vapor Dispersion in Spills of Liquid Energy Fuels. UCID-18237, Lawrence Livermore Laboratory, 1979.

A laser ranging (LIDAR) technique is described for measurement of gas concentrations in vapor clouds emanating from LNG spills. Results of a feasibility test at China Lake are discussed.

Munson, R. and Clifton, R. A., "Natural Gas Storage with Zeolites." PB Report No. 203892. U.S. National Technical Information Service, 1971.

Zeolites were used as an adsorbent for methane. For instance, Calcium A zeolite would retain up to 5 weight percent methane at 72°F and 200 psia. The potential of zeolites for vehicular natural gas storage was discussed.

Murgai, M. P., "Radiative Transfer Effects in Natural Convection Above Fires." Journal of Fluid Mechanics. 12(3):441-448, March 1962.

This paper describes the results of examining the influence of radiative heat transfer on turbulent natural convection above fires in an atmosphere of constant potential temperature, under both the 'opaque' and 'transparent' approximations. It turns out that on the basis of the overall approximations introduced in this investigation, the former case reduces to that of no radiative transfer.

Murgai, M. P. and Emmons, H. W., "Natural Convection Above Fires." Journal of Fluid Mechanics. 8:611-624, 1960.

The turbulent natural convection above fires in a dry calm atmosphere with a constant lapse rate has been the subject of several recent investigations. The present paper presents solution curves from which the natural convection may be computed over a fire of arbitrary size in an atmosphere with arbitrary lapse-rate variation.

Murray, F. W., Atmospheric Dispersion of Vaporized Liquefied Natural Gas. Rand Corp. Rpt. P5360, AD/A010940, 1975.

A sophisticated mathematical model for the dispersion of LNG clouds is proposed. However, no details on the equations and on their numerical treatment are given.

Murray, F. W., Jaquette, D. L. and King, W. S. Hazards Associated with the Importation of Liquefied Natural Gas. Rand Corp., NTIS No. AD/A037928, June 1976.

Four previous reports by Rand Corporation are summarized and updated in this most recent publication, which discloses probable cause of accidental spills of LNG, the hazards surrounding these spills, and methods of estimating the probabilities of major accidents. In assessing the risks associated with LNG transport and processing, it is concluded that not enough evidence has been collected to comment on the safety of LNG or the ability to extrapolate from past experience.

Muscari, C. C., The Evolution of Liquid Natural Gas on Water. M. S. Thesis, MIT, 1974.

Governing equations are given for the simultaneous spread and evaporation (burning) of an LNG spill on water. Equation solutions determine the 1) maximum radial extent of the spill, 2) time duration of complete dissipation of spill volume, 3) graphics of spill volume versus time, evaporation rate versus time and spill thickness versus distance (from origin of spill).

Nakagawa, A., "Japanese LNG Receiving Terminal is Reliable." Oil and Gas Journal. pp. 174-182, January 28, 1980.

The design, operation, and maintenance characteristics of the Sodegaura Terminal are described. The computer control system and the preventive maintenance operations are outlined.

Nakanishi, E. and Reid, R. C., "Liquid Natural Gas-Water Reactions." Chemical Engineering Progress. 67:36-41, December 1971.

This paper cites previous studies and discusses both quantitative and qualitative experimental results. Consideration is given to water on cryogen, underwater release of cryogen, cryogen on ice, cryogen spills on water and on coated liquids. Finally, a tentative hypothesis is presented for the explosion phenomena.

Neary, R. M., "Safety in LNG Semi-Trailer Design." Paper presented to the AGA Transmission Conference, Las Vegas, Nevada, May 3, 1976.

Included in this paper is a description of LNG semi-trailers and the various DOT regulations regarding them. Also included is a discussion of and a picture of an LNG trailer that was exposed to a fire as a result of an accident.

Nelson, W., "A New Theory to Explain Physical Explosions." Combustion. 44, May 1973.

This paper summarizes some known facts about explosions, with emphasis on physical explosions, describes a new explosion mechanism, and suggests current and future applications of the new theory to prevent smelt-water explosions in kraft chemical recovery furnaces.

Newell, R. G., "Station Coordination Critical in LNG Pipeline Efficiency." Oil and Gas J. 77(18):239-244, 1979.

Pumping and cooling stations along an LNG pipeline must be designed for unattended operation and must use only LNG as the source of energy. Technology for such pipeline operation is proven. The paper presents guidelines for the overall design of an LNG pipeline.

Nielson, H. J. and Tao, L. N., "The Fire Plume Above a Large Free-Burning Fire." Paper presented at the Tenth International Symposium on Combustion, Cambridge, U.K., August 17-21, 1964.

A model which describes the variation with altitude of the composition, temperature, and velocity of the gases within a plume above a large free-burning fire is presented. This model is an extension of previous analysis of buoyant plumes which includes the effects of combustion, composition variation, and radiation losses from the hot gases.

Nierman, A. J., "Transportation of Natural Gas as a Hydrate." U.S. Patent 3,975,167 (to Chevron Research Co.), U.S. Patent Office, 1976.

Transportation of LNG hydrate by submarine was described. This procedure required supplementary refrigeration, a hold or void in which natural gas can be hydrated, and a membrane pervious to gas and water within the hold. Provisions were suggested for in situ removal of hydrate heat of formation.

Nikodem, H. J., Flothmann, D., Geiger, W., Schnatz, G. and Schneider, W., "Risk Assessment Study for an Assumed LNG Terminal in the Lysekil Area." prepared for the Swedish Energy Commission by the Battelle-Institute e.V. Frankfurt BR-R-31.109-1, 1978.

This report presents a risk assessment for a proposed LNG terminal and distribution system in Sweden using state-of-the-art dispersion and gravity/spread models. Risks included direct contact with LNG, suffocation, radiation and pressure wave destruction.

Nuclear Regulatory Commission, "Safety Evaluation by the Office of Nuclear Reactor Regulation Regarding the Proximity of Cove Point LNG Facility: Baltimore Gas and Electric Company Calvert Cliffs Nuclear Power Plant. Units Nos. 1 and 2." Docket Nos. 50-317 and 50-318, March 13, 1978.

An analysis is described which shows the effects of various hypothetical LNG accidents at Cove Point on the Calvert Cliffs Power Plant. Results indicated that no new operating restrictions or other limitations needed to be placed on the plant to assure normal operations.

Office of Technology Assessment, Transportation of Liquefied Natural Gas. Congress of United States, Washington, DC.

A review of LNG transportation technology provided as support for Congress on Future Energy Legislation. The LNG import system is criticized; Public concerns are summarized; and laws, permit requirements and pending legislation are examined.

"Offshore LNG Terminal Deemed Feasible." Marine Equipment News. pp. 6-7, Spring 1977.

This article discusses the potential of offshore receiving terminals and describes several generic types that could be used. There are currently no offshore terminals in operation or construction, however, due to onshore siting difficulties they are being given serious attention.

Ohsaka, K. et al., Membrane Structure in a Liquefied Gas Storage Tank. U.S. Patent 4,149,652, 1979.

An improved structural design for LNG storage tanks is described. It minimizes thermal strains and practically eliminates potential sources of leaks that were present in earlier designs. Required labor for installing the new tanks is also greatly reduced.

Opschoor, G., "Investigations into the Spreading and Evaporation of LNG Spilled on Water." Cryogenics. 17:629-633, 1977.

Analytical expressions for the spreading of LNG spills on open and confined areas of water have been derived. They agree with known available experimental data.

Ordin, Paul M., Bibliography on Liquefied Natural Gas (LNG) Safety. NASA Technical Memorandum, NASA TM X-73408, April 1976.

This bibliography contains citations concerned with the safety of LNG and liquid methane. The raw data for this report was a computer printout based on a keyword search strategy of descriptions in the cryogenic safety data bank dealing with LNG.

O'Rourke, P.J. and F. Bracco, "Two Scaling Transformations for the Numerical Computation of Multidimensional Unsteady Laminar Flames." Journal of Computational Physics. 3(2), November 1979.

The authors of this paper address the problem of flame propagation in a multi-dimensional system. Problems involving sonic propagation and small flame thickness are solved by means of a transformation. An actual simulation of combustion of methane in a chemical bomb are presented.

Otterman, B., "Analysis of Large LNG Spills on Water - Part 1: Liquid Spread and Evaporation." Cryogenics. 15(8):445-460, August 1975.

The first part of this two-part review considers the theoretical and experimental results obtained on liquid spread and evaporation of large LNG spills on water. Both instantaneous spills, in which the spill time is much smaller than the time for complete vaporization, and continuous spills are considered. Also, applications of the correlations are discussed.

Overly, J. R. and Overholser, K. A., "Calculation of Minimum Ignition Energy and Time Dependent Luminar Flame Profiles." Combustion and Flame. 31:60-83, 1978.

The authors simplify the calculational method of Spalding by use of a transformation of variable. The authors employ this technique to calculate ignition energy and flame propagation.

Panofsky, H. A., "The Atmospheric Boundary Layer Below 150 Meters." Annual Review of Fluid Mechanics. 6:147-177, 1974.

The article considers profiles and fluxes over homogeneous terrain (surface layers, extension to the tower layer) and profiles over changing terrain (wind profiles, temperature characteristics, energy budgets, horizontal velocity components, temperature and humidity spectra, cospectra, and boundary layer models).

Parent, J. D., "The Storage of Natural Gas as Hydrate." Institute of Gas Technology Bulletin No. 1. 1948.

A very thorough review of the technical literature was presented. This included phase diagrams, heats of reaction, equilibrium ratios, cooling requirements, and operating pressures.

Parker, R. O., "Calculating Thermal Radiation Hazards in Large Fires." Fire Technology. 10(2):147-152, 1974.

The author has developed, and discusses here, a method for assessing the thermal radiation hazards to objects from fires. A comparison of the calculations to an actual fire experience seems to indicate that the method is reasonably accurate, though somewhat conservative.

Parker, R. O., "Study of Downwind Vapor Travel From LNG Spills." Paper presented at the American Gas Association Distribution Conference, May 1970.

The problem can be treated as a heat transfer calculation at the earth-liquid interface yielding the input; a second heat transfer problem if there is no wind, or if there is wind, an atmospheric dispersion problem. The conclusion is that it is very unlikely that vapor concentrations of more than 1/2 the lower flammable limit will exist 600 or more feet downwind of the lee dike.

Parker, R. O. and Spata, J. K., "Downwind Travel of Vapor From Large Pools of Cryogenic Liquids." Paper presented at LNG-1 Conference, Chicago, IL, 1968.

A method is developed for calculating vapor concentrations downwind of large pools of cryogenic liquids. Vapor concentrations at any downwind position is found as a function of time, wind speed, and wind structure. Lateral and vertical dispersion coefficients are determined using meteorological observations. Practical applications include hazard studies and air pollution estimates.

Parrish, W. R., Arvidson, J. M. and LaBrecque, J. F., "Evaluation of LNG Sampling Measurement Systems for Custody Transfer." 1978 Operating Section Proceedings, American Gas Association, Montreal, Quebec, May 1978.

A method for sampling moving LNG streams for composition and heating value is described. The main component of the technique and the main source of error is a gas chromatograph.

Parrish, W. R., Arvidson, J. M. and LaBrecque, J. F., "System is Accurate, Precise for LNG Sampling." Hydrocarbon Processing. April 1978.

A three component system including a sampling probe, vaporizer, and gas analyzer is described which can be used to monitor heating value from moving streams of LNG. Detection error is derived mainly from error in the gas analyzer.

Parrish, W. R., Brennen, J. A. and Siegwarth, J. D., "LNG Custody Transfer Research at the National Bureau of Standards." 1978 Operating Section Proceedings, American Gas Association, Montreal, Quebec, May 1978.

This paper presents a summary of research on determining the thermo-physical properties of LNG components, on flowmeters, and on LNG sampling and composition measurements.

Patankar, S. V. and Spalding, D. B., Heat and Mass Transfer in Boundary Layers. International Textbook Company, Ltd., 2nd edition, London, U.K., 1970.

The authors of this text describe a computational technique for solving the time dependent conservation equations (mass, momentum, energy and species) needed to describe flame propagation in one-dimensional planar, cylindrical or spherical geometry.

Pergament, H. S. and Fishburne, E. S., "Influence of Buoyancy on Turbulent Hydrogen/Air Diffusion Flames." Paper presented at the Central States Section Combustion Institute Meeting on Fluid Mechanics of Combustion Processes, Cleveland, OH, March 29-30, 1977.

The results show that: flame properties scale with nondimensional distance for Froude numbers (Fr) greater than about 10^6 ; buoyancy affects temperature decay rates downstream of the location of maximum temperature (after all the H_2 has burned); the predicted influence of Fr on buoyant flame lengths is consistent with the available data.

Petsinger, R. E. and Vance, R. W., LNG Terminals and Safety Symposium - Applications of Cryogenic Technology Volume 9, 1979.

The proceedings of the LNG Terminals and Safety Symposium held October 12-13, 1978, in San Diego, CA, are provided. Session topics include: LNG Export Terminals, LNG Import Terminals, and LNG Research and Safety.

Petrash, D. A., Barber, J. R., Chambellan, R., and Englund, D. R., "Gelled Liquid Methane." NASA Spec. Publ. NASA SP-5103, Sel. Technol. Gas Ind. pp. 86-88, 1975.

Results of work toward use of LNG as fuel for supersonic aircraft was reported. The problem of "boiloff" due to decrease of pressure with altitude was eliminated by preparing LNG gels with water or methanol. LNG-methanol gel was recommended due to the total heat of combustion.

Pfoertner, H., "Ignition Behavior of Natural-Gas/Air Mixtures in Free Clouds." Gas-Wasserfach, Gas/Erdas. 120(1):19-24, 1979 (in German). (For translation see Lawrence Livermore Laboratory UCRL-TRANS-11478.)

Based on combustion analysis it is concluded that only deflagrations and no detonations would occur when a natural-gas/air cloud is ignited. This conclusion is backed up by a series of tests.

Pipkin, O. A. and Sliepcevich, C. M., "Effect of Wind on Buoyant Diffusion Flames." Industrial and Engineering Chemistry Fundamentals. 3:147-154, 1964.

Buoyant diffusion flames of natural gas were observed in wind tunnel experiments to determine the extent of bending by wind. A flame drag coefficient, C_f , is introduced in the flame momentum balance. A single straight-line correlation of $\ln C_f(\text{Re})$ versus $\ln \text{Re}$ is obtained after extracting the influence of flame angle of tilt and applying an empirical correction to account for increasing flame roughness at larger diameters.

Ploum and Arnold, J. W., "The Brunei Liquefied Natural Gas Plant." LNG 5 - International Conference on Liquefied Natural Gas, Duesseldorf, Germany, August 29-September 1, 1977.

This paper reviews and highlights some of the design concepts and operating experiences gained particularly from the liquefaction plant at Brunei.

Porricelli, J. D., Keith, V. E. and Paramore, B., Recommended Qualifications of Liquefied Natural Gas Cargo Personnel, Volumes I, II and III. NTIS No. AD/A026109, AD/A026110, April 1976.

The report presents recommendations, based on task analysis, concerning training and other qualification requirements appropriate for personnel of liquefied natural gas (LNG) ships and barges.

The study was a pilot effort to demonstrate a method of determining qualifications for new technology ship occupations when there are few or no operating examples to study.

Porteous, W. M. and Blander, M., "Limits of Superheat and Explosive Boiling of Light Hydrocarbons, Halocarbons, and Hydrocarbon Mixtures." AICHE Journal. 21:560-566, May 1975.

Thirteen light hydrocarbons and 4 light halocarbons were tested to determine their limits of superheat at one atmosphere pressure using a superheating column. Even with some variation in temperature to which a compound could be superheated before boiling explosively, the reduced limits T_L/T_C were always close to 0.88. Super heat limits of binary hydrocarbon systems and tertiary mixtures were close to mole fraction averages of the limits of the pure compounds.

Porteous, W. M. and Reid, R. C., "Light Hydrocarbon Vapor Explosions." Chemical Engineering Progress. 73:83-89, May 1976.

This article includes information relating to spills on water of propane, propylene, isobutane, binary mixtures containing ethane, pure alkanes and pure alkenes. Some explosive compositions and ranges for hydrocarbon spills are also given. Previous studies are cited and factors affecting violence of explosions are discussed.

Priestley, C. H. B. and Taylor, R. J., "On the Assessment of Surface Heat Flux and Evaporation Using Large-Scale Parameters." Monthly Weather Review. 100(2):81-92, February 1972.

Data from a number of saturated land sites and open water sites in the absence of advection suggest a widely applicable formula for the relationship between sensible and latent heat fluxes.

Putnam, A. A., "A Model Study of Wind-Blown Free-Burning Fires." Paper presented at the 10th Symposium on Combustion, The Combustion Institute, 1965.

Specifically, the dimensionless flame height varied with the negative 1/4-power of the Froude number based on cross-wind velocity and undisturbed flame height, above a Froude number of 0.2. The horizontal extension of the flame, on the other hand, increased rapidly with increasing cross wind at first, and then less rapidly with the 1/6-power of the Froude number.

Putnam, A. A., "Area Fire Considered as a Perimeter-Line Fire." Combustion and Flame. 7:306-307, 1963.

The hypothesis that line fires and area fires are basically related was tested by examining available data on sources in a line and in a hexagonal pattern. A mathematical analysis is given to justify the hypothesis.

Putnam, A. A. and Grinberg, I. M., "Axial Temperature Variation in a Turbulent, Buoyancy-Controlled, Diffusion Flame." Combustion and Flame. 9(4):419-420, 1965.

An analytical expression was formulated which correlated the temperature profile of a turbulent diffusion, buoyancy-controlled flame to fuel properties and flow conditions. The expression is valid in the region after combustion is completed, and is valid at higher temperature levels than previously used correlations which are accommodated as a limiting case.

Putnam, A. A. and Speich, C. F., "A Model Study of the Interaction of Multiple Turbulent Diffusion Flames." Paper presented at the 9th International Symposium on Combustion, 1963.

This research program has shown that a valid model for studies of mass fires can be produced using multiple jets of gaseous fuels. The basic requirement is that the fuel jets produce turbulent diffusion flames which are buoyancy controlled. A specific operating range where this requirement is met was found for this model.

Radiative Transfer in Multidimensional Systems of Non-Gray Molecular Gases - Effects on Combustion. Columbia University. A.G.A. Project on LNG Fire Study. (See LNG 1976 Annual Report).

An analytical technique has been developed to treat band radiation from non-gray molecular gases. The technique has been simplified so that the frequency integrations can be performed with simple quadrature formulae. The simplified technique is being applied to multidimensional radiative transfer problems as well as problems involving combustion.

Raj, P. and Atallah, S., "Thermal Radiation from LNG Spill Fires." Advances in Cryogenic Engineering.

The authors of this paper present results of experimental measurements made in LNG fires which were 6, 20 and 80 ft in diameter. Correlations are given for the wind induced plane tilt angle and length to diameter ratio of the flame. Also measured are the radiative absorption coefficient, radiative flux at a distance from the plume and the fraction of energy which leaves the fire as thermal radiation.

Raj, P. and Emmons, H. W., "Burning of a Large Flammable Vapor Cloud." Paper presented at the Central States Section, Combustion Institute Meeting, San Antonio, Texas, April 21-22, 1975.

A theoretical analysis is presented to estimate the ground level width of a two-dimensional turbulent flame as a function of time for the burning of a large combustible vapor cloud in the atmosphere for a given turbulent flame speed. The base width of the flame is assumed to be controlled by the rate at which the vapor is fed into the combustion zone and the air entrainment rate.

Raj, P. and Kalelkar, A. S., Assessment Models in Support of the Hazard Assessment Handbook. A report by Arthur D. Little, Inc., to the Department of Transportation, U.S. Coast Guard, Report Numbers CG-D-65-74. NTIS No. AD/776617, January 1974.

Analytical models are derived to describe the hazards caused by the accidental release of chemicals into the atmosphere or spills onto water. The models encompass a variety of physical phenomena that can occur such as dispersion of vapor in the atmosphere, dispersion of liquid in water, spreading on water, burning of a liquid pool, etc. Analyses include the modeling of the phenomenon and solution to equations.

Raj, P. and Kalelkar, A. S., "Fire Hazard Presented by a Spreading, Burning Pool of Liquefied Natural Gas on Water." Paper presented at the Western States Section, Combustion Institute Meeting, 1973.

A time-growth rate for an LNG spill on water is obtained and the fire duration, determined by complete evaporation time, is established. An effective flame height is established and the radiation field about the flame calculated. Based on thermal radiation flux and fire duration, safe separation distances from the LNG pool fire for people and combustible materials (wood) are determined.

Ramsdell, J. V., Jr. and Hinds, W. T., "Concentration Fluctuations and Peak-to-Mean Concentration Ratios in Plumes From a Ground-Level Continuous Point Source." Atmospheric Environment. 5:483-495, 1971.

Diffusion data were collected by 63 incremental samplers during four short duration, continuous releases of ^{85}Kr . Cumulative frequency distributions and the intensity of short-term concentrations are shown to be a function of the relative crosswind position within the mean plume. Peak-to-mean concentration ratios are shown as a function of relative crosswind position within the plume and the ratio of the durations of the mean and peak.

Rasbach, D. J., Rogowski, A. W. and Stark, G. W. V., "Properties of Fires of Liquids." Fuel. 35:94-107, 1956.

Alcohol, petrol, benzole and kerosene fires, burning freely in a vessel of 30 cm dia, have been studied. Measurements were made on the temperature, rate of burning and change in composition of the liquid, and on the dimensions, upward velocity, temperature and emissivity of the flames. It was estimated that with hydrocarbon liquid fires, heat transfer to the surface was mainly by radiation, but for the alcohol fire mainly by conduction.

Rausch, A. A. and Levine, A. D., "Rapid Phase Transformations Caused by Thermodynamic Instability in Cryogenics." Cryogenics. 13:224-229, April 1973.

Thermodynamic metastability and incipient stability are used to explain the cause of rapid phase transformations. When liquid cryogen comes into sudden contact with a warmer host liquid, it is heated and forms a thin layer of metastable, superheated liquid at the interface. A heat transfer and thermodynamic model is used to predict the host liquid temperature that will cause a shockwave for a given cryogen.

Raynor, G. S., Michael, P., Brown, R. M. and SethuRaman, S., "A Research Program on Atmospheric Diffusion from an Oceanic Site." BNL 18924 presented at the Symposium on Atmospheric Diffusion and Air Pollution, Santa Barbara, CA, September 9-13, 1974.

Analyses of meteorological data collected in this program show that wind profiles measured on the beach are representative of those over the ocean during onshore flows. Data obtained from tracer releases show that diffusion over the sea differs appreciably from that over land at the same time and is largely determined by the air-water temperature difference.

Raynor, G. S., Michael, P., Brown, R. M. and SethuRaman, S., Studies of Atmospheric Diffusion From a Near-Shore Oceanic Site. BNL 18997, Brookhaven National Laboratory, June 1974.

Preliminary results show that diffusion is governed primarily by water and air temperature differences. With colder water, low-level air is very stable and diffusion minimal but water warmer than the air induces vigorous diffusion.

Reid, R. C., "Possible Mechanism for Pressurized-Liquid Tank Explosions or BLEVE's." Science. 203:1263-1265, 1979.

The hypothesis is made that rapid depressurization of hot saturated liquids may result in an explosion. Such a situation could arise, e.g., if a tank filled with liquefied propane would be engulfed in a fire due to some accident.

Reid, R. C., "Superheated Liquids." American Scientist. 64(2):146-156, March - April 1976.

The article cites numerous studies concerning superheated liquids and indicates that significant evidence suggests that superheated liquids are a trigger leading to the extensive arrangement that may well set off large vapor explosions.

Reid, R. C. et al., Flameless Vapor Explosions. American Gas Association, Catalog No. M20177, 1977.

Flameless vapor explosions are discussed for a wide variety of substances, including LNG. Theoretical explanations are based on the superheat limit temperature.

Reid, R. C. and Smith, K. A., "Behavior of LPG on Water." Hydrocarbon Processing. pp. 117-121, April 1978.

Boiling of LPG is described as initially but very briefly violent followed by quiet evaporation. Boiling rates are not sensitive to changes in composition.

Reid, R. C. and Smith, K. A., Boil-Off Rate of Liquid Nitrogen and Liquid Methane on Insulated Concrete. Interim Report from MIT LNG Research Center to A.G.A., December 1975.

Experiments were conducted to measure the boil-off rate of both liquid nitrogen and liquid methane on insulation concrete. Results are fragmentary but do allow approximations of the rate of vapor generation that could result from spills of cryogenics on typical insulating concretes.

Reid, R. C. and Wang, R., "The Boiling Rates of LNG on Typical Dike Floor Materials." Cryogenics. 18(3):401-404, 1978.

The insulating qualities for various types of floor materials for LNG dike storage compounds have been determined in LNG boiling tests. Their numerical values are tabulated.

Reisler, R. E., Ethridge, N. H., LeFevre, D. P. and Giglio-Tos, L., Air Blast Measurements From the Detonation of an Explosive Gas Contained in a Hemispherical Balloon (Operation Distant Plain, Event 2a). Ballistic Research Laboratories, BRL MR 2108, AD/73216, U.S. Army Aberdeen Research and Development Center, Aberdeen Proving Ground, Maryland, July 1971.

Air blast was measured from the detonation of a mixture of oxygen and propane equivalent to 20 tons of TNT in a hemispherical balloon anchored to the ground surface. Comparisons made of overpressure waveshape and impulse as a function of shock overpressure show an equivalent yield of 20 tons or larger and a dynamic pressure impulse about 60 percent larger than for a corresponding 20 ton TNT charge.

Rhoads, R. E. and Johnson, J. F., "Risk in Transporting Materials for Various Energy Industries." Nuclear Safety. 19(2):135-149, March-April 1978.

A risk assessment model is presented to assess the comparative safety of various energy systems in relation to other natural or man-related risks. Examples from assessments using the analysis technique are also presented along with future assessment plans. This paper encourages risk sensitivity studies and risk comparisons to provide a basis for decisions.

Ricou, F. P. and Spalding, D. B., "Measurements of Entrainment by Axisymmetrical Turbulent Jets." Journal of Fluid Mechanics. 11:21-32, 1961.

Measurements have allowed the deduction of an entrainment law relating mass flow rate, jet momentum, axial distance, and air density. When the injected gas burns in the jet the entrainment rate is up to 30% lower than when it does not.

Riedl, R. G., "Consumers' Gas LNG Satellite Firms Ottawa Valley Gas Supply." Pipeline & Gas J. 206(13):30-36, 1979.

New LNG peakshaving satellite plant, supplied from Montreal LNG peakshaving/liquefaction plant, is ideally located in middle of service area and has proven itself in both emergencies and for peakshaving service.

Rigard, J. and Vadot, L., "Evaluate LNG's Storage Hazards." Hydrocarb. Process. pp. 267-268, July 1979.

It is shown that experimental water modeling, based on Neyrtrec's water analog technique, can be a useful aid to planning protection of LNG tankage.

Rivard, W. C., Farmer, O. A. and Butler, T. D., RICE: A Computer Program for Multicomponent Chemically Reactive Flows at All Speeds. LA-5812, March 1975.

A computer code capable of solving the thermal-hydrodynamics of chemically reactive flows is presented. A strong point of the code is that it is not limited by sonic propagation constraints.

Rosenberg, S. D. and Vander Wall, E. M., "Gelled Cryogenic Liquids and Method of Making Same." U.S. Patent 4,011,730 (to Aerojet-General Corp.), 1977.

LNG or methane hydrates were prepared by introducing finely divided solid water or methanol into the cryogenic liquid. Less than 2 weight percent decreased the solubility of nitrogen in LNG to nearly zero at -280°F.

Russ, R. M., Detection of Atmospheric Methane Using a 2-Wavelength H_2N_2 Laser System. Masters Thesis, Mass. Institute of Tech., June 1978.

The report describes the design of a system to reliably measure concentrations of methane in air of 0.1 to 100% which may arise in LNG spill tests. Discussions of design requirements, alternatives, and model and laboratory test results are presented.

Santman, L. D., "The Department of Transportation's Role in LNG Safety Regulations." 1978 Operating Section Proceedings, American Gas Association, Montreal, Quebec, May 1978.

DOT authority over LNG safety is derived from the ports and waterways safety Act of 1972 and the natural gas pipeline safety Act of 1968. Proposed regulatory action on HR. 11622 is discussed.

Sarkes, L. A., Iribe, P. C. and Smith, R. B., "LNG: Current Status Confirms Its Technical Maturity." Pipeline and Gas Journal. November 1978.

The history and current developments in the LNG industry are summarized. Some of the safety concerns and safety related research are discussed.

Sarsten, J. A., "LNG Stratification and Rollover." Paper presented at the API Division of Refining, Philadelphia, PA, May 17, 1973.

This report covers an incident where LNG was stratified in an LNG storage tank during filling and how that stratification subsequently resulted in a rollover of the tank contents and the release of a large quantity of gas. A repetition will be positively prevented by the installation of a jet mixing nozzle that will thoroughly mix off-loaded cargo with different composition initial tank heels.

Schneider, A. L., "Liquified Natural Gas Safety Research." American Gas Association - Cryogenic Society of America, LNG Terminal and Safety Symposium, San Diego, 1978.

The paper summarizes experimental research programs for safety issues related to LNG transportation and storage.

Schneider, A. L., "LNG Research Overview." Proceedings of the Marine Safety Council, 36(3):52-54, 1979.

A condensed overview is given on U.S. Coast Guard sponsored safety projects connected with the marine transportation of LNG. The projects and their main results are listed briefly.

Schuller, M. R., Murphy, J. C. and Glasser, K. F., "LNG Storage Tanks for Metropolitan Areas." Paper presented at the 4th International LNG Conference, Algiers, Algeria, June 24-27, 1974.

This article describes in some detail the special design features of the 290,000 BBL storage tank built for Consolidated Edison of New York by the Pittsburgh Des Moines Steel Company. The special design features, including a 9% Ni outer tank shell and a concrete berm wall around the outside of the tank, were used because of the heavily populated surrounding area and the proximity of the facility to LaGuardia Airport.

Science Applications, Inc., LNG Terminal Risk Assessment Study for Los Angeles, California. SAI-75-614-LJ, for Western LNG Terminal Company, Los Angeles, CA, 1975.

SAI analyzed the potential risk of a proposed LNG import terminal in Los Angeles Harbor.

Sergeant, R. J. and Robinett, F. E., An Experimental Investigation of the Atmospheric Diffusion and Ignition of Boil Off Vapors Associated With a Spillage of Liquefied Natural Gas. TRW Systems Group Report No. 08072-7, to A.G.A., A.G.A. Catalog No. M19715, November 14, 1968.

Results of experimental spills of LNG into scaled earthen dikes are described. Emphasis of this phase of the program was directed toward qualitatively determining the path of the boil-off vapors, quantitatively measuring the gas/air mixture in the surrounding environment, and demonstrating the extent of the flammability with an ignition source. Correlation of the experimental data into empirical form is presented; radiation data were also obtained.

Seroka, S. and Bolan, R. J., "Safety Considerations in the Installation of an LNG Tank." Cryogenics and Industrial Gases. pp 22-27, September/October, 1970.

Design codes and standards for LNG storage tanks are detailed. Diagrams showing instrumentation for a typical tank are included.

Shaheen, E. I. and Vora, M. K., "Worldwide LNG Survey Cites Existing, Planned Projects." Oil and Gas Journal. pp 59-71, June 20, 1977.

This article discusses the various types of LNG facilities and briefly describes several existing facilities. A list of all the LNG facilities worldwide is included.

Shaw, P. and Briscoe, F., Evaporation from Spills of Hazardous Liquids on Land and Water. SRD R-100, 1978.

Mathematical models for an analytical description of cryogenic liquid spills both on water and on land are being developed and evaluated. Numerical results are given.

Shell International Research, "Transportation of Liquefied Natural Gas." Chem. Abstr. 66:97298b, Neth. Appl. 6,506,843, 1966.

An aqueous isopentane emulsion was used as a recyclable thermal carrier for heating or cooling LNG. A solid phase, such as silica-gel, was also suggested.

Shultz, F. D., "Safety at an LNG Peakshaving Facility." Presented at the ASME Winter Meeting, New York, NY, November 17-22, 1974.

Design and operation of the many safety related aspects of Long Island Lighting Company's Holbrook LNG plant is described. Such features include gas detectors, fire protection and vapor dispersion systems, and the emergency shutdown systems.

Sidjak, W., Arctic Pilot Project. Presented to the American Gas Association Transmission Conference, Montreal, Quebec, May 8-10, 1978.

This paper describes a pilot study involving a barge-mounted liquefaction and storage facility in the Arctic. The pilot study is in support of the Arctic Islands LNG project (see above).

Siegwarth, J. D., Radio Frequency Liquid Level Gauging In Propane Tank Car Safety Tests - A Feasibility Study. NBSIR 79-1660, National Bureau of Standards, 1979.

The report presents details of experiments to gauge liquid levels in tank cars using the change in resonant radio frequencies. Precision was tested and the method was recommended for routine tank car gauging.

Simanek, J. and Pick, P., "Hydrates of Natural Gas." Plyn. 53:167-9, June 1973.

Crystallographic data was presented concerning the unit cell and crystal dimensions. In natural gas, up to seven components can participate in mixed hydrate formation. Phase diagrams for several of the mixtures were shown.

Simmons, John A., Risk Assessment of Storage and Transport of Liquefied Natural Gas and LP-Gas. Science Applications, Inc., November 25, 1974.

A method for assessing the societal risk of transporting LPG and LNG is described. From an estimated 52 significant accidents per year with LPG tank trucks at the present truck-associated transportation rate of 20 billion gallons of LPG per year, a fatality rate of 1.2 per year is calculated. For the projected 1980 importation of 33 billion gallons by tanker ship, a fatality rate of 0.4 per year is calculated.

Simplified Methods for Estimating Vapor Concentration and Dispersion Distances for Continuous LNG Spills into Dikes with Flat or Sloping Floors. A. D. Little, Inc. for American Gas Association, AGA No. X50978, April 1978.

The report describes a set of techniques which allow calculation of dispersion of LNG spilled on a flat or sloped dike floor. Calculations include leakage flow rate, LNG flash vaporization, LNG boiling and vapor overflow, and vapor dispersion.

Sindt, C. F. and Ludtke, P. R., "Characteristics of Slush and Boiling Methane and Methane Mixtures." Proceedings of 13th Int. Congr. of the Int. Institute of Refrigeration. pp. 315-320, 1971.

Experiments were performed to determine the boiling behavior of methane and methane mixtures and also of the slush which is formed when vacuum pumping the ullage over the mixture.

Singer, I. A., "The Relationship Between Peak and Mean Concentrations." Journal of the Air Pollution Control Association. 11:336-341, July 1961.

A method of predicting average concentrations has been presented. It has been shown that the simplified normal bivariate distribution describing the average concentration pattern is composed of various short-term periodic distributions which may differ from it significantly. A descriptive, empirical method has been described.

Singer, I. A. and Smith, M. E., "Atmospheric Dispersion of Brookhaven National Laboratory." Air and Water Pollution - An International Journal. 10:125-135. 1966.

A variety of data relating to atmospheric dispersion has been obtained at the Brookhaven Laboratory site and its environs. Concentration measurements were made at distances ranging from 10 m to 60 km. Dispersion patterns developed are discussed in detail and values of the parameters appropriate for various theoretical treatments are summarized.

Slade, D. H., "Atmospheric Dispersion Over Chesapeake Bay." Monthly Weather Review. pp 217-224, June 1962.

It was found that, after the air had traveled for about 7 miles over the water, its direction fluctuations were always less than they had been before reaching the water. The wind speed usually increased as the air crossed the water. The ratio of overland to overwater dispersive capacity varied from less than 5:1, for heating from below, to greater than 35:1 for cooling from below.

Slawson, P. R. and Csanady, G. T., "The Effect of Atmospheric Condition on Plume Rise." Journal of Fluid Mechanics. 47:33-49, 1971.

The buoyant rise of chimney plumes is discussed for relatively large distances from the source, where atmospheric turbulence is the dominant cause of mixing (rather than turbulence due to the plume's own upward motion). A simple theory is developed which shows a number of different shapes plumes can have under different atmospheric conditions (particularly in an unstable environment).

Sloan, E., Dendy, Khoury, F. M., and Kobayashi, R., "Water Content of Methane Gas in Equilibrium with Hydrates." Ind. Eng. Chem. Fundam. 15:318-23, April 1976.

Experimental measurements of water content of methane gas in equilibrium with hydrate were presented at 1000 and 1500 psia for temperatures greater than -10°F. The differences between methane and natural gas hydrates were stressed.

Smith, J. M. S., Mathew, R. C. and Cool, J. A. F., "The Safety of Gas Carriers with Particular Reference to the ICS Tanker Safety Guideline (Liquefied Gas)." Presented at Gastech 75, Paris, September 30-October 3, 1975.

This paper provides an overview of the hazards of operating an LNG carrier with particular emphasis on personnel training.

Smith, K. A., Lewis, J. P., Randall, G. A. and Meldon, J. H., "Mixing and Rollover in LNG Tanks." Paper presented at the Cryogenic Engineering Conference, Atlanta, GA, August 8, 1973.

Criteria and data are presented for deciding whether a specific LNG installation need have both top and bottom fill capacity. In general, a large facility will benefit from such capability if it is to receive a variety of LNG compositions from a variety of ships. It is further shown that the top fill device requires surprisingly careful design in order to assure good mixing at the free surface.

Smith, K. A. and Reid, R. C., The Effect of Composition on the Boiling of LNG on Water. M.I.T. LNG Research Center, 1976 Annual Report, Task IV, to the American Gas Association BR 87-6, January 1977.

The results obtained thus far with binary and ternary mixtures indicate that a preferential evaporation of methane does indeed take place, followed by the preferential evaporation of the next more volatile component ethane. Propane is the last component to evaporate. Although a preferential evaporation takes place, the vapors are a mixture very rich in the volatile component but a mixture after all.

Smith, K. A. and Reid, R. C., Electrostatics and its Hazards in Petroleum Industry and LNG Systems. M.I.T. LNG Research Center, 1976 Annual Report, Task V, to the American Gas Association BR 87-6, January 1977.

The paper discusses streaming potentials and sedimentation potentials in relation to static charge generation as a consequence of hydrocarbon flow through pipes.

Smith, K. A. and Reid, R. C., Boiling of LNG on Dike Floor Materials. M.I.T. LNG Research Center, 1976 Annual Report, Task VI, to the American Gas Association BR 87-6, January 1977.

The rate of vaporization of LNG spilled on a number of substrates was measured experimentally. Included in the materials tested: insulated concrete of two densities, soil, sand, pebbles, wet and dry polyurethane. In all cases, the early rate of vaporization could be well correlated with simple, one-dimensional conduction heat transfer.

Smith, M., ed., Recommended Guide for the Prediction of the Dispersion of Airborne Effluents. Published by the American Society of Mechanical Engineers, May 1968.

The guide discusses meteorological fundamentals, airborne effluents, stack height, dispersion and deposition, data sources and experimental methods, and gives calculation methods and examples.

Smith, R. V., "The Influence of Surface Characteristics on the Boiling of Cryogenic Fluids." J. of Eng. for Industry. 91:1217-1221, 1969.

The influence of a solid heating surface on the boiling behavior of liquid helium, hydrogen and nitrogen is being discussed. This is a review article and contains essentially no new information.

Snellink, I. G., "Hazard Assessment of LNG Supply and Storage." Communication of the Netherlands Delegation, January 1978.

The author describes a risk analysis of the supply and storage of LNG at a facility near the river Maas on the Dutch coast.

Solberg, D. M., Nylund, J. and Hansen, H. R., "Safety and Reliability of Floating LNG Protection Facilities." Fifth International Conference on LNG, Session III, paper 6, Institute of Gas Technology, 1977.

Safety guidelines for the construction and classification of floating facilities for gas processing, liquefaction, and storage are being reviewed.

Solomon, B., "Cove Pt. LNG Terminal to Resume Operation After Accident." The Energy Daily. pp. 1-2, October 19, 1979.

A recent accident at the Cove Point, Maryland liquefied natural gas facility is described. Seepage of LNG from a high pressure pump resulted in a gas explosion which killed one employee and critically injured another.

Spangler, C. V., "Storing Gases." U.S. Patent 2,663,626 (to J. F. Pritchard and Co.), 1953.

Natural gas was cooled to slightly above its boiling point and adsorbed on activated carbon or silica gel. Release of adsorbed gas was achieved by contacting heated natural gas with the solid support.

Speir, G. A., "Indonesia's Badak LNG Project Sets New Records." Pipeline and Gas Journal. June 1978.

This article discusses design, construction, startup and operation of the Badak export terminal. The facility liquefies gas for shipment to Japan.

Srinivason, K., et al., "Effect of Floating Insulation on Free Surface of Cryogenic Liquids in Open Containers." 6th Internat. Cryog. Eng. Conf., pp. 258-262, IPC Science and Technology Press Ltd., Guilford, England, 1976.

The effect of floating insulation materials on the evaporation rate of cryogenic liquids is investigated. Normally, this rate can be reduced by up to 25%.

Stanfill, I.C., "Startup Experiences and Special Features at Memphis LNG Plant." Presented at the First LNG International Conference, Chicago, IL, April 7-12, 1968.

This paper describes four major and several minor equipment malfunctions which occurred during startup and the first six months of operation at the Memphis LNG plant. Several process flow diagrams for the Memphis plant are included.

Stein, W., LNG Fireball Thermal Radiation. UCID-18190, Lawrence Livermore Laboratory, 1977.

The highly simplified computational method is presented for the determination of thermal radiation, emanating from a LNG fireball. Quantitative results are given in a series of diagrams.

Stein, W., Vapor Generation from a 40 m³ Instantaneous LNG Spill into a 100 m² Diked Soil Area. UCID-18188, Lawrence Livermore Laboratory, 1978.

A simple heat transfer model is presented in the evaporation of LNG spilled into a diked area. Some numerical results are given.

Stein, W., "The Spreading of Differential Boil-Off for a Spill of LNG on a Water Surface." Report A, Liquefied Gaseous Fuels Safety and Environmental Control Assessment Program; A Status Report. DOE/EV-0036, Department of Energy, Washington, DC, 1979.

A computer program is described which calculates pool size, differential boil-off and spreading rate for LNG spills on water. Results compare favorably with experimental data.

Stephan, K., "Evaporation Rate of Liquid Natural Gas in Large Containers." Thermo and Fluid Dynamics. 11:53-61, 1978.

Natural gas is often stored in large isolated metal containers. Heat flow through the bottom, the side wall and the cover to the stored liquid are practically independent from each other due to the large dimensions of such containers. Based on this simplification the evaporation rate of the liquid is calculated by means of the Laplace Transformation and a specific difference equation. With the results it is possible to determine the time after which freezing in the surrounding soil commences. The rate of heat flow to the condensed gas proved to be practically unaffected by the ice-formation in the soil. (in German)

Steward, F. R., "Linear Flame Heights for Various Fuels." Combustion and Flame. 8(3):171-178, September 1964.

The flame heights of linear diffusion flames for several different fuels have been correlated with a single parameter derived from a model assuming mixing controlled combustion. The assumptions involved are stated clearly.

Steward, F. R., "Prediction of the Height of Turbulent Diffusion Buoyant Flames." Combustion Science and Technology. 2:203-212, 1970.

A mathematical model of a turbulent diffusion buoyant flame based on a number of simplifying assumptions is presented. It was found that the height at which 400% excess air has been entrained corresponds to the visible flame height according to data taken in our laboratory as well as that presented by a number of other workers.

Strehlow, R. A., "Unconfined Vapor Cloud Explosions - An Overview." Paper presented at the 14th Symposium on Combustion, The Combustion Institute, Pittsburgh, PA, 1973.

The author summarizes the history of accidental vapor cloud explosions, reviews the work that has been done to understand the dispersion, ignition, propagation and blast effects produced, then points out areas for future investigation.

Strehlow, R. A. et al., "On the Measurement of Energy Release Rates in Vapor Cloud Explosions." Combustion Science and Technology. 6:307-312, 1973.

The method is based on the finite amplitude isentropic acoustics of a centered spherical wave and involves the reduction of data from 3 pressure gauges which are measuring the explosion. The method of characteristics is used to back calculate to an effective spherical piston which replaces the explosion so energy release rates of the explosion can be calculated.

Strehlow, R. A. and Baker, W. E., "The Characterization of Accidental Explosions." Prog. Energy Combustion Science. Pergamon Press, 1976.

The authors review actual explosion incidents and classify them into several categories. Basic theory in blast wave damage is also discussed along with the effects of "non-ideal" blast waves. Future areas of research are recommended.

Strehlow, R. A., Luckiartz, R. T., Adamczyk, A. A. and Shimpi, S. A., "The Blast Wave Generated by Spherical Flame." Combustion and Flame. 35(3):297-310, August 1979.

The authors report on their work for determining the overpressures and impulses resulting from reactive fronts. Some results are presented for hydrocarbon mixtures. This paper may have application to blast wave effects estimation.

"Strong Global LNG Trade Growth Seen." Oil and Gas J. 77:36-37, December 1979.

It is expected that world LNG trade will double in the next 5 years, reaching about 3 trillion cu ft/yr by 1985. However, U.S. import policy will remain uncertain because of safety, siting, liability, and insurance issues.

Stuckly, J. M. and Walker, G., "Hydraulics a Key to Optimizing LNG Pipelines." Oil and Gas J. 77(17):68-70, 1979.

By carrying out detailed numerical calculations for the considered LNG pipeline, it is shown that under optimized conditions a liquid carrying pipeline offers improved fuel efficiency when compared with a conventional vapor-phase line.

Stuckly, J. M. and Walker, G., "LNG Long-Distance Pipelines--A Technology Assessment." Oil and Gas J. 77(16):59-63, 1979.

An outline design study for a 1,430-mile LNG pipeline in Northern Canada is described. The tradeoffs between operating temperatures, pressures, pipe diameter, insulation, and material requirements are discussed in some detail. So far no large-diameter, long-distance LNG pipelines have actually been built, but they have received a lot of attention recently.

Study of LNG Safety - Parts I and II. Tokyo Gas Company Ltd., Central Laboratory, February 1971.

This two-part study presents experimental results on LNG evaporation, combustion and dispersion characteristics in a dike, and on LNG evaporation, ice formation, and LNG dispersion on water.

Sunvala, P. D., "Dynamics of the Buoyant Diffusion Flame." Journal of the Institute of Fuel. 40:492-497, 1967.

A new theoretical treatment of the axial velocity growth and mass concentration decay in a buoyant diffusion flame is presented. It has been found that for the flame lengths of burning of various fuel gases, organic liquids as well as fuel oils, the one-fifth power index for the Froude Number holds good. However, for the flame lengths of burning firewood in cribs, the two-fifths power index for the Froude Number is suggested.

Sutherland, V. and J. E. Hughes, "Subterranean LNG Storage." Energy Digest. 3:15-17, October 1978.

The construction of six storage cavities in underground salt formations is described. Each cavity can hold about $60 \times 10^6 \text{ m}^3$ LNG at pressures between 120 and 270 bar.

Sutton, S. B., Overpressure Prediction. UCID-18189, Lawrence Livermore Laboratory, 1977.

A simple calculation is performed to determine the energy within a burning cloud of LNG. This energy is assumed to have the same pressure effect as an energy-equivalent quantity of TNT.

Taki, S. and Fujiwara, T., "Numerical Analysis of Two-Dimensional Nonsteady Detonators." AINA Journal. 16, January 1978.

This paper is a report about the numerical calculation of two-dimensional detonation propagation in a confined channel. A simplified chemical kinetics was employed. The method may have application to the study of detonation probabilities for methane-air mixtures.

Tanker Structural Analysis for Minor Collisions. U.S. Coast Guard Report CG-D-72-76. NTIS No. AD/A031031, December 1975.

This report describes the work accomplished during the course of the project of the Evaluation of Tanker Structure in Collision. The intent of the report is to present the investigations performed in evaluating the phenomena that contribute to the ability of a longitudinally framed ship, particularly a tanker, to withstand a minor collision. A minor collision is one in which the cargo tanks remain intact. The ability to withstand a minor collision is quantized by the total energy that can be absorbed during the collision.

Tarifa, C. S., Del Notario, P. P. and Valdes, C. F., Open Fires. Final Report, U.S. Department of Agriculture, Forest Service, Grant FG-SP-114 and 146, May 1967.

An experimental study was made of some basic laws of open fires by utilizing the pool fire techniques. Data were obtained for burning rates, energy balances and flame characteristics, including the influence of fuel type, vessel size and vessel configuration.

Taylor, P. B. and Foster, P. J., "Some Gray Gas Weighting Coefficients for CO₂-H₂O Soot Mixtures." International Journal of Heat Mass Transfer. 19:1331-1332, 1975.

Two tables are provided which give 1) the values of constants which specify weighting factors for various soot concentrations applicable in the temperature range 1400 to 2400°K and 2) values of constants which specify the gray gas absorption coefficient applicable in the 1200 to 2400°K temperature range.

Terry, M. C., "Floating LNG Facilities May Solve Many Problems." Pipeline and Gas Journal. pp. 25-28, June 1977.

This article discusses the history of development of offshore liquefaction facilities. Various generic types of floating facilities are discussed and their potential evaluated.

Thermal Radiation and Overpressure from Instantaneous LNG Release into the Atmosphere. TRW Systems Group Report No. 08072-4, to A.G.A., April 26, 1968.

The report conclusions express belief that 1) a stoichiometric mixture of natural gas and air at atmospheric pressure will not detonate with a charge of high energy explosive equivalent to 625 grams of TNT; 2) the parameters of charge energy, mixture composition and confining wall geometry should be further investigated.

Thomas, P. H., "The Size of Flames From Natural Fires." Paper presented at the 9th International Symposium on Combustion, 1963.

Uncontrolled fires produce flames where the initial momentum of the fuel is low compared with the momentum by buoyancy. The heights of such flames with wood as the fuel are examined and discussed in terms of both a dimensional analysis and the entrainment of air into the turbulent flame. Some recent experiments on the effects of wind on such flames are also reported.

Thomas, P. H., Baldwin, R. and Heselden, A. J. M., "Buoyant Diffusion Flames: Some Measurements of Air Entrainment, Heat Transfer, and Flame Merging." Paper presented at the 10th International Symposium on Combustion, the Combustion Institute, 1965.

Thistledown has been used as a tracer to measure the flow of air toward ethyl alcohol and wood fires 91 cm in diameter, and a smaller town gas fire. The measured mean axial temperature rise at the mean flame height was about 300° to 350°C for wood and alcohol and 500°C for town gas.

Timmerhaus, K. D. and Flynn, T. M., "Safety with Cryogenic Systems." Advances in Cryog. Eng. 23:721-729, 1978.

Safety aspects of cryogenic fluids are discussed from a practical point of view. Rules and suggestions for the safe handling of such fluids are given.

Tomkins, B. G., "LNG Plant Computer System: A Conceptual Philosophy." Oil and Gas J. 77(48):56-60, 1979.

A computer in an LNG plant must be designed around the plant operating plan. Consideration must also be given to maintenance and safety plants. Suggestions for useful hard and software selections are provided.

Tonnessen, A., Insulated Tanks for Liquefied Gas. U.S. Patent 4,141,465, 1979.

To reduce boil-off in spherical LNG tanks, the tank skirt is supplied with a special low conductivity ring insert, made of 18-8 SS. Such a heat flow resistance can reduce the heat leak through the skirt by about 50 percent.

Tsai, S. S. and Chan, S. H., A General Formulation and Analytical Solution for Multi-Dimensional Radiative Transfer in Non-Gray Gases. A.I.Ch.E., A.S.M.E. Heat Transfer Conference, Salt Lake City, Utah, (77-HT-51), August 1977.

The equations of radiative transfer (spectral) are cast into band absorptance from the multidimensional geometries. Optically thick and thin limiting expressions are thus deduced and discussed.

Tsatsaronis, G., "Prediction of Propagating Laminar Flames in Methane, Oxygen, Nitrogen Mixtures." Combustion and Flame. 33:217-239, 1978.

A fundamental analysis of one dimensional flame propagation (including chemical kinetics and transport [processes] of methane flames) is performed. Flame speed, flame structure and pressure effects are enumerated.

"Turbine/Compressor Serves First 50/50 Methane-Nitrogen Cycle Gas System." Diesel and Gas Turbine Progress.

A unique liquefaction plant at a peakshaving facility is described. Considerable detail, including several photographs, on the refrigerant compressor is provided.

Turner, D. B., Workbook of Atmospheric Dispersion Estimates. Publication No. 99-AP-26, Public Health Service, 1969.

This workbook presents methods of practical application of the binormal continuous plume dispersion model to estimate concentrations of air pollutants. Estimates of dispersion are those of Pasquill as restated by Gifford. Emphasis is on the estimation of concentrations from continuous sources for sampling times up to 1 hour.

Tutko, T. J., "How to Design an Integrated Security System for an LNG Facility." Pipeline and Gas Journal. 121:50-62, July 1979.

The need for a integrated security system at all major LNG facilities is demonstrated. Various suggestions are given as how to best implement such a system.

Uhl, A. E., Amoroso, L. A. and Seitir, R. H., "Safety and Reliability of LNG Facilities." Presented at the ASME Petroleum Mechanical Engineering and Pressure Vessels and Piping Conference, New Orleans, LA, September 17-21, 1972.

The prime factors behind the fine operational safety and reliability record of LNG facilities are the early definition and understanding of the nature of LNG, the establishment and utilization of relevant codes, the casting and observation of pertinent quality assurance programs, and thorough training of plant operators. This paper discusses each of these factors in detail.

Uldenvan, A. P., "The Unsteady Gravity Spread of a Dense Cloud in a Calm Environment," paper presented at the International Technical meeting on Air Pollution Modeling and its Application, NATO-CCMS, Rome, October 26, 1979.

Simplified bulk momentum equations for one dimensional and axisymmetric gravity spreading of dense clouds are presented. Analytical solutions indicate that a steady state is not reached during cloud spreading.

U.S. Comptroller General, Need to Improve Regulatory Review Process for Natural Gas Imports. ID-78-17, General Accounting Office, July 14, 1978.

The article highlights difficulties in the review process for LNG importation facilities and makes recommendations to Congress and federal agencies to mitigate the impacts.

U.S. General Accounting Office, Information on the U.S. Importation of Liquefied Natural Gas. EMD-79-48, March 22, 1979.

The report deals with questions on LNG consumption in the U.S., the sources and prices for the imported LNG and with its end use by the utility companies. It also addresses size and ownership of the LNG tanker fleet.

Valencia-Chavez, J. A. and Reid, R. C., "The Effect of Composition on the Boiling Rates of Liquefied Natural Gas for Confined Spills on Water." Int. J. Heat Mass Transfer. 22:831-838, 1979.

Boiling rates for spills of LNG on a confined area of water (calorimeter) were measured for various LNG compositions. A simplified model was developed which compared well with experimental results.

Vanderwall, E. M., "Investigation of the Suitability of Gelled Methane for Use in a Jet Engine." NAS 3-14305, NASA CR-72876, 1971.

Methanol gelled cryogenic methane was storable at -263°F for periods exceeding 100 hours with no significant gel structure degradation. The gel could be transferred through properly designed heat exchangers at comparatively high flow rates (10 lb/hr) without clogging. Fuel consumption by jet engines was not excessive due to the gelant.

Van Horn, A. J. and Wilson, R., Liquefied Natural Gas: Safety Issues, Public Concerns, and Decision Making. BNL 22284, Energy and Environmental Policy Center, Jefferson Physical Laboratory, Harvard University, November 1976.

The report provides background information on LNG and discusses safety issues, LNG facilities siting disputes, public concern for LNG facilities siting, LNG decision making, and gives recommendations concerning LNG terminal siting facilities.

Vanta, E. B. et al., Detonability of Some Natural Gas-Air Mixtures. Technical Report AFATL-TR-74-80, Air Force Armament Laboratory, Elgin Air Force Base, April 1974.

A bag test method to screen natural gas-air mixtures (5.2 to 12.5% by vol. natural gas) to determine detonability. At the 8.6 to 8.8% concentration level, erratic, uneven detonations were initiated and explosive charges ranged from 1001 to 1020 grams. Deflagration occurred at all other fuel concentrations. The detonations propagated the length of the bag, but a steady Chapman-Jouquet type wave front was not observed.

Van Ulden, A. P., "On the Spreading of a Heavy Gas Released Near the Ground." Loss Prevention and Safety Promotion in the Process Industries. Bushman, C. H., ed. Proceedings of the First International Loss Prevention Symposium. The Hague/Delft, The Netherlands, May 28-30, 1974, Elsevier Scientific Publishing Company, 1974.

It is shown that the spreading of a heavy gas differs essentially from the spreading of a neutral gas. Horizontal spread is increased considerably by gravity effects, whereas vertical spread is limited. Calculations are compared with experimental results.

Varma, R. K., Murgai, M. P. and Ghildyal, C. D., "Radiative Transfer Effects in Natural Convection Above Fires - General Case." Proc. Roy. Soc., London, A314, 1970.

The effect of radiation, on the overall dynamics of a hot plume above fires, has been considered. An approximate multidimensional transfer equation for heat radiation is derived from the Schwarzschild's equation. The plume material is assumed to be grey and the outside atmosphere is considered calm and is, otherwise, in a state of arbitrary lapse rate variation.

Verma, S. B. and Cermak, J. E., "Mass Transfer From Aerodynamically Rough Surface." International Journal of Heat and Mass Transfer. 17:567-579, 1974.

Mass transfer rates were determined by directly measuring the actual volume of water evaporated from saturated wavy (sinusoidal) surfaces in micrometeorological wind tunnel. Simultaneous measurements of mean velocity, humidity and temperature distributions were made over these saturated waves.

Vielvoye, R., "Abu Dhabi Activity Soars, but Government Keeps Lid on Production." Oil and Gas Journal. p. 74, July 9, 1978.

Included in this article is a discussion of some of the problems which have plagued the Das Island export terminal. These include cracked cryogenic pipelines, corrosion from high-sulfur gas, and a leak in the inner shell of a storage tank which eventually caused a crack in the outer shell.

Vora, M. K., Shaheen, E. I. and Knieves, D. V., "U.S. Energy Future: Higher LNG Imports Will be Needed." World Oil. pp. 134-148, June 1978.

The future U.S. energy needs and the potential of LNG imports are discussed. It is predicted that LNG could supply 4.7% of total U.S. energy requirements by 1985. This would require an import of 4.86 tcf including 1.17 tcf from Alaska.

Vreedenburger, H., "Steel or Prefab Concrete for Inshore Plants." Chemical Engineering Progress. pp. 82-85, 1979.

The use of steel and concrete in the construction of a floating LNG receiving terminal is discussed. Concrete can offer some advantages in the storage tank design and construction.

Wakeshima, H. and Takata, K., "On the Limit of Superheat." Journal of the Physical Society of Japan. 13(11):13-1403, November 1958.

A new method was devised in which small drops of a sample liquid are heated as they rise up in the nonsoluble heating liquid with a suitable temperature gradient upward. The limit of superheat was determined for saturated hydrocarbons and polymethylenes. The agreement between (Doring's) theory and experiment was satisfactory.

Welker, J. R., Brown, L. E., Ice, J. N., Martinsen, W. E. and West, H. H., Fire Safety Aboard LNG Vessels. U.S. Coast Guard Report No. CG-D-94-76. NTIC No. AD/A030619, January 1976.

This report presents results of an analytical examination of cargo spill and fire hazard potential associated with the marine handling of liquefied natural gas cargo. Principal emphasis was on cargo transfer operations at receiving terminals, and more specifically on the LNG tanker's cargo handling and hazard sensing and control equipment and operations.

Welker, J. R., Wesson, H. R. and Brown, L. E., "Use of Foam to Disperse LNG Vapors?" Hydrocarb. Process. pp. 119-120, 1974.

Tests have shown that a blanket of high-expansion foam effectively reduces ground-level methane concentrations downwind of an LNG spill.

Welker, J. R. et al., "LNG Spills: To Burn or Not to Burn." Paper presented at the A.G.A. Operating Section Distribution Conference, 1969.

This paper concludes that: flammable mixtures from large spills will penetrate a long distance downwind; a major spill should be ignited as soon as possible; a high-expansion foam system offers the best protection by suppressing either LNG evaporation or the burning rate and present standards that specify separation distance irrespective of pool size are meaningless.

Welker, J. R., Pipkin, O. A. and Sliepcevich, C. M., "The Effect of Wind on Flames." Fire Technology. 1(2):122-219, 1965.

A simplified and improved correlation for the drag coefficient of windblown natural gas flames is given. Experimental results leading to the correlation were obtained in a low-speed wind tunnel specifically designed for such studies at the University of Oklahoma North Campus.

Welker, J. R. and Sliepcevich, C. M., "Bending of Wind-Blown Flames From Liquid Pools." Fire Technology. 2, 1966.

The bending of a flame by wind influences the amount of heat transferred by radiation and convection, the fuel burning rate, and the flame spread rate. To what extent will a flame be bent by wind? The author presents correlations of data taken from liquid pool fires, which enable us to predict flame bending and trailing for large fires.

Welker, J. R., West, H. H., Mento, M. A. and Ice, J. N., A Survey of the Effectiveness of Control Methods for Fires in Some Hazardous Chemical Cargoes. U.S. Coast Guard Report CG-D-64-76. NTIS No. AD/A026300, March 1976.

Assessment of fire safety of marine bulk chemical carriers was attempted. It is recommended that standard fire control test methods be developed together with standardized test data collecting and reporting methods and that large-scale fire tests be made on chemicals from different families to attempt to develop methods of correlation with small-scale test results. If a reliable correlation can be developed, small-scale tests could be used in the future with more confidence to both predict behavior of chemical cargoes under fire conditions and to assess large fire extinguishing effectiveness.

Wesson, H. R., Lott, J. L., Feldman, R. and Closner, J. J., "Thermal Performance of a Fire Resistant Coating Applied to Prestressed Concrete." 1978 Operating Section Proceedings, American Gas Association, Montreal, Quebec, May 1978.

The fire resistance of coatings designed to protect weakening of prestressing wire in cryogenic tanks is tested. Degree of protection with coating thickness is discussed.

Wesson, H. R., Welker, J. R. and Brown, L. E., "Control LNG-Spill Fires." Hydrocarb. Process. 51:61-64, December 1972.

Control of LNG-spill fires is obtained by application of high expansion foam. Follow-up with dry chemical fire extinguishers will quickly extinguish the fire.

West, H. H., Brown, L. E. and Welker, J. R., "Vapor Dispersion, Fire Control, and Fire Extinguishment for LNG Spills." NTIS No. AD/A023505, pp. 509-518, Proceedings of the Fourth International Symposium on Transport of Hazardous Cargoes by Sea and Inland Waterway. Jacksonville, FL, October 26-30, 1975.

Dry chemical fire extinguishment systems can provide rapid extinguishment of LNG fires. High expansion foam can reduce the radiant flux from LNG fires, provide protection for the surroundings until the fire burns out, and reduce the concentration of methane in the vapor cloud downwind from an LNG fire.

West, H. H., Brown, L. E. and Welker, J. R., "Vapor Dispersion Fire Control and Fire Extinguishment for LNG Spills." The Combustion Institute, 1975 Spring Technical Meeting. San Antonio, Texas, 1975.

The paper reports results on AGA tests of LNG evaporation and pool fire radiation reductions by foam application. Tests also demonstrated flame extinguishment by dry chemicals if applied a short time after pool fire ignition.

Westbrook, C. K., A Generalized ICE Method for Chemically Reactive Flows in Combustion Systems. UCRL-78915, Rev. 1, Lawrence Livermore Lab., August 1977.

The ICE method is modified to allow the pressure calculated at a new time step to include the effects of changes in internal energy and species over that time step. This is important for reactive flows in which the change in temperature and/or species contributes significantly to changes in pressure.

Westbrook, C. and Haselman, L., Chemical Kinetics of LNG Detonations. UCRL-82293, Lawrence Livermore Laboratory, February 1979.

The authors of this paper theoretically investigate the effect of ethane on the detonability of methane. Small amounts of ethane were found to significantly increase the possibility of a detonation occurring. The chemical kinetics of the reaction mechanism are also presented.

Weston, H. and Brown, L.E., "Analyze Fire Protection System." Hydrocarbon Processing. pp. 89-92, August 1977.

This paper outlines a systems approach to fire safety and gives an example application to LNG Fire Control.

Wilcox, D. C., "Model for Fires With Low Initial Momentum and Nongray Thermal Radiation." AIAA Journal. 13(3):381-386, March 1975.

A new ambient-air entrainment law accounts for rapid fluid acceleration from initially low velocity at a liquid pool, to higher velocities established under buoyant rise of the combustion products. Radial-radiation heat transfer is computed with the exact radiation transport equation. Fire-model predictions fall within scatter of experimental flame-height and spectral-radiation data for LNG fires.

Wilcox, D. C., Non-Gray Thermal Radiation From a Flame Above a Pool of Liquid Natural Gas. Report by TRW Systems to A.G.A., A.G.A. Catalog No. M19714, February 1971.

This report indicates that a) spectral distribution of the radiation heat flux vector can be calculated, b) minimal data are required to extrapolate from small to large fires, c) an important scaling relationship may have been uncovered, and d) the flame model and associated computer program represent a solid foundation for investigation of radiation properties of a large LNG fire.

Williams, F. A., Combustion Theory - The Fundamental Theory of Chemically Reacting Flow Systems. Addison-Wesley Publishing Company, Inc., 1965.

Chapter 2 discusses Rankine-Hugoniot relations and pages 25-27 the properties of the Hugoniot curve.

Wissmiller, I. L. and Mattocks, E. O., "How to Use LNG Safely." Pipeline and Gas Journal. March 1972.

This article provides a general description of LNG equipment and facilities and how they are designed and operated for safety.

Withrington., J. K., "Analytical Methods for Verifying the Structural Integrity of LNG Carriers." LNG 3 - International Conference on Liquefied Natural Gas, Washington DC, September 24-28, 1972.

This paper identifies some of the structural problems that might occur with a very rapid increase in the size of LNG carriers and advocates the adoption of additional analytical methods to be used in conjunction with the normal procedures of the Classification Societies.

Witte, L. C. and Cox, J. E., Nonchemical Explosive Interaction of LNG and Water. ASME Preprint 71-WA/HT-31, 1972.

When LNG contacts water, an explosive incident may occur due to extremely rapid production of LNG vapor as heat is transferred from the surrounding water. Pertinent literature is summarized on similar reported explosions when hot molten materials contact cool liquids. Fragmentation of the LNG is believed to be the triggering mechanism for explosive vapor formation. Recent results of fragmentation research are presented.

Witte, L. C., Cox, J. E. and Bouvier, J. E., "The Vapor Explosion." Journal of Metals. 22:39-44, February 1970.

The article reviews the four theories of entrapment, violent boiling, shell theory, and Weber Number Effects. A common factor exists in that when molten material is fragmented prior to liquid contact, explosion danger is lessened.

Witte, L. C., Vyas, T. J. and Gelabert, A. A., "Heat Transfer and Fragmentation During Molten-Metal/Water Interactions." Journal of Heat Transfer. 95:521-527, November 1973.

This study indicates strongly that fragmentation occurs when a sample is molten and fragmentation is a response to an external stimulus. Alternate causes of fragmentation are proposed and are predicated upon the initial collapse of a vapor film around the molten metal.

Wolf, Sidney M., "Liquefied Natural Gas." The Bulletin of the Atomic Scientists. 25, Chicago, December 1978.

Wolf presents a review of LNG import questions including safety, security, and price applicable at the time of publication.

Wood, B. D., Blackshear, P. L., Jr, and Eckert, E. R. G., "Mass Fire Model: An Experimental Study of the Heat Transfer to Liquid Fuel Burning From a Sand-filled Pan Burner." Combustion Science and Technology. 4:113-129, 1971.

Heat flux data and the radiation heat flux data indicate that radiation contributes between 20 and 40 percent of the thermal load to the fuel surface for the methanol flame. For the acetone flame, approximately 40 to 60 percent of the total heat flux is radiation during the two steady burning rate periods.

Woolers, R. G., Marine Transportation of LNG and Related Products. Cornell Maritime Press, Cambridge, MD, 1975.

This book describes aspects of marine transport of LNG including ship design, container design, control systems, and a description of hazards and LNG importation. The hazards section describes experiments performed by the Bureau of Mines to determine the effects of LNG spillage on water.

Yamanouchi, N., and Nagasawa, H., "Using LNG Cold for Air Separation." Chem. Eng. Progr. 75(7):78-82, 1979.

By using the cryogenic energy contained in LNG, liquid oxygen, liquid nitrogen and liquid argon can be produced at a 40% saving in power consumption. In the same process LNG is evaporated. Three plants based on this principle are already operating in Japan, and a fourth one is under construction.

Yamazaki, D., Yokoyama, N, and Hino, M., "Storing and Transportation of Hydrocarbon Gases." Chem. Abstr. 80:85488q. Japan Kokai 73-92, 401 (to Mitsubishi Heavy Industries, Ltd.), 1973.

Natural gas was contacted with aqueous aliphatic amine solutions to obtain the hydrate. The hydrate product had a vapor pressure of 35 kg/cm² at 40°F.

Yang, K., "Explosive Interaction of Liquefied Natural Gas and Organic Liquids." Nature. 243:221-222, 1973.

Small scale experiments are described in which LNG is poured into organic liquids. In some cases resulting reactions were rather violent, indicating the possibility of vapor explosions.

Yilmaz, B. S., Clarke, S. F. and Westwater, J. M., Heat Transfer From Water in Film Boiling to an Upper Layer of Paraffinic Hydrocarbon. ASME paper 76-HT-24, 1976.

Laboratory experiments have been performed to measure the flux from a layer of water in the state of film boiling to a superimposed layer of various types of hydrocarbons.

Yumoto, T., "Heat Transfer From Flame to Fuel Surface in Large Pool Fires." Combustion and Flame. 17:108-110, 1971.

The study was made to obtain experimentally the ratio of radiation and convection transfers to total heat transfer from the flame to the fuel surface in the range where the burning rate has a constant value regardless of pan diameter.

Zahn, C. W. and Clayton, H. A., Recovery of Natural Gas Liquids by Partial Condensation. U.S. Patent 4,142,876, 1979.

A complex control scheme is proposed which sets the minimum temperature of the natural gas stream to the separator, allowing for the recovery of natural gas liquid by partial condensation of the inlet feed stream.

Zuber, K., "LNG Facilities - Engineered Fire Protection Systems." Fire Technology. 12:41-48, 1976.

Dry chemical fire extinguishers used in conjunction with high expansion foam have been used successfully in tests to extinguish LNG spill fires.

Zubiate, R., Pomonik, G. and Mostarda, S., "Single Point Mooring System for Floating LNG Plant." Ocean Industry. pp. 75-78, November 1978.

The advantages of portable floating offshore LNG terminals are discussed as a preface to a description of a mooring system for such a facility.