NBSIR 78 - 878

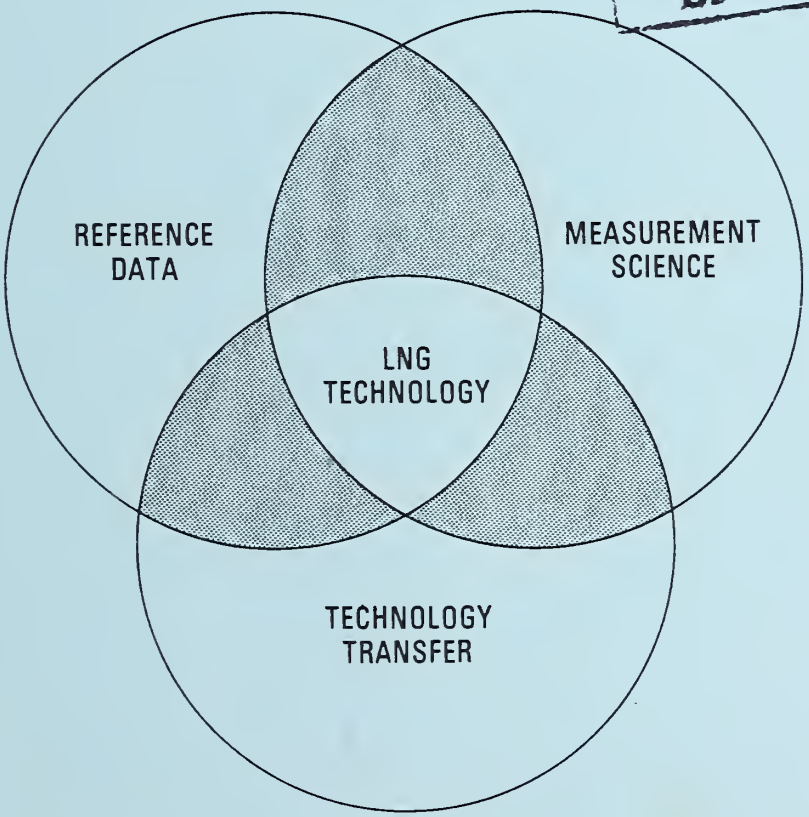
LIQUEFIED NATURAL GAS RESEARCH

at the

NATIONAL BUREAU OF STANDARDS

PROGRESS REPORT FOR THE PERIOD
1 July - 31 December 1977

D.E. Diller, Editor



CRYOGENICS DIVISION • NBS–INSTITUTE FOR BASIC STANDARDS • BOULDER, COLORADO

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Cryogenics Division
Institute for Basic Standards
National Bureau of Standards
Boulder, Colorado 80302

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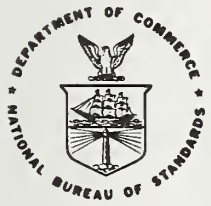

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LNG Custody Transfer Measurements Supervisory Committee

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ABSTRACT

Twenty-nine cost centers supported by seven other agency sponsors in addition to NBS, provide the basis for liquefied natural gas (LNG) research at NBS. During this six-month reporting period the level of effort was over 20 man-years/year with funding expenditures of over $500,000. This integrated progress report, to be issued in January and July, is designed to:

1) provide all sponsoring agencies with a semi-annual report on the activities of their individual programs;

2) inform all sponsoring agencies on related research being conducted at the Cryogenics Division;

3) provide a uniform reporting procedure which should maintain and improve communication while minimizing the time, effort and paperwork at the cost center level.

The contents of this report will augment the quarterly progress meetings of some sponsors, but will not necessarily replace such meetings. Distribution of this document is limited and intended primarily for the supporting agencies. Data or other information must be considered preliminary, subject to change and unpublished, and therefore not for citation in the open literature.

Key words: Cryogenics; liquefied natural gas; measurement; methane; properties; research.

CONTENTS

1. Title. THERMOPHYSICAL PROPERTIES DATA FOR PURE COMPONENTS AND MIXTURES OF LNG COMPONENTS

Principal Investigators. R. D. Goodwin, H. M. Roder, G. C. Straty, R. Tsumura*, W. M. Haynes, and R. D. McCarty

2. Cost Center Number. 2750574, 2750548

3. Sponsor Project Identification. American Gas Association, Inc., Project BR-50-10. National Aeronautics and Space Administration, Lewis Research Center, Purchase Order C-78014-C.

4. Introduction. Accurate phase equilibrium, equation of state (PVT), and thermodynamic properties data are needed to design and optimize gas separation and liquefaction processes and equipment, and for mass and heat transfer calculations. Accurate data for the pure components and selected mixtures of hydrocarbon systems will permit developing comprehensive accurate predictive calculation methods which take into account the dependence of the thermophysical properties of mixtures on the composition, temperature, and density.

   This project will provide comprehensive accurate thermophysical properties data and predictive calculation methods for compressed and liquefied hydrocarbon gases and their mixtures to support the development of LNG technology at NBS and throughout the fuel gas industry. It will also serve as the base for a comprehensive mixtures prediction methodology.

5. Objectives or Goals. The objectives of our work are the determination of comprehensive accurate thermophysical properties data and predictive calculation methods for the major pure components (methane, ethane, propane, butanes, and nitrogen) and selected mixtures of liquefied natural gas and hydrocarbon mixtures at temperatures between 90 K and 300 K and at pressures up to 35 MPa (5000 psi). Our goal is to provide a range and quality of data that will be recognized as definitive or standard for all foreseeable low temperature engineering calculations.

6. Background. Liquefied natural gas is expected to supply an increasing percentage of the United States' future energy requirements. It is likely that massive quantities of liquefied natural gas will be imported during the years 1978 - 1990. Ships and importation terminals are being built for transporting, storing, and vaporizing liquefied natural gas for distribution. Accurate physical and thermodynamic properties data for compressed and liquefied natural gas and hydrocarbon mixtures are needed to support these projects. For example, accurate compressibility and thermodynamic properties data are needed to design and optimize liquefaction and transport processes; accurate data for the heating value, which for liquefied natural gas mixtures depends on the total volume, the density, and the composition, are needed to provide a basis for equitable custody transfer. Accurate mixture data prediction methods are needed for use in automated heat transfer calculations.

   Accurate thermodynamic properties data for liquefied gas mixtures must be based on precise compressibility and calorimetric measurements; compressibility data give the dependence of thermodynamic properties on pressure and density (at fixed temperatures); calorimetric data give

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*Consejo Nacional de Ciencia y Tecnologia (CONACYT) Mexico City. Formerly a guest worker with the Cryogenics Division, National Bureau of Standards, Institute for Basic Standards in Boulder, Colorado.

the dependence of thermodynamic properties on temperature (at fixed pressures and densities). It is impossible, however, to perform enough compressibility and calorimetric measurements directly on multicomponent mixtures to permit accurate interpolation of the data to arbitrary compositions, temperatures and pressures. Instead, thermodynamic properties data for multicomponent mixtures must usually be predicted (extrapolated) from a limited number of measurements on the pure components and their binary mixtures. This project was initiated to provide the natural gas and aerospace industries with comprehensive accurate data for pure compressed and liquefied methane, the most abundant component in LNG mixtures. We have published National Bureau of Standards Technical Note 653, "Thermophysical Properties of Methane, From 90 to 500 K at Pressures to 700 Bar," by Robert D. Goodwin (April 1974), and National Bureau of Standards Technical Note 684, "Thermophysical Properties of Ethane, From 90 to 600 K at Pressures to 700 Bar," by Robert D. Goodwin, H. M. Roder, and G. C. Straty (August 1976). These reports contain the most comprehensive and accurate tables available for the thermophysical properties of pure gaseous and liquid methane and ethane, and provide accurate basis for calculating thermophysical properties data for LNG and other hydrocarbon mixtures.

7. Program and Results.

7.1 Ethane, Specific Heat Data -- H. M. Roder

This phase of the program is complete. Two manuscripts describing the results of the research have been published:

H. M. Roder, Measurements of the Specific Heats, C_σ and C_v, of Dense Gaseous and Liquid Ethane, J. Res. Nat. Bur. Stand. (U.S.), Vol 80A, No. 5, 739-59 (Sep-Oct 1976).

H. M. Roder, The Heats of Transition of Solid Ethane, J. Chem. Phys. Vol 65, No. 4, 1371-3 (Aug 1976).

7.2 Ethane, Sound Velocity Data -- R. Tsumura, G. C. Straty

This phase of the program is complete. The results of the research have been reported in the following publication:

R. Tsumura, G. C. Straty, Speed of Sound in Saturated and Compressed Fluid Ethane, Cryogenics Vol 17, No. 4, 195-200 (Apr 1977).

7.3 Ethane, Thermophysical Properties Data -- R. D. Goodwin

The manuscript, National Bureau of Standards Technical Note 684, "Thermophysical Properties of Ethane, From 90 to 600 K at Pressures to 700 Bar," by R. D. Goodwin, H. M. Roder, and G. C. Straty (August 1976) has been published and distributed.

7.4 Propane, Thermophysical Properties Data -- R. D. Goodwin

Available, published physical properties data, acquired through our Cryogenic Data Center, have been evaluated and formulated as required for thermodynamic computations. These numerous properties now have been used to compute a complete set of provisional tables of thermodynamic functions.

The manuscript, "Provisional Thermodynamic Functions of Propane, From 85 to 700 K at Pressures to 700 Bar," has been published as National Bureau of Standards Internal Report, NBSIR 77-860 (July 1977).

7.5 Propane, PVTx and Dielectric Constant Measurements -- W. M. Haynes

As noted in the last semiannual progress report a new apparatus has been developed for pressure, temperature, density, composition, and dielectric constant measurements on liquids and liquid mixtures at temperatures between 70 and 350 K and at pressures to 35 MPa (approximately 5000 psi). The major features of the apparatus were described in detail in that report. Several significant changes have been made to the apparatus as a result of performance tests during the past few months. Difficulties with the servosystem have precluded any density measurements up to the present.

The problems with the servosystem, especially the capacitance sensor, appear to have been resolved during the past month. Thin nylon screen disks have been placed over the plates of the capacitance sensor. These screens serve two purposes. They eliminate false signals to servosystem resulting from the metal-plated float, when not in suspension, electrically shorting the plates. (For example, when the float shorts the upper capacitance plates, it gives a signal that says the float is down.) The thickness of the nylon disks (although small) helps to prevent the float from going from a region (close to the plates), for which the sensitivity $(\frac{\Delta C}{\Delta Z})$ is extremely large, to a relatively linear region near the midpoint of the sensor where the sensitivity is an order of magnitude less; however, it is still sufficient to support the magnet in the middle region. The servosystem was difficult to stabilize when the sensor had such a drastic change in sensitivity. The circuit components depended critically on the particular experimental conditions.

Compensation circuits have been added to the servosystem to allow for the large reduction in electrical resistivity of the copper cell in going from room temperature to 100 K. As mentioned earlier the servosystem is finally behaving as expected and density tests will be started within the next week. The only part of the instrument that has not been tested is the microscope. This will be done once the servosystem is behaving reliably. It appears that with a new objective lens with a larger working distance (less power) and a new higher powered eyepiece that changes of 0.001 mm in the position of the float can be detected. However, the fiducial tool marks on the float are not as clear as they were with a shorter working distance.

Although density measurements have not been performed yet, many important tests of the apparatus have been carried out with the following results:

(a) the cell has been cooled to approximately 80 K using the refluxing action of nitrogen in the central support tube; the cooling rate was greater than 40 K/h above 150 K and approximately 20 K/h at 100 K.

(b) the temperatures of the cell and guard ring have been controlled at low temperatures (110-125 K) and near room temperature within a few mK; nitrogen gas must be put into reflux tube for sufficient cooling to regulate the temperature of the cell below 140 K; some difficulties have been encountered in realizing a constant cooling rate under these conditions; it would be nice if changes could be made to provide more cooling to cell without adding any to guard ring and with the reflux tube evacuated.

(c) the temperature differences between the bottom and top of the cell and between the cell and guard ring as determined with vapor bulb pressure readings agreed with the differences indicated by differential thermocouples at the same locations.

(d) temperature gradients along the length of the cell can be routinely reduced to an allowable level (< 20 mK) with the independent heaters along the length of the cell.

(e) measured vapor pressures for liquid methane in cell and in vapor bulbs at top and bottom of cell at temperatures between 110 and 125 K corresponded to a difference of less than 20 mK when compared with previous vapor pressure measurements obtained in this laboratory.

(f) cell and guard ring are essentially isolated from each other so that the temperature of either can be independently controlled.

(g) a preliminary measurement of the dielectric constant of saturated liquid methane agreed to better than 0.005% with previous results from this laboratory.

(h) the current in the support coil is stable and measurable to better than 10 μA; noise level is substantially less.

(i) no problems have been encountered with heating in the water-cooled support coil at power levels approaching 200 W.

Assorted rather significant changes to the apparatus (in addition to those discussed earlier for the servosystem) during the past few months include the following:

(a) a nut, bolt (fiberglass), and spring arrangement was installed between the cold shield and bottom of the cell to eliminate horizontal vibrations of the cell.

(b) all coaxial cables into cell were replaced with new stock after a cold leak (below 120 K) developed in apparatus resulting from tiny cracks in the stainless steel sheaths of these cables; apparently the first supply of the coaxial cables came from a defective batch of stainless steel material; the search for the source of this leak and the replacement of the cables consumed approximately six weeks.

(c) metal bellows were placed in the fill and vent lines of the liquid nitrogen reservoir to eliminate relative movement, as a function of temperature, between the cell and the outer stainless can of the cryostat; this step was necessary since the capacitance sensor and the float inside the cell must remain in the middle of the support coil located outside the cryostat, independent of the cell temperature.

It is believed that with all of the performance tests and changes of the past few months that the apparatus is essentially ready for density measurements. After preliminary checks on some pure fluids, measurements will be started on LNG mixtures.

7.6 Calculational Methods -- R. D. McCarty

Efforts to develop a predictive calculational method for the thermodynamic properties of mixtures have concentrated on the extended corresponding states method. The rigorous mapping of the equation of state of one fluid to the equation of state of another has been accomplished for the methane-nitrogen system (see earlier progress reports), but to achieve the maximum utility from the method other systems must exhibit similar transformation functions. For example, in the case of liquefied natural gas the methane-ethane system is very important. Therefore some commonality between the methane-nitrogen transformation and the methane-ethane transformation would be very beneficial to the utility of the method. This argument is immediately extendable to all of the components of any multicomponent system. It is this "generality" of the extended corresponding states concept that is currently being studied and no definite conclusions may be drawn at this stage of the investigation.

7.7 Propane, Specific Heat Data -- R. D. Goodwin

An apparatus used previously for hydrogen, oxygen, fluorine, methane and ethane measurements is being used; however, the platinum resistance thermometer has been replaced. Eighty-eight measurements on the empty calorimeter from 80.3 K through 345.3 K have been represented by a new fitting function with an rms deviation of 0.078 percent in the total, empty heat capacity. Below 250 K, maximum deviations are only a few hundredths of one percent.

Experimental data for propane specific heats have been obtained for the saturated liquid from below the triple-point (85.5 K) to 242.8 K and to 288.8 K in two runs at densities of 12.6 and 11.3 mol/L respectively. Additional data (C_V) for the single phase have been obtained at five different densities, over diminishing ranges of temperature from about 350 K down to 155 K. These measurements are currently continuing.

8. Problem Areas. None.

9. Funding. July 1 - December 31, 1977.

Man-years expended	0.6
Equipment and/or Services Purchased	6.3K$
Total Reporting Period Cost	43.8K$
Balance Remaining	94.3K$

10. Future Plans.

Objectives and Schedule: Quarter	1	2
Prepare and performance test PVT and dielectric constant properties apparatus for propane.	⟶	
Measure, analyze and report PVT and dielectric constant data for hydrocarbon mixtures and LNG.	———	———
Evaluate and optimize promising calculation methods for the thermodynamic properties of methane-nitrogen mixtures.	———	———
Measure, analyze and report specific heat data for propane.	———	——— ⟶

1. Title. FLUID TRANSPORT PROPERTIES
Principal Investigator. Howard J. M. Hanley

2. Cost Center Number. 2750124

3. Sponsor Project Identification. NBS-Office of Standard Reference Data

4. Introduction. Methods for predicting the transport properties of fluid mixtures are unreliable and data are scarce. Prediction methods are needed, however, to supply the necessary design data needed to increase efficiency and reduce costs.

5. Objectives or Goals. The long range or continuing goal of the program is to perform a systematic study of the theories and experimental measurements relating to transport properties, specifically the viscosity and thermal conductivity coefficients, of simple mixtures over a wide range of experimental conditions. The specific objectives of the program include: 1) the systematic correlation of the transport properties of simple binary mixtures and the development of prediction techniques, 2) development of a mixture theory for the dilute gas region and the dense gas and liquid regions, 3) extension of the theory and prediction techniques to multicomponent systems, and 4) suggested guidelines for future areas of experimental work.

6. Background. A continuing program has successfully expanded the state-of-the-art of transport phenomena for pure fluids. Information for pure fluids is required as a prerequisite for mixture studies. The theory of transport phenomena has been developed and applied to produce practical numerical tables of the viscosity, thermal conductivity and diffusion coefficients of simple fluids: Ar, Kr, Xe, N_2, O_2, F_2, He, H_2, CH_4,[3] C_2H_6.[4]
It has been shown that a successful mixture program can emerge from combining the results for pure fluids with mixture equation of state studies. The equation of state work is being carried out by other investigators in this laboratory.

7. Program and Results. A procedure to predict the transport properties of mixtures has been developed via corresponding states.[1-2] The method has been shown to be satisfactory. Current studies include investigating the effects of internal degrees of freedom on the thermal conductivity coefficient and the behavior of the transport coefficients near a critical point.[2] Tables of transport properties for propane have been prepared and submitted for publication.[5]

8. Problem Areas. The lack of suitable experimental mixture transport properties data for comparison purposes is the main problem. Also equation of state (PVT) data for mixtures are needed.

9. Funding. July 1 - December 31, 1977.

Allocation	63.0K$/yr.	
Labor	0.5 MY	32.9K$
Other Costs		2.7K$
Total		35.6K$

10. Future Plans. The transport properties of ethylene will be investigated. The corresponding states predictive procedure for mixtures will be more fully developed and expanded in line with the concurrent equation of state studies.

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1. H. J. M. Hanley, Prediction of the Viscosity and Thermal Conductivity Coefficients of Mixtures, Cryogenics, Vol 16, No. 11, 643-51 (Nov 1976); H. J. M. Hanley, Prediction of the Thermal Conductivity of Fluid Mixtures, Proceedings 7th ASME Conf. on Thermophysical properties; H. J. M. Hanley in "Phase Equilibria and Fluid Properties in the Chemical Industry," ACS Symp. Series No. 60 (1977).

2. H. J. M. Hanley, Transport Coefficients in the One-Fluid Approximation: Behavior in the Critical Region, J. Res. Nat. Bur. Stand. (U.S.) 82, 18 (1977).

3. H. J. M. Hanley, W. M. Haynes and R. D. McCarty, The Viscosity and Thermal Conductivity Coefficients for Dense Gaseous and Liquid Methane, J. Phys. Chem. Ref. Data, Vol 6, No. 2, 597-609 (1977).

4. H. J. M. Hanley, K. E. Gubbins and S. Murad, A Correlation of the Existing Viscosity and Thermal Conductivity Coefficients of Gaseous and Liquid Ethane, J. Phys. Chem. Ref. Data, Vol 6, No. 4, 1167 (1977).

5. H. J. M. Hanley, P. M. Holland, K. E. Gubbins and J. M. Haile, J. Phys. Chem. Ref. Data (in preparation).

1. Title. PROPERTIES OF CRYOGENIC FLUIDS

Principal Investigators. G. C. Straty, H. M. Roder, L. A. Weber, B. J. Ackerson, and D. E. Diller

2. Cost Center Number. 2750122

3. Sponsor Project Identification. NBS

4. Introduction. Accurate thermophysical properties data and predictive calculation methods for cryogenic fluids are needed to support advanced cryogenic technology projects. For example, liquefied natural gas is expected to supply an increasing percentage of the United States' energy requirements through 1990. Liquefaction plants, ships and receiving terminals are being constructed to transport and store natural gas in the liquid state (LNG). Accurate thermophysical properties data for LNG are needed to design low temperature processes and equipment. Accurate data will benefit the energy industries and the consumer by providing for safe and efficient operations and reduced costs.

5. Objectives or Goals. The objectives of this project are to provide comprehensive accurate thermodynamic, electromagnetic and transport properties data and calculation methods for technically important compressed and liquefied gases (helium, hydrogen, oxygen, nitrogen, methane, ethane, etc.) at low temperatures. Precise compressibility, calorimetric and other physical property measurements will be performed to fill gaps and reconcile inconsistencies. Definitive interpolation functions, computer programs and tables will be prepared for engineering calculations. The immediate goals of this work are to obtain accurate sound velocity and thermal diffusivity data for compressed and liquefied gases by using laser light scattering spectroscopy techniques. Sound velocity data are useful for testing the consistency of volumetric, calorimetric and thermodynamic properties data, and are potentially useful for density gauging applications. Thermal diffusivity data are required for performing thermodynamic and heat transfer calculations.

6. Background. When light is incident on a perfectly homogeneous fluid, the reradiated (scattered) light field sums to zero in all but the exact forward direction. For a "real" fluid, however, fluctuations, arising through various mechanisms, destroy the perfect homogeneity and result in the scattering of light in other directions as well. For example, thermally activated density fluctuations (phonons), propagating with the characteristic velocity of sound, give rise to scattered light which is Doppler shifted in frequency from the incident light frequency and whose spectrum contains information on the sound velocity and attenuation. Local non-propagating temperature fluctuations, which decay diffusively, give rise to scattered light in a narrow frequency band about the incident light frequency and whose spectrum contains information on the lifetime of the fluctuations (thermal diffusivity). Since the frequency shifts are generally very small, it was not until the advent of the lasers with their extremely well defined frequency, that practical experiments using these phenomena were possible.

The application of laser light scattering techniques to obtaining thermophysical properties data was initiated to complement and check other measurement methods and to solve measurement problems inherent in more conventional methods. For example, laser light scattering techniques permit measurements of sound velocities for fluids under conditions for which sound absorption is too large to perform ultrasonic measurements; laser light scattering techniques permit measurements of thermal diffusivities under conditions for which convection interferes with measurements of thermal conduction. The feasibility of light scattering experiments to obtain data on binary diffusion coefficients has also been demonstrated.

7. Program and Results. An apparatus has been assembled for laser light scattering spectroscopy measurements on compressed and liquefied gases (76-300 K, 35 MPa). The apparatus consists of a high pressure optical cell, a cryostat refrigerated by means of liquid nitrogen, an argon ion laser and low-level light detection equipment.

The light scattered from fluctuations in the fluid can be analyzed with either digital autocorrelation techniques for the examination of the very narrow lines associated with scattering from temperature fluctuations (Rayleigh scattering) or with a scanned Fabry Perot interferometer for the measurement of the Doppler frequency shifts associated with the scattering from propagating density (pressure) fluctuations (Brillouin scattering).

Apparatus for photon-counting and digital autocorrelation has been assembled, interfaced with computer facilities and programmed to enable on-line data accumulation and analysis. Initial problems associated with signal modulations from excessive building vibrations have been solved by levitating the apparatus on an air suspension system. A small, highly stable capacitor has also been designed, constructed and installed inside the scattering cell to permit the dielectric constant of the scattering fluid to be determined, which should allow more accurate fluid densities to be obtained for use in the data analysis. Apparatus tests on well characterized, strongly scattering, test fluids have been made to verify data analysis programs.

Extensive thermal diffusivity data have been obtained for methane. Measurements have been made along the coexistence curve, the critical isochore, and critical isotherm. The measurements extend outside the critical region as well as deep into the critical region. In the deep critical region the effect of temperature gradients and impurities have been investigated. Outside the critical region, these effects do not affect measurements beyond experimental accuracy. The range of the measurements extends from 150 K to 230 K and 3 mol/L to 22 mol/L. The accuracy of the measurements is about 5% in the critical region, increasing to 10% or greater further away. A detailed analysis of the data and experimental error has been made and a paper[1] reporting the results has been submitted to the Journal of Chemical Physics.

Some preliminary results on a mixture of 70% methane and 30% ethane were obtained very near the vapor-liquid critical point (plait point). The results are interesting in that the thermal conductivity of the mixture does not exhibit a critical anomaly whereas pure methane does exhibit an anomaly in the thermal conductivity as the critical point is approached. The anomalous behavior of pure fluids and non-anomalous behavior of mixtures is qualitatively and quantitatively in agreement with theoretical predictions (see preceeding title 'Fluid Transport Properties'). We hope to be able to perform more definitive measurements on hydrocarbon mixtures in the near future.

8. Problem Areas. Light scattering has proven to be a valuable tool for obtaining thermal diffusivity data on fluids. This is particularly true in a broad temperature and density range around the critical point, where more conventional experimental methods fail or are severely limited. The intensity of the scattered light however decreases drastically as one moves away from the critical region. Data accuracy in this region becomes limited by the statistical nature of the scattering process and the ability to maintain stability and precise experimental parameters over the extended periods of time necessary for data accumulation.

We have investigated other experimental techniques for obtaining wide-range thermal conductivity measurements on compressed and liquefied gases and have decided that the transient hot-wire method offers the

clearest advantages. The cell has been constructed and several pieces of equipment have been ordered. The electronic circuits have been designed and all drawings have been completed or are in the final stages of preparation.

9. Funding. July 1 - December 31, 1977

Man-years expended	0.6
Equipment and/or Services Purchased	3.6K$
Total Reporting Period Cost	45.0K$
Balance Remaining	40.0K$

10. Future Plans.

Objectives and Schedule: Quarter	1	2
Design, construct and performance test transient hot-wire thermal conductivity apparatus.	——————————→	

Reference

1. B. J. Ackerson and G. C. Straty, Rayleigh Scattering from Methane, J. Chem. Phys. (submitted).

1. Title. PROPERTIES OF CRYOGENIC FLUID MIXTURES

Principal Investigators. M. J. Hiza, A. J. Kidnay (part-time), and R. C. Miller (part-time).

2. Cost Center Numbers. 2750123, 2750129 and 2754574

3. Sponsor Project Identification. NBS, NBS (OSRD), AGA

4. Introduction. Accurate thermodynamic properties data and prediction methods for mixtures of cryogenic fluids are needed to design and optimize low temperature processes and equipment. This project provides new experimental measurements on equilibrium properties and compilations of evaluated equilibrium properties data which are suitable for direct technological use or for the evaluation of prediction methods.

5. Objectives or Goals. The overall objectives of this project are to provide critically evaluated data on the phase equilibria and thermodynamic properties of cryogenic fluid mixtures. The program has been divided into the following elements:

   a) Preparation of a comprehensive bibliography on experimental measurements of equilibrium properties for mixtures of selected molecular species of principal interest in cryogenic technology.

   b) Selection and/or development of methods for correlation, evaluation and prediction of equilibrium properties data.

   c) Retrieval and evaluation of experimental data for specific mixture systems selected on the basis of theoretical and/or technological importance.

   d) Preparation of guidelines for future research based on the deficiencies noted in (a), (b), and (c).

   e) Performing experimental research to alleviate deficiencies and provide a basis for improvement of prediction methods.

6. Background. A physical equilibria of mixtures research project was established in the Cryogenics Division in 1959. The initial effort, based on a bibliographic search and other considerations, was directed toward the acquisition of new experimental data on the solid-vapor and liquid-vapor equilibria and physical adsorption properties for a limited number of binary and ternary mixtures of components with widely separated critical temperatures. Most of the systems studied included one of the light hydrocarbon species -- methane, ethane, or ethylene (ethene) -- with one of the quantum gases -- helium, hydrogen, or neon. The data for these systems led to significant improvements in the predictions of physical adsorption equilibrium and a correlation for the prediction of deviations from the geometric mean rule for combining characteristic energy parameters. In addition, significant new information was obtained for interaction third virial coefficients which was used in a correlation by one of our consultants, J. M. Prausnitz. The approach taken in this work has been as fundamental as possible with the intention of having an impact on a broad range of mixture problems.

   Recent efforts have been directed toward problems associated with systems containing components with overlapping liquid temperature ranges, such as nitrogen + methane, methane + ethane, etc.

7. Program and Results. The recent progress is summarized as follows:

a) A paper[1] discussing compilation, evaluation, and correlation of liquid-vapor equilibria data - excess Gibbs energies, liquid phase heats of mixing, Henry's constants, equation of state representation, and liquid phase excess volumes - for methane + ethane is now being reviewed by readers selected by the editor of the Journal of Physical and Chemical Reference Data. These reviews are in lieu of the outside review for the NBS (Boulder) Editorial Review Board.

b) The Peng-Robinson equation of state, optimized to the selected data in a), has now been used to generate methane + ethane K-values and liquid-vapor equilibrium compositions for inclusion in the LNG Materials and Fluids user's manual. In addition, graphs of orthobaric liquid densities of methane + ethane, methane + propane, and ethane + propane over the entire composition range from 105-130 K were prepared from a temperature dependent Redlich-Kister representation of NBS data obtained in the LNG density project. These graphs are also to be included in the LNG Materials and Fluids user's manual.

c) A paper[2] discussing the development of an excess volume model to predict orthobaric densities of LNG mixtures has been accepted for publication in the journal Fluid Phase Equilibria. The model has been programmed and is available for use. In the program Redlich-Kister constants for methane + ethane obtained in a) are now being used which extends the low temperature limit at least down to 95 K vs. 105 K in the original form.

d) Evaluation of the molar volume measurements made at the University of Wyoming on one methane + ethane binary mixture and on four multicomponent mixtures has been completed. The results were compared with the excess volume model in c), the optimized hard-sphere model of Rodosevich and Miller, and a revised and optimized version of the Klosek and McKinley model. A paper[3], communicating these results and comparisons with predicted values, has been submitted to the journal Fluid Phase Equilibria.

e) In conjunction with the correlation and evaluation of mixtures data, various computer programs are needed. In the past several months, fifteen programs have been written or modified for this purpose. Properties include liquid-vapor equilibrium, orthobaric liquid mixture densities, enthalpy departures, and derived excess Gibbs energies. Most of these programs will be used in the compilation, evaluation, and correlation of methane + propane data.

f) As mentioned in b) above, graphs have been prepared for density and phase equilibria properties of several mixtures for the "LNG Materials and Fluids Data Book." The first edition of the book contained four graphs covering the methane-nitrogen system. The supplement will include similar graphs covering methane-ethane, methane-propane and ethane-propane systems as well as several density graphs for LNG and LNG-like multicomponent systems.

8. Problem Areas. None.

9. Funding. July 1 - December 31, 1977

Man-years expended	1.1
Equipment and/or Services Purchased	4.1K$
Total Reporting Period Cost	89.3K$
Balance Remaining	64.2K$

10. Future Plans.

Objectives and Schedule: Quarter	1	2
Prepare and report graphs of liquid-vapor equilibrium K-values and equilibrium phase compositions for methane + ethane.	——→	
Prepare and report graphs of orthobaric liquid densities for methane + ethane, methane + propane, and ethane + propane.	——→	
Compile and evaluate liquid-vapor equilibrium properties data for methane + propane.	——→	
Design and construct a phase equilibria apparatus for total vapor pressure measurements (methane + isobutane).	——	

References

1. M. J. Hiza, R. C. Miller, and A. J. Kidnay, A Review, Evaluation, and Correlation of the Phase Equilibria, Heat of Mixing, and Change in Volume on Mixing for Liquid Mixtures of Methane + Ethane, J. Phys. Chem. Ref. Data (to be submitted).

2. M. J. Hiza, An Empirical Excess Volume Model for Estimating Liquefied Natural Gas Densities, Fluid Phase Equilibria (in press).

3. R. C. Miller and M. J. Hiza, Experimental Molar Volumes for Some LNG-Related Saturated Liquid Mixtures, Fluid Phase Equilibria (submitted September 1977).

1. Title. DENSITIES OF LIQUEFIED NATURAL GAS MIXTURES

Principal Investigators. M. J. Hiza, W. M. Haynes, R. D. McCarty and W. R. Parrish

2. Cost Center Numbers. 2751574

3. Sponsor Project Identification. LNG Density Project Steering Committee; American Gas Association, Inc., Project BR-50-11.

4. Introduction. Accurate density measurements and calculational methods for liquefied natural gas mixtures are needed to provide a basis for custody transfer agreements and for mass, density, and heating value gauging throughout the fuel gas industry.

The basis for the custody transfer of natural gas is its heating value. It is difficult to determine and agree on the heating value of extremely large volumes of natural gas in the liquid state. For example, methods for calculating the heating value of a liquefied natural gas mixture require knowing its density, which in turn depends on its composition, temperature, and pressure. As the compositions of LNG mixtures vary considerably, depending on the sources of the gas and the processing conditions, accurate methods are needed for calculating liquid densities at arbitrary compositions, temperatures and pressures. The accuracy is important because of the extremely large volumes of liquid involved.

5. Objectives or Goals. The objectives of this work are to perform accurate (0.1%) and precise (0.02%) measurements of the densities of saturated liquid methane, ethane, propane, butanes, nitrogen and their mixtures mainly in the temperature range 105-140 K, and to test and optimize mathematical models for calculating the densities of LNG mixtures at arbitrary compositions and temperatures.

6. Background. This project is being carried out at NBS because of the realization that equitable custody transfer agreements could be reached more readily if the density measurements and the evaluation and development of calculational methods were performed by independent professionals.

An apparatus incorporating a magnetic suspension technique has been developed for absolute density measurements on liquids and liquid mixtures, particularly at saturation, for temperatures between 90 and 300 K. The estimated imprecision of measurement is less than 0.02% and the estimated inaccuracy is less than 0.15%.

7. Program and Results.

7.1 Measurements. All measurements on pure fluids and on selected binary mixtures have been completed and reported.[1,2,3,4] Inconsistencies found in the butane-containing multicomponent mixtures (without nitrogen) were mentioned in the last report. These have been identified as probably arising from inadequate mixing within the cell. Previous data, published and unpublished, from the University of Wyoming and Elf Aquitaine in France tend to support this supposition. This hypothesis was further supported by additional measurements performed on the Wyoming apparatus[9] by a member of the NBS staff. (See report of Project 2750123 for more details.) The LNG Density Project Steering Committee has funded additional measurements to fully resolve the inconsistencies as well as to include data on additional mixtures. The report on the previous NBS multicomponent mixtures data has been delayed. The magnetic densimeter has been extensively modified to allow measurements to higher pressures. This work and the new apparatus is fully described in the report for cost center number 2750574.

A two part paper[6] (experimental and calculational) was presented at the Fifth International Conference on Liquefied Natural Gas in Düsseldorf, Germany in August 1977.

7.2 Calculational Methods. Four promising methods for calculating the densities of liquid mixtures have been tested, modified and optimized utilizing the pure component and binary mixture data reported above. The four methods are a corresponding states method, a cell model, a hard-sphere model and an excess volume model. Computer programs have been written for all four methods and these have been used to calculate densities for comparisons with the data for the mixtures measured. The calculated results agree with the experimental data to within 0.1% for all multicomponent mixtures except those containing methane and butanes but no nitrogen. If nitrogen is present the differences reduce to 0.1% or less. Comparisons of the four methods with both published and unpublished data from the University of Wyoming[9] and Elf Aquitaine in France show deviations of less than $\pm$ 0.15% between measured and calculated densities. It is felt that only small corrections to the four methods will likely need to be made as a result of the new measurements proposed in 7.1 above.

Two of the four methods have been modified to account for the presence of small amounts of the pentanes. The modifications were based on published data for pure, normal and iso-pentane.

The results of the calculational efforts were presented to the Fifth International Conference on Liquefied Natural Gas[6] as mentioned in 7.1 above. A more complete account of the calculational methods study (including the four computer programs) has been prepared. This report was published as NBSIR 77-867[10]. Approximately 100 copies have been distributed.

8. Problem Areas. Several experimental problems have delayed the planned measurements on the new apparatus.

9. Funding. July 1 - December 31, 1977.

Man-years expended	0.3
Equipment and/or Services Purchased	1.0K$
Total Reporting Period Cost	21.1K$
Balance Remaining	55.9K$

10. Future Plans.

Objectives and Schedule: Quarter	1	2
Performance test new magnetic densimeter PVTx apparatus.	——→	
Measure, analyze, and report multicomponent mixture data, including selected LNG-like mixtures.	————————	

References

1. W. M. Haynes and M. J. Hiza, Orthobaric Liquid Densities of Normal Butane from 135 to 300 K as Determined with a Magnetic Suspension Densimeter, Advan. Cryog. Eng. Vol 21, 516-21 (Plenum Press, New York, 1976).

2. W. M. Haynes and M. J. Hiza, Measurements of the Orthobaric Liquid Densities of Methane, Ethane, Propane, Isobutane, and Normal Butane, J. Chem. Thermodynamics Vol 9, 179-87 (Feb 1977).

3. M. J. Hiza, W. M. Haynes and W. R. Parrish, Orthobaric Liquid Densities and Excess Volumes for Binary Mixtures of Low Molar Mass Alkanes and Nitrogen Between 105 and 140 K, J. Chem. Thermodynamics Vol 9, No. 9, 873-96 (Sep 1977).

4. W. M. Haynes, M. J. Hiza and N. V. Frederick, Magnetic Suspension Densimeter for Measurements on Fluids of Cryogenic Interest, Rev. Sci. Instrum. Vol 47, No. 10, 1237-50 (Oct 1976).

5. W. M. Haynes, A Simplified Magnetic Suspension Densimeter for Absolute Density Measurements, Rev. Sci. Instrum. Vol 48, 39 (1977).

6. W. M. Haynes, M. J. Hiza, and R. D. McCarty, Densities of LNG for Custody Transfer, Proc. Fifth International Conference on Liquefied Natural Gas, Düsseldorf, Germany, Aug 29-Sep 1, 1977, Session III, Paper No. 11, Vol 2 (1977).

7. D. E. Diller, LNG Density Determination, Hydrocarbon Proc. Vol 56, No. 4, 142-4 (Apr 1977).

8. M. J. Hiza, An Empirical Excess Volume Model for Estimating Liquefied Natural Gas Densities, Fluid Phase Equilibria (to be published).

9. R. C. Miller and M. J. Hiza, Experimental Molar Volumes for Some LNG-Related Saturated Liquid Mixtures, Fluid Phase Equilibria (to be published).

10. R. D. McCarty, A Comparison of Mathematical Models for the Prediction of LNG Densities, Nat. Bur. Stand. (U.S.), Interagency Rept. 77-867 (Oct 1977).

1. Title. PROGRAM FOR REDUCING THE COST OF LNG SHIP HULL CONSTRUCTION -- PHASE II SHIP STEEL IMPROVEMENT PROGRAM

Principal Investigators. H. I. McHenry, M. B. Kasen, and R. P. Reed

2. Cost Center Number.
2753430 - LNG Ship Hull Materials (Shipyard Contracts)
2751430 - LNG Ship Construction Materials (Metallurgical Evaluation)
2752430 - LNG Ship Hull Materials (Fracture Properties)

3. Sponsor Project Identification. Maritime Administration Misc. P. O. 400-58073.

4. Introduction. Construction of LNG tankers requires the use of fine grain normalized steels for the part of the hull structure that is cooled by the cargo to temperatures in the range of 0 to -50°F. Several ABS steels have satisfactory base plate properties but extreme care must be exercised during welding to avoid degradation of the steel adjacent to weld (the heat affected zone) to a level of toughness below U. S. Coast Guard requirements. Significant cost problems are being encountered by U. S. shipyards due to the resulting inefficient low-heat-input welding procedures that must be employed to meet the fracture requirements in the heat affected zone.

The feasibility of reducing the cost of LNG ship hull construction was investigated in Phase I of this project, leading to the Phase II program described below.

5. Objective. The objectives of the Phase II program are 1) to have the four major plate producers supply three LNG shipyards with production heats of ABS steels modified to possess improved transverse fracture properties at low temperatures, 2) to have the LNG shipyards evaluate these plates by qualifying optimum welding procedures in accordance with the USCG requirements, and 3) to provide a metallurgical evaluation of factors that influence heat affected zone toughness in the improved steels.

6. Background. Early in 1974, the Welding Panel of MarAd's Ship Production Committee recommended that a program be conducted to reduce the cost of ship hull construction. NBS was requested by MarAd to propose such a program to the LNG subcommittee of the Welding Panel at a meeting in Boulder in August. In mid-October, MarAd approved the initial phase of NBS's recommended program, i.e., to survey the problem and the technology available for its solution. On the basis of this survey and as the result of a meeting of the Welding Panel in March, 1975, a coordinated program involving the LNG shipyards, the steel suppliers, and NBS was recommended to MarAd and to the Welding Panel. This program was approved and work started in May 1975. Cost-sharing contracts for the evaluation of the improved steels were awarded in 1975 to the three participating shipyards: Avondale Shipyards, Inc., Newport News Shipbuilding and Drydock Co. and General Dynamics-Quincy Shipbuilding Division. A similar contract was signed with Lukens Steel Company to evaluate Cb-treated V-051 steel with and without sulfide shape control. The three participating shipyards completed the shipyard evaluation phase of the program in the spring of 1977. The ABS steels with sulfide shape control had excellent toughness and the HAZ toughness was improved, particularly for shielded metal arc (SMA) and gas metal arc (GMA) welds.

7. Program and Results. During this reporting period, the evaluation of ABS grade V-051 steel (Cb treated with and without sulfide shape (SSC) control) was completed and contracts were awarded for further evaluation of selected ship steels by the three participating shipyards.

The results of Lukens evaluation of V-051 (Cb, SSC) were particularly encouraging. The 1-inch thick plates were welded using the 3-wire tandem-arc submerged-arc process. One pass per side at 125 kJ/in was required to fill the joint. The travel speed was 40 in/min. The test weldment passed the USCG requirements at -40, -60 and -75°F. Two complete Charpy traverses were taken -- one with the notch on the root side and one with the notch on the face side. Of the 108 Charpy tests only two individual specimens fell below 20 ft lb and one of those was in the weld metal. The normal sulfur plate of the same steel did not meet the USCG requirements at any of the temperatures; however, the degradation relative to the base metal properties was minimal. These results suggest that the Cb-treatment may be having a significant beneficial effect. In 0.5 inch thick plate of V-051 (Cb, SSC), two passes per side were needed to meet the USCG requirements.

The follow-on work with the three shipyards will consist of an evaluation of the following steels:

Steel Type	Thicknesses	Source
V-062 (low sulfur)	1/2 and 1 inch	Armco/Avondale
V-062 (SSC)	1/2 and 1 inch	Armco/Avondale
V-062 (Cb-treated, low sulfur)	1/2 and 1 inch	Armco
V-062 (Cb-treated, SSC)	1/2 and 1 inch	Armco
V-051 (Cb-treated, SSC)	1/2 and 1 inch	Lukens
C-Mn-Mo-Cb (line pipe skelp)	1.2 inch	Climax Molybdenum

Evaluation of the Cb-treated steels is considered essential for this program because of the promising results obtained by Lukens. These steels will be sub-arc welded, one pass per side, using either single or multiple arc techniques. In addition, one test plate from each steel will be welded using the SMA process in the vertical position. The SMA welds are advisable in order to avoid low heat-input problems similar to those encountered with A537 steel during the original shipyard evaluation.

Tests will be conducted at -60 and -75°F. Each shipyard will weld 24 test plates and conduct complete Charpy traverses (15 specimens) on each test plate. As in the original shipyard evaluation, a few additional tests will be conducted as the need develops.

8. Problem Areas. None

9. Funding. July 1, 1977 to December 31, 1977.

Cost Center	Cost to 12/31/77	Balance
2753430	180 K	0
2751430	65 K	15 K
2752430	58 K	22 K

10. Future Plans. Work should be completed on the follow-on testing program (Phase II of the Ship Steel Improvement Program) in 1978.

1. Title. CUSTODY TRANSFER - LNG SHIPS
Principal Investigators. J. D. Siegwarth and R. S. Collier.

2. Cost Center Number. 2750460, 2751575, 2752575 and 2753575.

3. Sponsor Project Identification. Maritime Administration, Misc. P.O. #400-79005.

4. Introduction. In response to a request from the U.S. shipbuilding industry, NBS is conducting an independent design review of the shipboard custody transfer systems under the sponsorship of the Maritime Administration and in cooperation with the major U.S. shipbuilding companies.

5. Objectives. The objectives of this program are to 1) Identify the major technical areas relating to uncertainties in the measurement of total mass and total heating value, 2) Estimate uncertainties in the total mass and total heating value due to these identified factors, 3) Develop a proposed testing program for custody transfer system components, and 4) Investigate improved gauging techniques.

6. Background. Previous funding provided for the initial design review of ships designated by MA Design LG8-S-102a MA Hulls 289, 290, 291. The current funding provides for an extension of this program to include ships of other designs which are being built by the major U.S. shipbuilding companies and also to verify tank survey and gauging methods for LNG custody transfer.

7. Program. The LNG Aquarius ship tank #4 was chosen to evaluate the tank survey techniques and capacity tables for spherical tank LNG carriers; this was done in cooperation with the General Dynamics Quincy Shipyards Division. Work was started on the verification of tank calibration of the three membrane type LNG ships under construction at Newport News and the three ships being built at Avondale Shipyards using prismatic tanks.

Gage rods and tapes, which are used by NBS for independently verifying coordinate distances, have been calibrated in the NBS Dimensional Metrology Labs. Gage rod distances were determined to within $\pm$ 0.1 mm (3σ standard deviation).

For the spherical tanks, the target coordinate data was received from the surveyor and used to analyze the tank shape factors. Capacity tables were determined independently and compared with those provided by the surveyor. A report of this evaluation is being prepared and will be submitted to the Maritime Administration during the next report period.

For RF gaging research, data from the LNG Aquarius tank #4 was compared with a scale model of that tank. The data for the resonance spectrum is within the known uncertainty of the tank dimensions. This data is shown in table 1. The first column shows the measured resonance spectum for the large tank; the second column shows the resonance spectrum for the scale model; the third column shows the ratio of the corresponding frequencies which should equal the scale factor if the tank is modeled perfectly; the fourth column is theoretical results for a perfect sphere with no center column, this is for mode I.D. only. Some of the resonances split when the spherical symmetry is broken due to the degeneracies of the sphere. These results verify the RF scaling laws and have proven the utility of the RF technique for large tanks.

Other work on large land based cylindrical tanks have shown that these results are independent of construction material.

Mode Designation	Large Tank Frequencies (Experimental) R = 18.288M	Scale Model Frequencies (Experimental) r = 0.2429M	Scale Factor c - r/R = Fn/fn 1.328 x 10^{-2}	Perfect Sphere Theoretical R = 18.288M
TM_{11}	F_1 = 7.120 MHz	f_1 = 540 MHz	1.318 x 10^{-2}	7.14 MHz
TM_{21}	F_2 = 10.145 MHz	f_2 = 764.9 MHz	1.326 x 10^{-2}	10.07 MHz
TE_{11}	F_3 = 11.525 MHz	f_3 = 867.2 MHz	1.329 x 10^{-2}	11.691 MHz
Split	F_4 = 11.827 MHz	f_4 = 894 MHz	1.323 x 10^{-2}	
TM_{31}	F_5 = 13.10 MHz	f_5 = 987.4 MHz	1.327 x 10^{-2}	
Split	F_6 = 13.51 MHz	f_6 = 1021.3 MHz	1.323 x 10^{-2}	12.94 MHz
	F_7 = 14.69 MHz	f_7 = 1103.2 MHz	1.332 x 10^{-2}	
TE_{21}	F_8 = 14.925 MHz	f_8 = 1127 MHz	1.324 x 10^{-2}	14.99 MHz
TM_{12}	F_9 = 15.838 MHz	f_9 = 1193.5 MHz	1.327 x 10^{-2}	15.917 MHz

Resonance Spectrum Showing RF Scaling Law For A Sphere Containing A Cylindrical Column
Table 1

8. Problem Areas. None.

9. Funding. July 1 - December 31, 1977.

Funds Available	$36.5 K
Balance Remaining	$ 0.0 K

10. Future Work. The ship tank capacity table determinations for six El Paso Marine LNG Co. ships are being reviewed. NBS will be monitoring the calibration process and will do some independent tank volume calibrations, both to verify the present techniques and to develop improved techniques.

The feasibility will be determined for using the RF technique to determine shape changes in prismatic LNG tanks with extensive internal supporting structure. This will be done in cooperation with the Avondale Shipyards.

1. Title. HEATING VALUE OF FLOWING LNG
Principal Investigators. J. A. Brennan.

2. Cost Center Number. 2756579

3. Sponsor Project Identification. Pipeline Research Committee (American Gas Association) PR-50-48.

4. Introduction. This project will test instrumentation for making heating value measurements on flowing LNG in actual applications. Information from projects currently underway by Siegwarth (cost center 2757574) on densimeters, by Haynes and Hiza (cost center 2751574) on mixture densities and by Parrish (cost center 2750575) on LNG sampling will be utilized where appropriate to provide state of the art information.

5. Objectives. The objective of this project is to measure total heating value of LNG flowing in a pipeline by the integration of individual measurements of flow, density and specific heating value. Flow measurement requires determination of flowmeter performance in line sizes larger than presently available calibration facilities. Therefore, a secondary objective is to establish appropriate flowmeter scaling laws.

6. Background. The LNG flow facility at NBS was used to evaluate the response and the integration of the individual elements of the heating value measurement. Different compositions of LNG were tested to provide a range of densities and temperatures sufficient to determine any dependencies. Sampling work was combined with the sampling project (cost center 2750575) to better define the important criteria of this phase of the measurement problem.

   Flowmeter scaling work utilizes the cryogenic and water flow facilities at NBS as well as private LNG peak shaving and import facilities.

7. Program and Results.

   A. Tests at NBS.

   LNG flow tests run at NBS in conjunction with the sampling project resulted in a marked decrease in the discrepancies described in the last report. These discrepancies were between the heating values calculated from gas analysis and measured with the calorimeter. The differences were an indication that the sampling and/or the gas analysis were not correct. Therefore, a correct density could not be calculated to check the densitometer if a sampling error were involved.

   Once the sampling-gas analysis problems were solved it was possible to check the densitometer over an 11% density range with LNG. It was not possible to accumulate large amounts of data but the data obtained tested several parameters that could have affected densitometer performance. One parameter, thermal cycling, had been shown to be a problem in earlier tests but did not appear to be a problem during the last test. The stabilizing effect of repeated thermal cycling that was observed in the earlier liquid nitrogen tests did continue during the LNG tests.

   All the measurement elements functioned properly during the LNG flow test but the test was designed primarily to investigate the sampling problem. Therefore, the amount and kind of data obtained was somewhat limited as far as the flow measurement station was concerned. Within those restraints the test results were all good.

   B. Tests at Transco.

   All the test equipment, except the eight inch flowmeter, has been removed from the Transco site. The flowmeter was left installed so that the LNG line would not have to be opened up and also to allow the possibility of future testing, if required.

A paper [1] describing some of the test results will be published in the January 30, 1978 issue of The Oil and Gas Journal. Complete test results have been reported to the PRC Supervisory Committee [2].

C. Tests at Southern Energy.

Water calibration of the 12 inch flowmeter test section was completed at NBS Gaithersburg. The flowmeter performance was not as linear as the eight inch flowmeter installed at Transco but was repeatable.

The test section has been installed at Southern Energy without the densitometer. The densitometer is a retractable model and will be installed after a relief valve has been attached. It was also necessary to repair some wiring in the densitometer before cryogenic testing could be completed. All this work should be completed in January 1978 and the densitometer installed at the test section.

8. Problem Areas. The problems described above have resulted in delays in performing all the desired tests and in the delivery of equipment to Southern. These delays should end in January 1978.

9. Funding. July 1 - December 31, 1977.

Man-years expended	.25
Total reporting period costs	$14K
Balance remaining	$ 1K.

10. Future Plans. Installation of the equipment required to run tests at Southern Energy will be completed during the next reporting period. LNG flow tests will be run when appropriate, consistent with the start-up of the terminal.

References

1. J. A. Brennan, Better LNG flow measurement sought, Oil and Gas Journal 76, 168 (1978).

2. J. A. Brennan, C. H. Kneebone and J. E. Cruz, 1976-1977 Summary Report to Pipeline Research Committee on Project PR-48-50, report to sponsor (Dec. 1977).

1. Title. LNG DENSITY REFERENCE SYSTEM

   Principal Investigators. J. D. Siegwarth and J. F. LaBrecque

2. Cost Center Number. 2757574, 2750154

3. Sponsor Project Identification. American Gas Association, Inc., Project BR-50-10; National Bureau of Standards

4. Introduction. A density reference system has been developed to evaluate the ability of commercially available instruments to measure densities of LNG directly. Density is an essential measurement in determining the total energy content of natural gas reservoirs. This effort is oriented towards metrology, whereas the output from cost center 2751574 will provide basic reference data on pure liquids and mixtures to evaluate methods for calculating the density indirectly.

5. Objectives. The objective of this research is to evaluate the density measurement capability of commercially available meters. From the commercial meters we will attempt to select one or two capable of performance as transfer standards, in order to provide traceability of accuracy to field density measurement systems.

6. Background. The density reference system project was initiated in 1973. Since that time the reference system has been designed, constructed, and is now in operation, evaluating commercial density metering systems.

7. Program and Results. The report describing the density reference system has been completed and printed. The report describing results of the tests of four commercial densitmeters has been completed and has also been printed. These two reports are:

   Siegwarth, J. D., Younglove, B. A. and LaBrecque, J. F., Cryogenic fluids density reference system: provisional accuracy statement, Nat. Bur. Stand. (U.S.) Tech. Note 698, 24 pages (1977), and

   Siegwarth, J. D., Younglove, B. A. and LaBrecque, J. F., An evaluation of commercial densimeters for use in LNG, Nat. Bur. Stand. (U.S.) Tech. Note 697, 43 pages (1977), respectively.

   The density reference system is being prepared to test two additional densimeters of the Archimedes type. These densimeters will be used in the custody transfer of LNG.

8. Problem Areas. The DRS is performing in a satisfactory manner but the sample container is too small and too inflexible to permit testing some other densimeters which we would like to test.

9. Funding. July 1 - December 31, 1977.

Man-years expended	0.1
Total reporting period cost	6.0K$
Balance remaining	0.0K$

10. Future Plans. The DRS will be used to evaluate and calibrate transfer standards. A transfer standard will be sent to Gaz de France, Paris to intercompare our two calibration systems.

1. Title. LNG SAMPLING MEASUREMENT STUDY

Principal Investigators. W. R. Parrish, J. M. Arvidson and J. D. Siegwarth

2. Cost Center Number. 2750575 and 2755574.

3. Sponsor Project Identification. LNG Sampling Measurements Supervisory Committee and A.G.A.-PRC LNG Supervisory Committee.

4. Introduction. Composition is used to determine both the heating value and the quantity (through density) of LNG shipments. Thus, any error in composition doubles when calculating the total heating value and dollar value of a LNG tanker cargo. Compositions are determined by sampling LNG, on either a batch or continuous basis, and analyzing the vaporized mixture. Although several sampling techniques exist, none have received widespread acceptance in the LNG industry. Also, a standard technique has not been established for analyzing the vaporized sample.

5. Objectives or Goals. The objectives of this work were to evaluate existing sampling techniques appropriate to LNG systems and to recommend the most accurate analytical technique. Only sampling devices applicable to pipelines were considered. The sampling techniques were judged on:

   a) representativeness of sample,

   b) insensitivity of results to composition, temperature, pressure, degree of liquid subcooling, flow rate and operator, and

   c) simplicity.

   Initial evaluations were made in a laboratory-scale apparatus; final evaluation of the most promising sampling techniques was performed in the LNG flow facility and aboard an LNG tanker.

6. Background. This work was performed because there is a need to determine the best means for obtaining the composition of LNG shipments. Current LNG buying contracts include specifications on when and how many liquid samples are to be taken but omit the sampling technique to be used. The evaluation of sampling techniques by NBS is expected to lead to the acceptance of the most accurate composition determination method by all parties involved in LNG custody transfer.

7. Program and Results.

   A. LNG Flow Facility Tests.

   The final set of sampling tests were made in the Flow Facility in August. These tests showed that a sampling and analysis precision of $\pm$ 0.15 percent (based on three standard deviations) in the computed heating value was readily obtainable. Comparisons between computed heating values and those measured using combustion calorimetry were well within the precision of the calorimeter.

   The tests showed that:

   1. steam and electrically heated sample vaporizers gave comparable sampling precision,
   2. using uninsulated sample lines produces unrepresentative samples which are lean in nitrogen and methane, and
   3. the sampling system should be at steady state conditions before collecting samples.

B. Final Report.

A final report [1] detailing all of the LNG sampling work was written and will be available in early 1978.

8. Problem Areas. None.

9. Funding. July 1 - December 31, 1977.

Man-years expended	.75
Total reporting period cost	53.K$
Balance remaining	0.0

10. Future Plans. The work under this cost center (2750575) is complete. However, additional work is being supported by the Pipeline Research Committee, A.G.A., to improve the sample vaporizer design (2755574).

References

1. W. R. Parrish, J. M. Arvidson and J. F. LaBrecque, Development and evaluation of the LNG sampling measurement system (NBSIR, in preparation).

1. Title. SURVEY OF CURRENT LITERATURE ON LNG AND METHANE
Principal Investigator. Neil A. Olien

2. Cost Center Number. 2759574

3. Sponsor Project Identification. American Gas Association, Inc., Project BR-50-10.

4. Introduction. It is important that all NBS personnel working in LNG, as well as the AGA and others, keep up with what is going on throughout the world in the LNG field. This project is designed to provide the Current Awareness and other information services to allow workers to keep abreast of new research and other developments.

5. Objectives or Goals. We will publish and distribute each April, July, October, and January a listing of all significant papers, reports, and patents relating to methane and LNG properties and technology. The references will be listed under convenient subject headings. The Quarterly will be distributed to all interested AGA member companies and be made available to the general public on a subscription basis. In addition, LNG related information will be entered into the Cryogenic Data Center's Information System for quick retrieval. A continuing awareness of the current publication scene is maintained for any new periodicals to be reviewed cover-to-cover. Finally we will update and make available comprehensive bibliographies on the properties and technology of LNG. There are four bibliographies involved: methane properties, methane mixtures properties, processes and equipment involving methane and LNG, and patents relating to methane and LNG technology. These four will be updated annually.

6. Background. In 1969 we made a thorough review of the world's publications to determine which periodicals and abstracting services should be scanned cover-to-cover to adequately encompass the LNG field. The result is that we now scan over 330 primary publications and nearly 25 secondary publications. Of these, approximately one-third are directly related to LNG. In addition, we have increased our coverage of the energy field to include hydrogen as a future fuel. Much of this information is also pertinent to LNG and as such is listed in our LNG-related publications. Our Current Awareness Service has been published weekly since 1964 (beginning in 1975 the publication became biweekly) and the Liquefied Natural Gas Survey has been published quarterly since 1970.

7. Program and Results. Four issues of the LNG Quarterly are prepared each year and distributed. There are now 122 subscriptions going to AGA Member Companies and 166 to other subscribers.

The four comprehensive bibliographies mentioned in section 5 have been reviewed and shortened, and more selective bibliographies have resulted. The latest versions were completed as of January 21, 1977.

B-1525 THE THERMOPHYSICAL PROPERTIES OF METHANE AND DEUTERO-METHANE IN THE SOLID, LIQUID AND GASEOUS PHASES - A SELECTED BIBLIOGRAPHY. Indexed by property, phase and author, 100 pages (Jan 1977). ($10.00).

B-1526 THE THERMOPHYSICAL PROPERTIES OF METHANE MIXTURES - A SELECTED BIBLIOGRAPHY. Indexed by property, system and author, 166 pages (Jan 1977). ($15.00).

B-1524 PROCESSES AND EQUIPMENT INVOLVING LIQUEFIED NATURAL GAS AND METHANE - A SELECTED BIBLIOGRAPHY. Indexed by subject and author, 285 pages (Jan 1977). ($25.00).

B-1527 PATENTS RELATING TO METHANE AND LNG TECHNOLOGY - A SELECTED BIBLIOGRAPHY. Indexed by author, 150 pages (Jan 1977). ($15.00).

Over the past six years we have distributed over 500 copies of these and the comprehensive bibliographies.

8. Problem Areas. None.

9. Funding. July 1 - December 31, 1977.

Labor	8.4K$
Other Costs	1.3K$
Total	9.7K$
Remaining	.6K$

10. Future Plans. Issue 77-4 was delivered to the printer the first week of January and should be distributed before the end of January. The four bibliographies described above will be updated and made available in early February.

1. Title. LIQUEFIED NATURAL GAS TECHNOLOGY TRANSFER

Principal Investigators. Douglas B. Mann and Dwain E. Diller

2. Cost Centers. 2750403, 2751403, 2752403, 2750570, 2754574, 2758574, 2750127, and 2750461.

3. Sponsor Project Identification. Maritime Administration, Miscellaneous Purchase Order No. 400-79005; American Gas Association, Inc. Project BR 50-10; American Bureau of Shipping letter dated 21 November 1975; and NBS-Office of Standard Reference Data.

4. Introduction. The liquefied natural gas program at the Cryogenics Division of NBS-IBS/Boulder represents an investment by industry and government agencies of over $5 million over the past six years. This investment was designed to develop reference quality properties data for both fluids and materials and instrumentation and measurement technology for the use of the LNG and related industries. Information developed under this program must be transmitted to the ultimate user in a timely and useful format. The classical publication methods of NBS most certainly provide the scientist and research engineer information in a form most useful to the academic or near academic community. However, as a result of extensive assessments of user requirements, it was found that an additional effective mode for technology transfer would be an LNG Materials and Fluids User's Manual. A complete outline and planned table of contents has appeared in previous semi-annual reports. The Maritime Administration of the Department of Commerce and the American Bureau of Shipping have agreed to sponsor the first year's efforts on the materials section, and the American Gas Association, Inc. and the NBS Office of Standard Reference data have agreed to sponsor the section on fluids and fluid mixtures. The project was begun on April 1, 1976.

5. Objectives. The Liquefied Natural Gas Materials and Fluids User's Manual will provide a method of rapid dissemination of property data and related information for the effective generation, utilization and transportation of LNG. The object is to improve technology transfer from the current NBS Cryogenics Division LNG physical measurements program to the users, including federal agencies, the states and industry. For the purpose of this data book, liquefied natural gas is defined as a liquefied mixture (at less than approximately 150 K) of hydrocarbons, predominantly methane, with less than a total of 20% of the minor components ethane, propane, iso and normal butane, and nitrogen as an inert contaminant. LNG materials will be those associated with the liquefaction, transport and storage of liquefied natural gas.

6. Background. The user's manual is only one of a number of information dissemination methods used to provide workers in the liquefied natural gas (LNG) industry with properties data of known quality in a format consistent with the requirements of the intended user. In the case of the LNG user's manual the intended audience is the field engineer, plant manager, ship designer or process engineer interested in a ready reference of assessed quality for data to be used in conceptual design, process monitoring, process analysis, and intercomparisons where precision and accuracy are secondary to specific problem solutions. The hierarchy of accuracy and precision will be defined and traceable through references to scientific and engineering literature.

Data is classified into three groups by the NBS Cryogenics Division.

Group 1. Data which has been generated experimentally by NBS, or has been assessed, evaluated or experimentally verified by NBS.

Group 2. Data which has been assessed and evaluated by NBS.

Group 3. Data available in the scientific engineering literature through the NBS Cryogenic Data Center or elsewhere. No NBS evaluation or assessment has been made at this date.

In general, most data included in the LNG user's manual will be from groups 1 and 2. Few new assessments or correlations are anticipated or required for this work.

Data will be presented primarily in graphical form. Tables and analytical expressions will be used only where absolutely necessary. Graphs and charts will be in loose-leaf form for ease of updating and additions. This form will also allow immediate implementation for data already available under the NBS LNG program and will provide a convenient format for the output of data from existing projects. The user's manual will not be a substitute for traditional publications in the scientific literature where measurement science, technique, precision and accuracy are paramount, but will provide the data and references for the necessary assessment by the user.

The publication of both graphical and tabular data will be in a dual system of physical units. These units will be the traditional LNG industry British System of BTU, pound, degree Fahrenheit and the SI system of joule, kilogram and kelvin. It is the intent to give equal weight to each system of units.

Nine structural metals have been selected with additions possible upon consultation with the sponsors. Primary emphasis in the fluids section will be on data for pure methane, pure nitrogen, and methane-nitrogen mixtures.

7. Program and Results. The first edition of the user's manual became available for distribution in September. A complete description and ordering information is included as part of this report. Of the original 750 first printing over 250 copies have been distributed to sponsors or sold directly.

   Work on the first supplement to the user's manual is in progress. Ethane thermophysical properties graphs are now being printed. Mixture thermophysical property graphs are nearly complete. Thermal insulation property graphs and materials specification tables are being prepared.

   In addition to the tasks described above, the U.S. Maritime Administration has asked NBS to assist with planning and coordination of an expanded MarAd LNG research program in the areas of safety, economics and LNG technology. A draft report "Maritime Administration LNG Research Program Plan" identifying suggested program areas and describing suggested subprograms and projects has been prepared and submitted to the sponsor.

8. Problem Areas. None.

9. Funding. July 1 - December 31, 1977.

Labor - man-years expended	0.5
Funds expended	20.0K$
Balance remaining (first edition)	0.0K$

10. Future Plans. The first supplement, which will include additional materials properties (thermal insulations and additional ferrous alloys) and specifications, properties of ethane, additional binary mixtures data and densities of commercial LNG compositions, will be available in 1978. This supplement will be distributed to current holders of the first edition on request.

    The draft report "Maritime Administration LNG Research Program Plan" will be revised and updated as appropriate.

LNG MATERIALS AND FLUIDS

A USER'S MANUAL OF PROPERTY DATA IN GRAPHIC FORMAT

The National Bureau of Standards Cryogenics Division is distributing a loose-leaf LNG Materials and Fluids User's Manual. The User's Manual is designed to provide property data and related information for the effective generation, utilization and transport of LNG.

The total edition is planned to include:

- pure fluids data on methane, nitrogen, ethane, propane and iso and normal butane,
- fluid mixtures data involving methane with nitrogen, ethane, propane and iso and normal butane, including commercial LNG compositions,
- LNG materials data on structural metals and alloys, and
- materials data on thermal insulations, joining compounds, structural composite materials and aggregates, polymeric materials, and miscellaneous non-structural materials.

The first edition and expandable binder contains 138 two-color (8½ x 11-inch) charts and six wall charts (22 x 34-inch). This edition's property data are pressure-density-temperature, thermodynamic, transport and electromagnetic properties of pure methane and nitrogen; fluid mixtures of methane with nitrogen; and, the elastic, thermal and mechanical properties of aluminum alloys (3003, 5083 and 6061), stainless steels (304, 304L, 310 and 316), nickel steels (2.25, 3.5, 5 and 9% nickel) and invar. The wall charts are of the thermodynamic properties enthalpy-entropy (H-S), pressure-enthalpy (P-H) and temperature-entropy (T-S) for pure methane and pure nitrogen.

Both British and SI (International System) units are used throughout, easily discernable by printing in separate colors.

The expandable binder allows for future supplements. Purchasers of the first edition will be notified upon completion of addtitional supplements and their respective prices. All charts are printed on a high wet strength lithographic map paper designed for a strong durable life.

Copies of the first edition @ $35 each and additional rolled wall charts @ $1 each may be obtained by forwarding the order form below with payment. For additional information contact LNG Materials and Fluids; National Bureau of Standards; Cryogenics Division; 325 Broadway; Boulder, Colorado 80302.

ORDER FORM		QUANTITY	PRICE
First Edition LNG Materials and Fluids User's Manual	@ $35 ea.	_____	_____
Additional Rolled 22 x 34 Charts:			
Nitrogen thermodynamic data			
Enthalpy-entropy wall chart (H-S)	@ $ 1 ea.	_____	_____
Pressure-enthalpy wall chart (P-H)	@ $ 1 ea.	_____	_____
Temperature-entropy wall chart (T-S)	@ $ 1 ea.	_____	_____
Methane thermodynamic data			
Enthalpy-entropy wall chart (H-S)	@ $ 1 ea.	_____	_____
Pressure-enthalpy wall chart (P-H)	@ $ 1 ea.	_____	_____
Temperature-entropy wall chart (T-S)	@ $ 1 ea.	_____	_____
		TOTAL	_____

Mail form and remittance to:

LNG Materials and Fluids; National Bureau of Standards; Cryogenics Division; 325 Broadway; Boulder, Colorado 80302.

1. Title. OIML JOINT SECRETARIAT ON LNG MEASUREMENTS

Principal Investigators. Douglas Mann and James A. Brennan.

2. Cost Center Number. 2750104

3. Sponsor Project Identification. American Gas Association, Inc., NBS-Office of International Standards; and NBS-Cryogenics Division.

4. Introduction. The liquefied natural gas program of the National Bureau of Standards Cryogenics Division has, over the past five years, provided the gas industry and interested Government agencies with properties data on materials and fluids, instrumentation, and measurement assistance in the support of commerce in this significant and growing segment of the supplementary fossil energy supply. Support of this program by the American Gas Association, Inc. and Federal Government agencies such as the Maritime Administration (MarAd), NASA, GSA, Federal Power Commission and the NBS-Office of Standard Reference Data has provided a basis for the national acceptance of the results of the NBS LNG program. Through the U.S. membership in the International Organization of Legal Metrology there exists, at the present time, an opportunity to extend, internationally, the utility of data and measurement practice developed under our joint Government/industry program. We have been requested (by OIML membership) to establish an LNG Measurement Secretariat within OIML which, if implemented, would provide a significant international forum for the results of our joint work. It is believed that a joint Secretariat with the LNG industry would provide the most effective means of accomplishing these objectives.

5. Objectives or Goals. Our objective is to accomplish the following goals within the next three years.

a) To establish U.S. (NBS) thermophysical properties data for LNG as the standard data in international usage.

b) To establish U.S. (NBS) materials property data used in fabrication and construction of LNG facilities (liquefiers, storage, transport) as the standard data in international usage.

c) To establish U.S. (NBS) approved measurement technology and instrumentation as related to LNG (pressure, temperature, density, liquid level, flow) as the standard in international LNG trade. The precedent has been established with the successful completion of the joint NBS-CGA cryogenic flow measurement program which has resulted in the adoption of a cryogenic flow measurement code by the National Conference on Weights and Measures. We wish to extend this code on an international basis.

d) To establish and maintain the leadership of U.S. science, engineering, and industry in the research, technology, manufacture and marketing of instruments and measurement systems for liquefied natural gas.

6. Background. OIML was founded in 1955 to promote intergovernmental cooperation in the field of legal metrology which relates to the compatibility of standards of measurement and the legislation and government regulations which may affect such standards of measurement. OIML recommends uniform international requirements for scientific and measurement instruments used in industry and commerce and works out model laws and regulations for consideration by member nations; and, in addition, serves as a center of documentation and information exchange in legal metrology. At present 43 nations are members of this intergovernmental organization.

The United States joined OIML in 1972 (the Senate by resolution of August 11, 1972 gave its advice and consent to the accession of the U.S. to the convention establishing OIML). The responsibility for managing U.S. participation in OIML was assigned to the Department of Commerce

and has since been delegated by the Department to the National Bureau of Standards (NBS). Under the general guidance of the Department of State and the Secretary of Commerce, NBS is directly responsible for formulating and implementing U.S. policy towards OIML. U. S. participation in the organization is deemed important for two reasons: First, to protect and enhance some $1 billion worth of scientific and measurement instruments exported each year by U. S. firms and to insure equity in the trade of commodities measured by these instruments; and second, to maintain the U.S. as the world leader in the field of metrology.

In the spring of 1975 at a meeting in Paris of the International Committee of Legal Metrology, the French and U.S. representatives discussed the possibility of creating a new Reporting Secretariat No. 13 on "Liquefied Natural Gas (LNG) Measurement". The U. S. representative, W. E. Andrus, Jr. of NBS, agreed to explore the possibility with U. S. industry and interested government agencies. These discussions resulted in a decision to propose a joint Secretariat with the American Gas Association and NBS-Cryogenics Division in order to best accomplish the tasks. These conclusions were reached during several meetings extending through the latter part of 1975 and early 1976.

7. Program and Results. Representatives of NBS met with PTB (West Germany) and SIM (France) to discuss the proposed scope and to explore expansion of the effort to include cryogenic fluids in general. Results of those discussions indicate some resistance to including different physical measurements (flow, density, etc.) under a single recommendation for a specific group of fluids.

   The proposed plan and scope were presented at the meeting of The Advisory Committee for International Legal Metrology held at NBS-Boulder in September. The committee encouraged NBS to proceed with the present scope and to continue to explore the possible inclusion of other cryogenic fluids.

8. Problem Areas. None.

9. Funding. July 1 - December 31, 1978.

Labor - Man-years expended	0.1
Funds expended	11.0K$
Balance remaining	0.0K$

10. Future Plans. Two areas will continue to be explored. The first concerns expanding the scope of the LNG measurements to include other cryogenic fluids and thereby taking advantage of existing codes and standards within the U.S. and Europe. Second, continued development of the scope for LNG measurements to identify recommendations already available under OIML and those which must be written separately.

1. Title. FEDERAL POWER COMMISSION CONSULTATION

   Principal Investigators. D. B. Chelton, T. R. Strobridge and A. F. Schmidt.

2. Cost Center Number. 2750404

3. Sponsor. Federal Power Commission - Bureau of Natural Gas -- letter agreement dated 4 June 1973.

4. Goals. The Cryogenics Division has provided consultation and advisory services to the Federal Power Commission on the cryogenic safety and the design aspects of current applications before the FPC for authorization of LNG terminal and storage facilities. These services covered properties of cryogenic environments, insulation systems, cryogenic safety, thermodynamics, heat transfer, instrumentation, and cryogenic processes such as refrigeration and liquefaction.

5. Background. Cost Center initiated July 7, 1973.

6. Program and Results. The status of those facilities under the jurisdiction of the Federal Power Commission and subjected to our review are outlined in the following table (updated through December 31, 1977).

   Elements of the facilities that were subject to review are the land-based cryogenic storage tank components, bounded by the tanker or barge, the inlet and distribution pipelines. These included, but were not limited to the transfer lines, the storage tanks, the vaporizers and the process piping as it interacts with the storage tanks. It was essential that the reviews covered the operation, maintenance and emergency procedural philosophies for each terminal. Based upon these studies, reports were submitted to the staff of the FPC setting forth the technical evaluations and conclusions on each proposal.

   Emphasis was placed on the safety aspects of the facilities including their possible interactions with the surrounding areas. The impact of engineering design such as appropriate use of existing technology and material selection for structural integrity were assessed. The basis of review included various codes and standards, prior experience, precedent and engineering knowledge. Vapor cloud generation and plume dispersion was considered a subject beyond our area of expertise.

7. Funding.

FY 77 Allocation	70K$
Balance remaining	0K$

8. Future Plans. This cost center was terminated at the end of FY 1977 at the discretion of the National Bureau of Standards. Further reviews by the National Bureau of Standards will be negotiated as required.

FPC CONSULTATION - LNG FACILITY REVIEW

Applicant	Location	Type Facility	Storage Facility	Status		
				Site Inspection	Technical Meeting	Review
Distrigas - New York Terminal	Staten Island, NY	Import Terminal	2-900,000 barrel	8/21/73	8/21/73	Complete
Distrigas - Everett Marine Terminal	Everett, MA	Import Terminal	1-600,000 barrel 1-374,000 barrel	8/23/73 4/02/76 6/29/77	8/23/73	Complete†
Algonquin LNG, Inc.	Providence, RI	Import Terminal	1-600,000 barrel	8/24/73	8/24/73	Complete
Northern Natural Gas Co.	Carlton, MN	Peak Shaving	1-630,000 barrel 10.8 MMCFD liquefier	10/30/73 7/29/75	10/30/73	Complete
Northwest Pipeline Corp.	Plymouth, WA	Peak Shaving	1-348,000 barrel 6.0 MMCFD liquefier	10/31/73 7/31/75	10/31/73	Complete
East Tennessee Natural Gas Co.	Kingsport, TN	Peak Shaving	1-348,000 barrel 5.0 MMCFD liquefier	6/24/75	11/29/73	Complete
Transco Terminal Co.	Bridgeport, NJ	Import Terminal	3-600,000 barrel	1/23/74	1/23/74	Complete
Southern Energy Co.	Savannah, GA	Import Terminal	4-400,000 barrel	1/24/74 4/19/77	2/06/74	Complete
Alabama-Tennessee Natural Gas Co.	Greenbrier, AL	Peak Shaving	1-117,000 barrel 2.0 MMCFD liquefier	**	2/05/74	Complete
Trunkline LNG, Inc.	Lake Charles, LA	Import Terminal	3-600,000 barrel	2/07/74	5/14/74	Complete
Chattanooga Gas Co.	Chattanooga, TN	Peak Shaving	1-348,000 barrel 10.0 MMCFD liquefier	2/28/74	2/28/74	Complete
Tennessee Natural Gas Co.	Nashville, TN	Peak Shaving	1-290,000 barrel 5.0 MMCFD liquefier	2/27/74	2/27/74	Complete
Northern Natural Gas Co.	Hancock Co., IA	Peak Shaving	1-630,000 barrel 10.8 MMCFD liquefier	2/02/77	2/02/77	Complete†
Texas Eastern Transmission Company	Staten Island, NY	Peak Shaving/ Import	* 9.0 MMCFD liquefier	*	*	In process
El Paso Alaska Co.	Gravina Pt., Alaska	Export Terminal	4-550,000 barrel	8/19/74	*	Pending

* to be determined
** NBS visit not scheduled
† additional review/site inspection is pending final design

FPC CONSULTATION - LNG FACILITY REVIEW (Continued)

Applicant	Location	Type Facility	Storage Facility	Status		
				Site Inspection	Technical Meeting	Review
Pacific Alaska LNG Co.	Nikiski, Alaska	Export Terminal	2-550,000 barrel 400 MMCFD liquefier	*	3/02/76	Complete†
Western LNG Terminal Co.	L. A. Harbor, CA	Import Terminal	2-550,000 barrel	*	10/21/76	Complete†
	Oxnard, CA	Import Terminal	2-550,000 barrel	12/09/75	12/09/75	Complete†
	Pt. Conception, CA	Import Terminal	2-550,000 barrel	12/10/75	*	Pending
Northern States Power Co.	Eau Claire, WI	Peak Shaving	1- 78,000 barrel 2.0 MMCFD liquefier	3/30/76	3/30/76	In process
Northern States Power Co.	Wescott, MN	Peak Shaving	1-580,000 barrel 1- 38,000 barrel 10 MMCFD liquefier	3/31/76 8/04/76	8/04/76	Complete
Northwest Pipeline Corp. LNG-II	Plymouth, WA	Peak Shaving	1-522,000 barrel 10.0 MMCFD liquefier	*	*	In process
Peoples Natural Gas	Hancock Co., IA	Peak Shaving	1-630,000 barrel 14.5 MMCFD liquefier	*	2/02/77	Complete†
Tenneco LNG, Inc.	W. Deptford, NJ	Import Terminal	4-550,000 barrel	*	*	Pending
Distrigas-Everett Marine Terminal	Everett, MA	Import Terminal	Modification	6/29/77	*	†
EI Paso LNG Terminal Co.	Matagordo Bay, TX	Import Terminal	3-629,000 barrel	*	†	†
Tenneco Atlantic Pipeline Company	New Brunswick, Canada	Import Terminal	4-600,000 barrel	*	*	Pending

* to be determined
** NBS visit not scheduled
† additional review/site inspection is pending final design.

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7. AUTHOR(S): D. E. Diller, Editor

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NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

10. Project/Task/Work Unit No.: 2750104

11. Contract/Grant No.

12. Sponsoring Organization Name and Complete Address *(Street, City, State, ZIP)*

See block 16 below.

13. Type of Report & Period Covered: Semi-Annual
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14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Twenty-nine cost centers, supported by seven other agency sponsors in addition to NBS, provide the basis for liquefied natural gas (LNG) research at NBS. During this six-month reporting period the level of effort was over 20 man-years/year with funding expenditures of over $500,000. This integrated progress report, to be issued in January and July, is designed to:

1) provide all sponsoring agencies with a semi-annual report on the activities of their individual programs;

2) inform all sponsoring agencies on related research being conducted at the Cryogenics Division;

3) provide a uniform reporting procedure which should maintain and improve communication while minimizing the time, effort and paperwork at the cost center level.

The contents of this report will augment the quarterly progress meetings of some sponsors, but will not necessarily replace such meetings. Distribution of this document is limited and intended primarily for the supporting agencies. Data or other information must be considered preliminary, subject to change and unpublished, and therefore not for citation in the open literature.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Cryogenics; liquefied natural gas; measurement; methane; properties; research.

6434

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