NBSIR 74-358 (R)

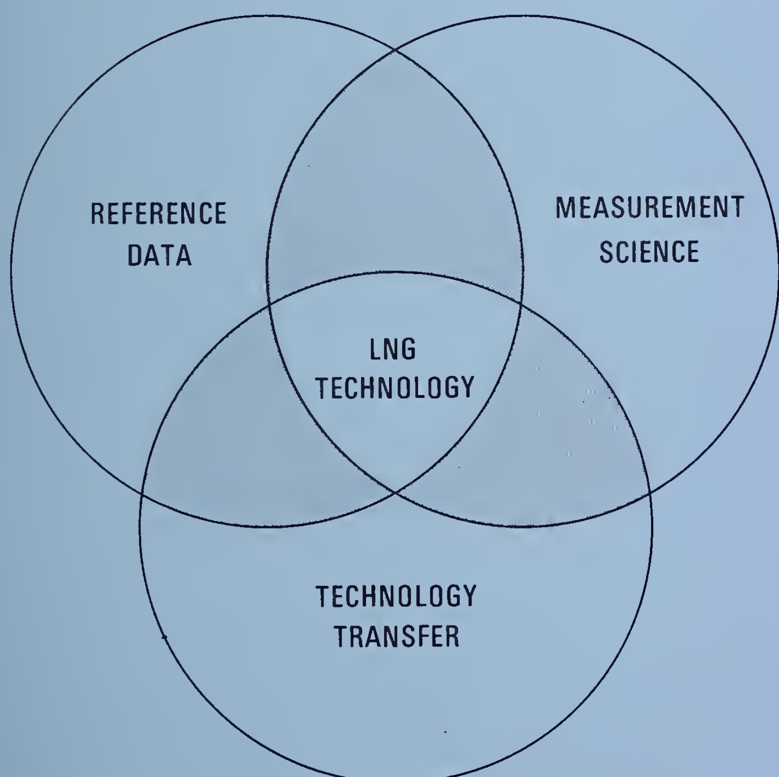
LIQUEFIED NATURAL GAS RESEARCH

at the

NATIONAL BUREAU OF STANDARDS

PROGRESS REPORT FOR THE PERIOD
JULY 1-DEC 31, 1973

D. B. Mann, Editor



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

NBSIR 74-358

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D. B. Mann, Editor

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

Progress Report for the Period
July 1 - December 31, 1973

U.S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary

NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

Prepared for:

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Arlington, Virginia 22209

LNG Density Project Steering Committee
(in cooperation with the American Gas Association)

Pipeline Research Committee
(American Gas Association)

Federal Power Commission
Bureau of Natural Gas
Washington, D. C. 20426

General Services Administration
Motor Equipment Research & Technology Division
Washington, D. C. 20406

U. S. Department of Commerce
Maritime Administration
Washington, D. C. 20235

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U. S. Department of Commerce
National Bureau of Standards
Office of Standard Reference Data
Washington, D. C. 20234

ABSTRACT

Fourteen cost centers supported by six other agency sponsors in addition to NBS provide the basis for liquefied natural gas (LNG) research at NBS. This integrated progress report to be issued in January and July is designed to:

1) Provide all sponsoring agencies with a semi-annual and annual report on the activities of their individual programs.

2) Inform all sponsoring agencies on related research being conducted at the Cryogenics Division of NBS-IBS.

3) Provide a uniform reporting procedure which should maintain and improve communication while minimizing the time, effort and paper work 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 Data or other information must be considered preliminary, subject to change and unpublished; and therefore not for citation in the open literature.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: Cryogenic; liquefied natural gas; measurement; methane; properties; research.

Contents

1. Title. Refractive Index of Fluid Methane

Principal Investigator. James D. Olson

2. Cost Center Number. 2750122

3. Sponsor Project Identification. NBS-NRC Postdoctoral Research Associate Program

4. Introduction. This experimental program will provide accurate measurements of the refractive index of liquid and gaseous methane. The data can be related to the fluid density by the Lorentz-Lorenz electromagnetic equation of state and, as such, offers the possibility of fluid density gauging by optical techniques. This pure fluid data is essential to the possible study of mixture refractive index properties.

5. Objectives or Goals. The refractive index of liquid and vapor methane will be measured along the two-phase saturation boundary. In addition gaseous isotherms will be obtained at 220 K, 250 K, 280 K, and 300 K at pressures to 200 atm. Low pressure isotherms will be measured below the saturation boundary.

6. Background. The high precision interferometric technique used to measure the refractive index was developed in this laboratory by D. E. Diller (J. Chem. Phys. 49, 3096 (1968)). An improved optical data gathering method was the principal modification of this technique. Prior to this reporting period, a literature survey of Lorentz-Lorenz and Calusius-Mossotti virial equation data was conducted. A cryostat was constructed using the design of Diller.

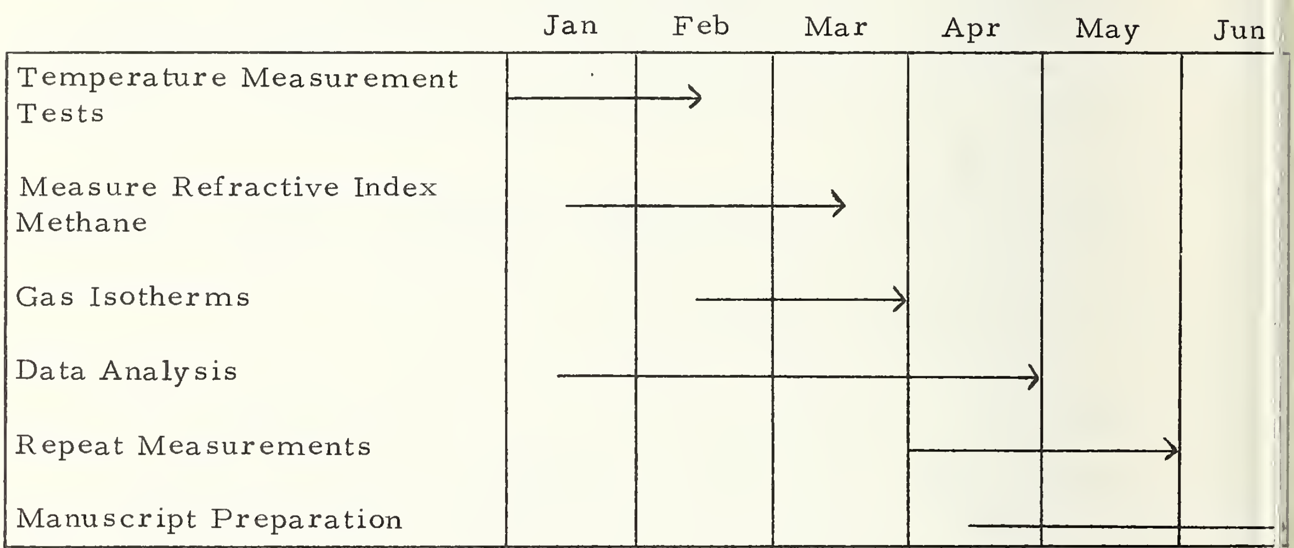
7. Program and Results. The apparatus was completed in July and preliminary refractive index isotherms were obtained at 300 K without refrigeration in the cryostat. These tests of the modified optical technique were successful. In October, the apparatus was cold-tested with liquid N_2 for the first time. Temperature control problems were encountered and corrected. In November, vapor pressure measurements on liquid methane indicated thermal gradients were present in the pressure bomb-guard ring arrangement. These were responsible for temperature measurement errors of about 40 mk. During December it was necessary to disassemble the apparatus and redesign a portion of the guard ring to eliminate the temperature gradient. Thus far there have been no results.

8. Problem Areas. The temperature measurement problem was discussed in section 7. As a consequence, the measurement program is two months behind schedule.

9. Funding. July 1 - December 31, 1973

Labor		0.5 MY	17.0 K$
Other Costs			1.5 K$
	Total		18.5 K$
	Remaining		21.5 K$

10. Future Plans.



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. Studies of mixtures have not received the attention or support that have been given to equivalent studies of pure fluids. This is especially true for transport properties where the mixture effort has been negligible. Yet from the standpoint of the liquefied natural gas industry mixtures are more important than pure fluids. At this time there is no adequate method in existence for predicting the transport properties of fluid mixtures even in the dilute regions. Properties cannot be measured for all possible mixtures, thus adequate predictions methods are needed in order 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 program was started in 1965 with the goal of producing tables of fluid transport properties through many approaches; e.g. data correlation and evaluation, statistical mechanics, kinetic theory, thermodynamics and statistics. A theory was developed based on a modification of the Enskog theory. In addition a systematic study of intermolecular potential functions was performed which resulted in a new potential function, the M-6-8. The theoretical studies along with data analysis resulted in prediction techniques for the dilute gas region for monatomic and polyatomic fluids. These techniques were then successfully extended to the dense gas and liquid regions. To date tables of transport properties have been prepared for argon,

krypton, xenon, oxygen, nitrogen, fluorine and hydrogen. In addition an analytical representation of the anomalous behavior of the thermal conductivity coefficient in the "critical region" has been developed. As a precursor to the study of fluid mixtures we have started a task to apply numerical techniques such as molecular dynamics to transport properties. To this end the Principal Investigator will be spending the period November 1973 to August 1974 at Australian National University working with International Authorities in the field, Dr. R. O. Watts and Professor R. J. Bearman.

7. Program and Results. The mixtures part of the program has not started as yet. As mentioned above the Principal Investigator is in Australia gaining experience in advanced theoretical techniques. During the current reporting period a molecular dynamics model has been modified and applied to methane. The program has been run for a system of 108 methane molecules. The resulting output are, in effect, experimental data and will be compared with methane data and equations of state from the Cryogenics Division.

8. Problem Areas. There are no problem areas at this time except a financial one, since the level of support is less than what is required for the project. The projected shortage at the end of FY74 is 12 K$, which may require a reduction in scope of mixture work.

9. Funding. July 1 - December 31, 1973

Allocation	50 K$	--	OSRD
Labor	0.5 MY		27.8 K$
Other Costs			1.5 K$
	Total		29.3 K$
	Remaining		20.7 K$

10. Future Plans. During the next six months studies will continue and the mixture part of the program will begin after August 1974. If the methane calculations prove successful, it may be possible to make preliminary calculations on binary systems of methane with ethane and nitrogen at an earlier date.

1. Title. PROPERTIES OF CRYOGENIC FLUIDS: HYPERSONIC VELOCITY AND THERMAL DIFFUSIVITY MEASUREMENTS

Principal Investigator. G. C. Straty

2. Cost Center Number. 2750141

3. Sponsor. NBS

4. Introduction. Laser light scattering techniques will be used to obtain accurate thermophysical properties data for compressed and liquefied pure methane. This work will complement related work on the thermodynamic properties of the pure components of LNG mixtures (2751364). This work will provide data for the development of LNG technology involving density gauging and heat and mass transfer calculations at NBS and throughout the natural gas industry.

5. Objectives or Goals. The objectives of this project are to obtain accurate sound velocity and thermal diffusivity data for pure methane (90-300 K, 350 bars) by using laser light scattering techniques. Sound velocity data are useful for testing the consistency of volumetric, calorimetric and thermodynamic properties data for the pure components of LNG, and are potentially useful for LNG density gauging applications. Thermal diffusivity data are useful for calculating transport properties of LNG mixtures required for performing 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 results 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 and 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 recently been demonstrated.

We have constructed a facility for laser light scattering measurements of hypersound velocities in compressed and liquefied gases (76-300 K, 350 bars). The apparatus consists of a copper optical cell with fused quartz windows, cryostat for refrigeration with liquid nitrogen, an argon ion laser, pressure scanned Fabry-Perot interferometer, and photon counting equipment. We have obtained spectra of the light scattered from liquid toluene and compressed gaseous methane at room temperature previous to this reporting period.

7. <u>Program and Results</u>. Preparations are being made to obtain sound velocity measurements for pure methane at low temperatures and at low densities (< 14 mol/ℓ) where the sound absorption in methane is too large to permit ultrasonic measurements.

8. <u>Problem Areas</u>. No significant problems have been encountered. Progress on the light scattering experiment has been limited primarily by our arrangement of priorities to other LNG related efforts. Emphasis has been placed on the measurement of ultrasonic sound velocity in pure methane. Inability to make ultra-sound velocity measurements at low density, however, has placed additional emphasis on the light scattering experiments to obtain this needed data and progress in this area is expected to accelerate.

9. <u>Funding</u>.

Manyears Expended, July - Dec 1973	0.2
Equipment and/or Services Purchased	\$ 3,942
Total Reporting Period Cost	\$ 12,122
Balance Remaining (Jan 5, 1974)	\$ 27,378

10. <u>Future Plans</u>.

Schedule: year / quarter	1974	
	1	2
Methane:		
measure hypersonic (GHz) sound velocities		(completion scheduled for October 1974)

1. Title. PROPERTIES OF CRYOGENIC FLUID MIXTURES: EQUILIBRIUM DATA, COMPILATION AND EVALUATION, PREDICTION METHODS

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

2. Cost Center Numbers. 2750142; 2750145

3. Sponsors. NBS; NBS-OSRD

4. Introduction. This project provides compilations of evaluated equilibrium data and experimental measurements on equilibrium properties which are suitable for direct technological use or for the evaluation of prediction and calculation methods. Correlation and prediction methods have, therefore, been of direct concern in these efforts. This project supports the development of LNG technology in the areas of separation, purification, and custody transfer by defining relationships between temperature, pressure, and equilibrium state properties for mixtures related to LNG.

5. Objectives or Goals. The overall objective is to provide critically evaluated data, original and from other sources, on the phase equilibria and thermodynamic properties of cryogenic fluid mixtures. The program has been divided logically into specific steps as follows:

(a) preparation of a bibliography on experimental measurements of equilibrium properties for selected molecular species of principal interest for cryogenics

(b) selection and/or development of methods for prediction, correlation, and evaluation of equilibria properties.

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

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

(e) directing the experimental research effort to alleviate deficiencies and provide the 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 experimental data on the solid-vapor and liquid vapor equilibria and physical adsorption properties for a limited number of binary and ternary systems of components with widely separated critical points. Most of the systems studied were those containing 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 new correlation for the prediction of deviations from the geometric mean rule for combining characteristic energy parameters. In addition, significant new information was gained on interaction third virial coefficients which was used in a new 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 in general.

The recent efforts have been directed toward problems associated with systems containing components with overlapping liquid ranges, such as the nitrogen + methane system.

Up to this reporting period, an expanded bibliography was prepared to update NBS Technical Note 56 published in May 1960 (objective a). Experimental liquid-vapor equilibria measurements were also completed for selected temperatures on the argon + methane, nitrogen + methane, nitrogen + argon, and nigrogen + argon + methane systems.

7. Program and Results. The progress of this program is summarized as follows:

(a) A comprehensive bibliography of experimental data for ten equilibrium properties has been completed and is presently undergoing editorial review prior to publication. The bibliography includes sections on solid-liquid, solid-vapor, solid-liquid-vapor, liquid-liquid, liquid-vapor, and gas-gas equilibria, as well as sections on liquid mixture densities, gas or vapor mixture densities, Joule-Thomson coefficients, and calorimetric measurements. The materials considered are hydrogen, helium-3, helium-4, deuterium, neon, carbon monoxide, nitrogen, oxygen, hydrogen sulfide, fluorine, argon, carbon dioxide, krypton, xenon, methane, acetylene, ethylene, ethane, propylene, propane, cyclopropane, n-butane, and isobutane.

Because of its importance, the section on liquid-vapor equilibria was published as a survey paper in Cryogenics 13, No. 10, 575 (Oct. 1973). It is anticipated that the complete bibliography will be available by July 1, 1974.

(b) Work is currently in progress on the retrieval and evaluation of equilibria data for both the argon + methane and the nitrogen + methane systems. To maintain this phase of the program within reasonable bounds, the only properties under study are liquid-vapor equilibria, liquid mixture densities, and gas or vapor mixture densities. This effort also requires selection of the pure vapor pressures and saturation densities. The new vapor pressure measurements of Wagner (Cryogenics, August 1973) for nitrogen and argon are being programmed and evaluated. These new measurements indicate that the argon vapor pressure temperature relationship given in NBS-NSRDS 27 is in error by 0.04 K.

(c) Our most recent liquid-vapor equilibria data for the nitrogen + methane system between 95 and 120 K were presented at the Cryogenic Engineering Conference in Atlanta, August 1973. These data are also being assessed at the present time to determine if additional information on the second interaction virial coefficients might be derived.

(d) The development and organization of the LNG technical sessions for the Cryogenic Engineering Conference held in August 1973 evolved a considerable contribution of time and effort.

8. Problem Areas. The major problem that may affect progress on the evaluation of mixtures data is the lack of generally accepted, rigorous methods for critically evaluating phase equilibria data. Each binary system poses special problems of its own, and it may be necessary to tailor the techniques employed. Generating new experimental data may not be possible within the next six months due to apparatus commitments for other mixture data and a lack of qualified manpower.

9. Funding.

Man-years expended (July-Dec 1973)	0.4
Equipment and/or Services Purchased	$ 2,529
Total Reporting Period Cost	$ 21,750
Balance Remaining (Jan 5, 1974)	$ 38,250

10. Future Plans.

Schedule: year / quarter	1974: 1	1974: 2
Retrieve phase equilibrium data for methane-argon and methane-nitrogen mixtures	→	
Select pure component (methane, argon, nitrogen) data	→	
Calculate excess Gibbs energies for methane-argon and methane-nitrogen mixtures		→
Compare calculated excess Gibbs energies for different sets of data		→
Compare calculated excess volumes V^E for different sets of data		→

1. Title. Survey of Current Literature on LNG and Methane.

Principal Investigator. Neil A. Olien

2. Cost Center Number. 2750362

3. Sponsor Project Identification. American Gas Association 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 will be 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 three bibliographies involved: methane properties, methane mixtures properties, and processes and equipment involving methane and LNG. These three will be updated each October.

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 300 primary publications and nearly 30 secondary publications. Of these approximately one-third are directly related to LNG. In addition, within the past year 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 and the Liquefied Natural Gas Survey has been published quarterly since 1970.

7. Program and Results. Two issues of the LNG Quarterly were prepared and distributed. There are now 108 subscriptions going to AGA Member Companies and 195 to other subscribers. In September and October we updated the three bibliographies covering methane properties, methane mixtures properties and processes and equipment involving methane and LNG.

For some time we have realized that the above mentioned comprehensive bibliographies had grown to such a large size as to limit their usefulness (e.g., B-965 covering processes and equipment listed over 1500 references). With this in mind we have reviewed the individual references in each bibliography and selected those which were most useful either from the standpoint of accuracy of the data or the appropriateness of the subject matter. These are now complete and copies have been printed and are available for sale as listed below.

B-1055 THERMOPHYSICAL PROPERTIES OF METHANE - A SELECTED BIBLIOGRAPHY, 61 pp, indexed by property, phase and author (Sep 1973) $8.00

B-1056 PROPERTIES OF METHANE MIXTURES - A SELECTED BIBLIOGRAPHY, 94 pp, indexed by property, system and author (Sep 1973) $10.00

B-1075 PROCESSES AND EQUIPMENT INVOLVING LIQUEFIED NATURAL GAS AND METHANE - A SELECTED BIBLIOGRAPHY, 52 pp, indexed by subject and author (Oct 1973) $5.00

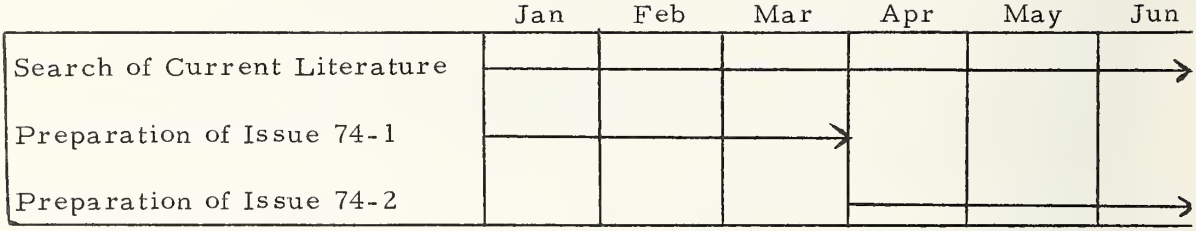
During the period July through December 1973 we have distributed 75 copies of these and the comprehensive bibliographies.

8. Problem Areas. We have no problem areas at this time.

9. Funding. July 1 - December 31, 1973

Labor	6.8 K$
Other Costs	1.6 K$
Total	8.4 K$
Remaining	8.4 K$

10. Future Plans. Issue 73-4 of the LNG Quarterly was mailed to the National Technical Information Service for printing and distribution on January 8, 1974.


Jan
Feb
Mar
Apr
May
Jun
Search of Current Literature
Preparation of Issue 74-1
Preparation of Issue 74-2

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

Principal Investigators. R. D. Goodwin, G. C. Straty

2. Cost Center Number. 2750364

3. Sponsor. American Gas Association Project BR 50-10

4. Introduction. This cost center will provide an accurate data base for LNG mixtures for cryogenic engineering at NBS and throughout the gas industry.

5. Objectives or Goals. The objective of our work is the determination of accurate, comprehensive thermophysical properties data for the major pure components (methane, ethane, propane, butanes, and nitrogen) of liquefied natural gas mixtures at temperatures between 90K and 300K and at pressures up to 350 atm (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.

Accurate phase equilibrium, compressibility, and thermodynamic properties data are needed to design and optimize gas separation and liquefaction equipment such as compressors and heat exchangers. Accurate data for the pure components of LNG mixtures will permit taking into account the dependence of the thermophysical properties of the mixtures on the composition.

6. Background. Liquefied natural gas is expected to supply an increasing percentage of the United States' future energy requirements. In spite of the desire to make the U.S.A. self sufficient in energy resources, it is likely that we will import all of the natural gas we can obtain during the years 1976-1985. Ships and importation terminals are being built for

transporting, storing, and vaporizing massive quantities of liquefied natural gas for distribution. Accurate physical and thermodynamic properties data for compressed and liquefied natural gas 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.

There is little accurate (~1%) phase equilibrium, compressibility, and thermodynamic properties data available for compressed and liquefied natural gas mixtures at low temperatures. Natural gas mixtures liquefy at temperatures below -120°F (189 K), boil at temperatures near -256°F (113 K), and freeze at temperatures below -296°F (91 K). There is little accurate thermodynamic properties data available, even for the liquefied pure components (methane, ethane, propane, butanes, etc.) in this temperature range. In addition, the compositions of natural gas mixtures vary considerably from one source to another and change continuously during transport and storage because of selective vaporization. The introduction of composition as an additional independent variable adds a new dimension to the scope and complexity of the task of providing an adequate data base.

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 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 usually must 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 industry with comprehensive accurate data for pure compressed and liquefied methane, because methane is the most abundant component (>70%) in LNG mixtures. Thermophysical properties data for pure methane satisfactorily approximates data for LNG mixtures in some cases. The project includes acquiring thermodynamic properties data for ethane and the other pure components to permit more accurate calculations of the dependence of the properties on composition.

We have recently completed a National Bureau of Standards Interagency Report, NBSIR 73-342, Thermophysical Properties of Methane, From 90 to 500 K at Pressures to 700 Bar, by Robert D. Goodwin. This report is the final report of our work on the physical and thermodynamic properties of compressed and liquefied methane and summarizes the results obtained by R. D. Goodwin, R. Prydz, B. A. Younglove, G. C. Straty, and others of the Cryogenics Division during the period April 1970 to April 1973. This report contains the most comprehensive and accurate tables available for the thermophysical properties of pure methane. It gives numerical values for all of the technically important thermodynamic properties at temperature and pressure intervals small enough for accurate interpolation. The interpolation functions and computer programs used to generate the tables are also included. Consistency between the various tabulated properties is assured, because they have all been calculated using a single equation of state. Calculated compressibilities, heats of vaporization, specific heats, and sound velocities have been compared with all of the measured data we could obtain. This report will provide an accurate basis for calculating thermophysical properties data for LNG mixtures, in cases when it is necessary to take into account the dependence of properties data on the mixture composition.

We have also completed and published (Cryogenics, 13, 712 (December 1973)) accurate dielectric constant and Clausius-Mossotti function data for pure compressed and liquefied methane. This data will provide a data base for mass and density gauging.

7. Program and Results.

7.1 Ethane, Thermodynamic Properties Data -- R. D. Goodwin

In the past six months we have completed and published our work on the physical and thermodynamic properties of methane [1].

We now are laying foundations for computing tables of provisional values of thermodynamic functions for ethane. This activity has two purposes: to indicate those physical properties for which experimental data are lacking or inadequate, and to provide the AGA with useful results at an early date. The scope and detailed progress of this work is given in the following List of Current Reports [2-6].

We now are bringing to final form a simplified version of our unique equation of state [1]. The objective is a form free of redundancies, which is qualitatively correct in all of its derivatives. It is needed to begin our examination of PVT data for ethane (density and temperature ranges shown in Figure 1) because the high-density data of A. K. Pal are known to have systematic errors. More important, our ultimate goal is to provide a basis for work on mixtures, via an accurate, simple equation of state of identical form for each of the pure components.

List of Current Reports

[1[R. D. Goodwin, The Thermophysical Properties of Methane from 90 to 500K at Pressures to 700 Bar, NBSIR 73-342, (Cryogenics Division, National Bureau of Standards, Boulder, Colorado 80302, October 1973).

[2] R. D. Goodwin, The Vapor Pressures of Ethane, Laboratory Note 73-3, July 9, 1973. (Unpublished)

[3] R. D. Goodwin, Ethane Virial Coefficients and Saturated Vapor Densities, Laboratory Note 73-4, Aug. 14, 1973. (Unpublished)

[4] R. D. Goodwin, The Orthobaric Densities of Ethane, Methane, Oxygen and Fluorine, Laboratory Note 73-5, Sept. 18, 1973. (Unpublished)

[5] R. D. Goodwin, Liquid-Vapor Saturation Temperatures of Ethane and Methane, Laboratory Note 73-6, Nov. 28, 1973. (Unpublished)

[6] R. D. Goodwin, Unpublished formulations of the melting line and of the ideal gas thermofunctions for ethane.

7.2 Ethane, Compressibility (PVT) Data -- G. C. Straty

In the gas expansion technique used in this laboratory for accurate, absolute, compressibility (PVT) determinations, the molar volume V of a cryogenic fluid contained in a cell at temperature T and pressure P is determined by expanding the fluid from the calibrated cell into large calibrated volumes

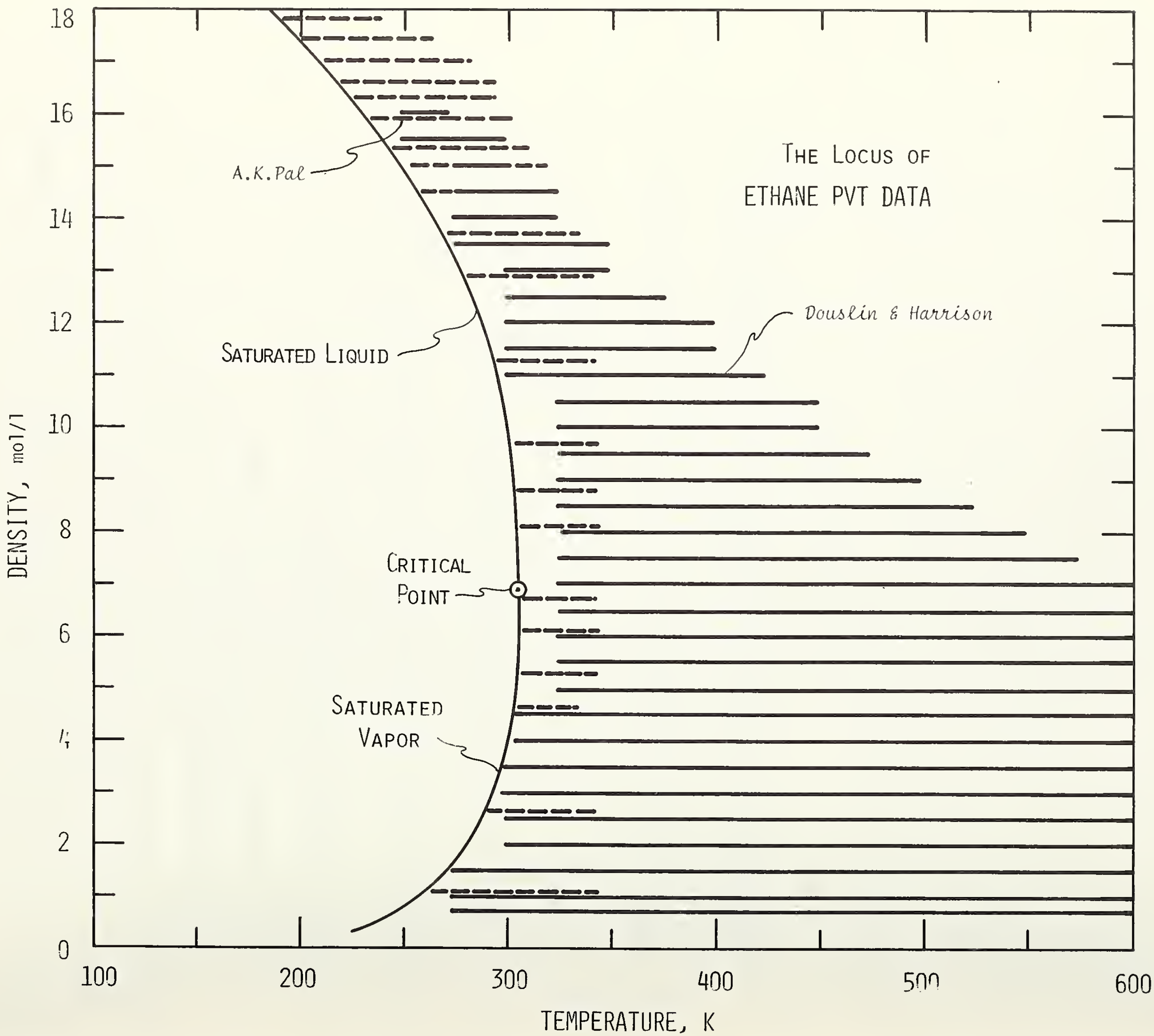


Fig. 1. Density and Temperature Ranges of Available PVT Data for Ethane.

maintained near room temperature (~295K). Using the near-ideal-gas-like behavior of the room temperature gas, the number of moles of gas residing in the total system can be computed accurately. One of the factors limiting the accuracy of this method is the ability to assign correctly the appropriate proportions of the fluid to the cell and to the various noxious volumes elsewhere in the system.

PVT measurements on ethane present an additional problem not encountered with most cryogenic fluids such as methane, oxygen, etc., because the critical temperature of ethane (305.33K) is well above room temperature. The consequence is that during many of the density measurements relatively high density liquid ethane will reside in external parts of the system and cannot be accurately accounted for in the present apparatus without some modifications.

Plans are underway to modify the PVT apparatus used previously for methane for use with ethane. Appropriate portions of the apparatus will be enclosed in ovens or provided with heaters to maintain the temperature of these parts well above the critical temperature of ethane in the various parts of the system to be made and accurate PVT data to be obtained.

7.3 Methane, Sound Velocity Data -- G. C. Straty

The ultrasonic velocities of sound in pure saturated and compressed fluid methane have been measured at MHz frequencies. Data have been obtained along the saturation boundary from near the triple point to 186K and along several isotherms from 100K to 300K at pressures up to about 345 bar. The sound velocity data have been combined with the previously measured PVT data to calculate the isentropic and isothermal compressibilities and the specific heat ratio C_p/C_v. Measurements along the compressed fluid isotherms at temperatures of 210K and above were limited to a minimum density ranging from about 14 mol/l at 210K to about 10 mol/l at 300K due to the large sound attenuation in methane. A manuscript reporting the results of the ultrasonic sound velocity measurements on methane is in preparation.

8. Problem Areas. Work on the thermodynamic properties of ethane was delayed by completion of the final report on the thermodynamic properties of methane.

As mentioned previously, our attempts to obtain velocity of sound data for methane at low densities by conventional ultrasonic means have been unsuccessful because of an abnormally large sound attenuation in gaseous methane. This large attenuation has been observed by other experimenters and has been attributed to either bulk viscosity or relaxation phenomenon.

We are now attempting to use newly constructed light scattering spectroscopy apparatus to obtain hypersonic velocity data at the lower densities. These data, although somewhat less accurate than conventional ultrasonic data, should be sufficient to verify the accuracy of the PVT data and the sound velocities obtained by direct calculation from the PVT data.

9. Funding.

Man-years Expended, July - Dec. 1973	1.0
Equipment and/or Services Purchased	$ 7,567
Total Reporting Period Cost	$66,207
Balance Remaining (Jan 5, 1974)	$28,532

10. Future Plans.

Schedule	year: 1974, quarter: 1	2
Ethane:		
analyze available physical properties data	——→	
calculate provisional thermodynamic properties data		——→
modify and test compressibility (PVT) apparatus	————	——→
Methane:		
analyze ultrasonic (MHz) velocity measurements	——→	
report ultrasonic (MHz) velocity measurements		——→

1. Title. DENSITIES OF LIQUEFIED NATURAL GAS MIXTURES

Principal Investigators. M. J. Hiza, W. M. Haynes

2. Cost Center Number. 2751364

3. Sponsor. Consortium of Energy Companies through the American Gas Association, Inc. Project BR 50-11.

4. Introduction. Accurate density data are needed for liquefied natural gas mixtures to provide a basis for custody transfer methods and equitable custody transfer agreements. This project will also provide a data base for developing accurate methods for mass and density gauging at NBS.

5. Objectives or Goals. The objective of this work is to perform accurate (0.1%) measurements of the densities of saturated liquid methane, ethane, propane, butanes, nitrogen and their mixtures, mainly in the temperature range 90-150K, at pressures to 10 atm. Measurements will be performed on six pure components, on about 60 binary mixture compositions, and on about 13 multicomponent mixture compositions.

This project will provide accurate density measurements for testing and developing methods for calculating the densities of LNG mixtures at arbitrary compositions and temperatures. 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. Methods for calculating the heating value of a large volume of liquefied natural gas require knowing its density, which in turn depends on its composition and temperature. As the compositions of LNG mixtures vary considerably depending on the source of the gas and the processing conditions, methods are needed for calculating accurate density data at arbitrary compositions and temperatures. The accuracy (0.1%) of density data is important because of the extremely large volumes of liquid involved. A systematic error of 1% in the density is equivalent to an inequity of $15-20 thousand dollars per ship load of LNG.

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 calculation methods were performed by independent professionals of established reputation.

A high precision (0.05%) magnetic densimeter (based on Archimedes Principle) was designed and constructed prior to this reporting period. Details of this work have been given in previous reports.

7. Program and Results. 1 July 1973 - 31 December 1973

The assembly of the cryostat, the sample holder and its contents, the magnetic densimeter components (support coils, servo-circuit, magnetic buoy, constant current source, sensor coils, etc.), and auxiliary measurement and control systems (pressure, temperature, sample handling and refrigeration) was completed during the past six months. Performance testing of the entire assembly at low temperatures commenced approximately a month ago.

Room temperature tests of the magnetic densimeter were completed at the beginning of this report period. During the past month several essential tests of the servo-circuit and associated parts were carried out at low temperatures. The magnetic buoy was suspended in a stable configuration at

110K in liquid methane and in vacuum with all parts of apparatus in place. Additionally, the buoy was maintained in support in vacuum, while cooling from room temperature to 105K, without making any changes in circuitry components. Only the values of the currents in the coils changed as a result of expected changes in the magnetic moment of the buoy (approx. 0.1%/K near room temp.).

The ceramic magnetic buoy, presently inside the sample holder, was ground in the shape of a right circular cylinder with chamfered edges. Its diameter and length are approximately 0.2 and 0.25 inch, respectively. The ceramic magnet has been plated with a minimum of 0.002 inch of copper over its entire surface. The copper is considerably thicker at the edges since the buoy (after plating) has no chamfered edges. Gold was flashed (2×10^{-5} inch) over the copper surface for protection.

The finished float was observed for defects under a 100 X microscope. Its length and diameter were determined to better than 5×10^{-5} inch using gauge blocks. Its mass was measured using a microbalance. Thus, the density of the buoy at room temperature was determined to better than 0.05%.

Problems with heating in the main coil have been resolved. Water-cooled copper plates were installed in close contact with each of the faces of the two layers of aluminum ribbon which comprise the main coil. By passing water (15°C) through copper coils soldered to the copper plates the average temperature of the main coil was maintained below room temperature for a current of 1 amp. (100 watts). Nominal main coil currents for low temperature measurements will be in the range 0.6 - 0.8 amp. All of the effort towards controlling the temperature of the main coil is a result of an attempt to control its position relative to the sensor coils within 0.002 mm. Additionally, for this purpose three 12 inch fused quartz rods have been employed to support the main coil at its midpoint in the cylindrical axis direction. By supporting at the midpoint, thermal expansion effects partially cancel. Quartz is used because of its low thermal expansion coefficient.

Most of the past month has been devoted to performance testing of the cryostat, the sample holder, the temperature and pressure measurement and control systems, and the refrigeration system. This performance testing has been facilitated with vapor pressure measurements on liquid methane at temperatures between 105 and 120K. A summary of the results of these tests which have led to minor changes in the cryostat-sample holder assembly is as follows:

(a) Measured vapor pressures (using platinum resistance thermometer for temperature measurements and a Texas Inst. Co. quartz bourdon gauge for pressure measurements) have been consistently higher (0.13 psi, maximum difference) than the previous results of Prydz and Goodwin[1] (the thermometer reading was lower (0.1K maximum difference) than expected);

(b) We observed a temperature gradient (0.1K maximum difference) between the liquid in the bottom of the sample cell and that in the vapor bulb (both measurements were accomplished with the same pressure gauge; sample holder is colder at bottom); and

(c) The massive sample holder was slow to react to changes in the flow rate of the nitrogen refrigerant through the heat exchanger at the top of the copper shield because of the long conduction path between the heat exchanger and the bottom of the sample holder

Steps taken to resolve these problems have been:

(a) Additional tempering of thermometer wires,

(b) additional radiation shielding between copper shield and sample cell,

(c) additional cooling directly to the top of the sample cell from the top of the copper shield (this was accomplished by copper braid cables connecting the sample holder to the shield; previously, cooling by conduction was only through the copper bellows at bottom of cell),

(d) additional heaters were wrapped tightly around sample holder at each end at points to intercept the cooling (the primary heater had previously been located on the central portion of the cell surface opposite the window),

(e) the support rod and electrical lead cable (sensor coils) have been thermally shorted to the top of the copper shield (again using copper braid cables), and

(f) a transfer line has been installed to continuously feed liquid nitrogen to the cryostat reservoir.

The results of having incorporated these new features into the system are now being tested and analyzed.

A progress report was made at a meeting of the sponsoring companies held in Boulder on 4 December 1973.

<u>Reference</u>

1. R. Prydz and R. D. Goodwin, J. Chem. Thermodynamics <u>4</u>, 127 (1972).

8. Problem Areas. Apparatus changes have been required to reduce the temperature difference between the top and bottom of the sample cell at low temperatures, to obtain accurate (0. 02K) temperature measurements, and to reduce the response time of the sample cell to the nitrogen refrigerant.

Although these changes have delayed performance of density measurements on liquid methane, it is expected that the pure component measurements will be completed on schedule.

9. Funding.

Manyears Expended, July - Dec 1973	1. 0
Equipment and/or Services Purchased	$20,197
Total Reporting Period Cost	$67, 263
Balance Remaining (Jan 5, 1974)	$35, 002

10. Future Work .

Schedule:	year: 1974, quarter 1	year: 1974, quarter 2
Perform accurate density measurements:		
pure components	——→	
binary mixture compositions containing methane		——

(completion scheduled for October 1, 1974)

1. Title & Principle Investigators: Low Temperature Material Behavior

R. P. Reed
R. L. Tobler
R. P. Mikesell
R. L. Durcholz

2. Cost Center Number: 275 0430

3. Sponsor Project Identification: Maritime Administration Project 55-300-15-011

4. Introduction:

Data on thermal and mechanical properties of structural and insulation materials are essential to facilitate material selection on the basis of cost and safety. Proper material choice is of major economic importance for cryogenic containers in the sea transport of LNG.

5. Objectives:

The objective of this program is to obtain fracture toughness and fatigue crack growth rate data in the temperature range 76 - 300 K. These measurements are being conducted on a series of Fe-Ni alloys and Al alloys.

6. Background:

To construct tanks for sea transport of LNG requires between 500,000 and 7,000,000 pounds of expensive alloys, depending on the type of tanker chosen. This large-scale consumption of costly alloys demands very careful material selection to insure economical but safe, storage tanks. Therefore, since MARAD's goal is to reduce ship costs, it is in their interest to insure the availability of relevant thermal and mechanical property data to enable the best possible selection and design.

7. Program and Results:

The materials effort in this program has concentrated on two areas, a general materials properties assessment and the initiation of an experimental low temperature tensile, fatigue, and fracture study of candidate materials. The materials properties assessment has included a compilation of all the fatigue and fracture data on Fe-Ni steels and their weldments, a collection of ship design data and an analysis of materials in use, an assessment of the current production and/or research efforts of the materials suppliers, an assessment of the current materials requirements for LNG containers by the American Bureau of Shipping, U. S. Coast Guard, and the ASME pressure vessel code, and a bibliography of literature containing data on aluminum alloys, non-metallics, and insulation materials. For the experimental program most of the materials and selected weldments have been procured; specimens have been made for tensile, fatigue and fracture tests for selected materials; a variable temperature cryostat has been built; and the experimental procedures have been proofed.

Materials Properties Assessment:

The literature data from some 60 references on the fatigue and fracture properties of the ferritic Fe-Ni steels (Ni $<$ 18%) has been extracted, critically evaluated, and compiled. The fracture data in the compilation are the impact energy; nil ductibility transition, crack opening displacement, fracture toughness, and dynamic tear tests and their dependencies on temperatures, composition, and heat treating or cold working. Fatigue data include fatigue lifetime and fatigue crack growth rates at LNG temperatures. The welding techniques and welding materials used with these steels were also considered. An assessment of the heat input and effects of stress relief for the properties of the heat-affected-zone (HAZ) has been compiled. Included are the tensile properties, hardness, impact energies, explosion bulge tests, and fracture toughness.

The entire compilation will be sent as an interagency report and included in a review article on LNG materials in the open literature. The literature references are now being collected on candidate aluminum alloys, non-metallics that have been proposed for structural use, and on insulation materials. Their extraction and evaluations will begin as soon as the acquisition is complete.

The production and research capabilities of the major suppliers of LNG structural alloys were also assessed. Direct contact was made with the research personnel of all the major suppliers to assess what work on these materials has been done or was in progress. These in-house efforts indicated are generally low level. We have attended the LNG Materials Conference at the British Welding Institute and visited Technigaz, Det Norske Veritas, and The Welding Institute to provide information about the foreign efforts in LNG materials research. We also have a member of our staff on the Cryogenic Materials for LNG Tank Applications Committee of the Metals Properties Council.

Experimental Program:

Test materials of $1\frac{1}{2}$-inch thick plate have been obtained for the $3\frac{1}{2}$, 5, 6 and 9% Ni steels and $A\ell$ 5083. Plates of Fe-5Ni are being welded by ARMCO and the Fe-9Ni welding has been arranged with Chicago Bridge and Iron. Specimens will be made from these materials upon return. All efforts have been made to have the welds be as characteristic of actual fabrication as possible.

A cryostat for variable temperature control around LNG temperatures has been designed and built. The experimental procedures, including J integral test techniques, have been evaluated and prove satisfactory. All the auxiliary load cells, x-y recorders, oscilloscopes, etc. are functional. New methods have been devised to monitor the crack growth and crack opening. Tensile measurements and pre-cracking of fatigue and fracture specimens have begun and are proceeding routinely.

8. Problem Areas:

Some delay has been experienced in obtaining Fe-9Ni and Fe-$3\frac{1}{2}$ Ni alloy thick plate from the suppliers. Currently, we have been assured that these materials will arrive during January.

9. Funding:

During this reporting period, about $35,000 has been spent. This leaves $115,000 for concentrated research during the next reporting period.

10. Future Plans:

Next 3 months:

The fatigue and fracture toughness properties of Fe-5 Ni (heat treated), Fe-6 Ni (heat treated) and Fe-9 Ni will be measured at 300, 195, 111 and 76 K. Specimens will be prepared for 5083 Aℓ, Fe-$3\frac{1}{2}$ Ni, and Fe-5 Ni (welded).

Following 3 months:

The fatigue and fracture toughness properties of 5083 Aℓ, Fe-$3\frac{1}{2}$ Ni, and Fe-5 Ni (welded) will be obtained at 300, 195, 111, and 76 K. A report will be written describing test results.

1. Title and Principal Investigators. Heating Value of Flowing LNG - J. A. Brennan and R. J. Richards.

2. Cost Center Number. 2750361

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

4. Introduction. This project will draw on information and facilities generated by other sectors of the NBS LNG effort. Thus the calibration of a densimeter used will be traceable to the NBS density reference system being constructed by Younglove under cost center #2751361. Mixture density data produced under #2751364 by Haynes and Hiza will also provide a necessary input to the proper interpretation of results.

5. Objectives. The original objective of this program was to set up a LNG flow facility and to evaluate selected flowmeters in LNG service. In November 1973 the objective was expanded to demonstrate the accuracy of measurement of the heating value of LNG flowing in a pipeline through integration of state-of-the-art instrumentation for flow, density and heating value. The expanded project has been conceived of in a three year time frame. In the first year individual components will be calibrated and installed in the NBS LNG flow facility.

6. Background. The need for accurate flowmetering of LNG provided the original impetus for the work in this program (unpublished NBS Report [1972], NBSIR 73-300). Since liquid natural gas may be sold on the basis of heating value the program was broadened to include the necessary instrumentation for determining heating value of LNG, this expanded program to commence early in 1974. The objectives are based on scaling small flowmeters capable of laboratory testing up to full line size components. Appropriate intermediate sizes are included with field tests scheduled as part of the overall project.

7. Results. A portion of the funding for the program during this reporting period was designated for the installation of a refrigerator in the LNG flow facility. The installation has been completed and consists of a bath type heat exchanger in the flow line downstream of the meters. Figure 1 is a photograph of the flow line that was placed inside the dewar shown in figure 2. Liquid nitrogen is used as the refrigerant. Constant temperatures can be maintained in the flow line by adjusting the amount of liquid nitrogen in the heat exchanger. Tests have been successfully conducted at constant temperatures ranging from 103 to 120 K.

Technical content and planning of this program is determined at meetings of the PRC Supervisory Committee. At the August 14, 1973, committee meeting discussions were held with a representative from the manufacturer of the 1-1/2 inch vortex meter previously tested in this program. The purpose of this discussion was to find an explanation for the large bias obtained [NBSIR 73-300]. No explanation could be found so it was decided to verify the meter K-factor (pulses/gallon) in water at NBS-Gaithersburg, Maryland. It was decided to determine the K-factor of a 2 inch meter of the same type also. If the 1-1/2 inch meter K-factor in water were close to the value predicted based on the liquid nitrogen data then all future tests would be on the 2 inch meter.

The results of the water and liquid nitrogen calibrations are shown in table 1. Three different meter error values are also shown in table 1. These values were determined respectively by:

(1) calculating the error between the specified and the actual water K-factor

(2) correcting the manufacturers K-factor for temperature and calculating the error between that value and the actual liquid nitrogen K-factor

(3) correcting the actual water K-factor to liquid nitrogen temperature and calculating the error between that value and the actual liquid nitrogen K-factor.

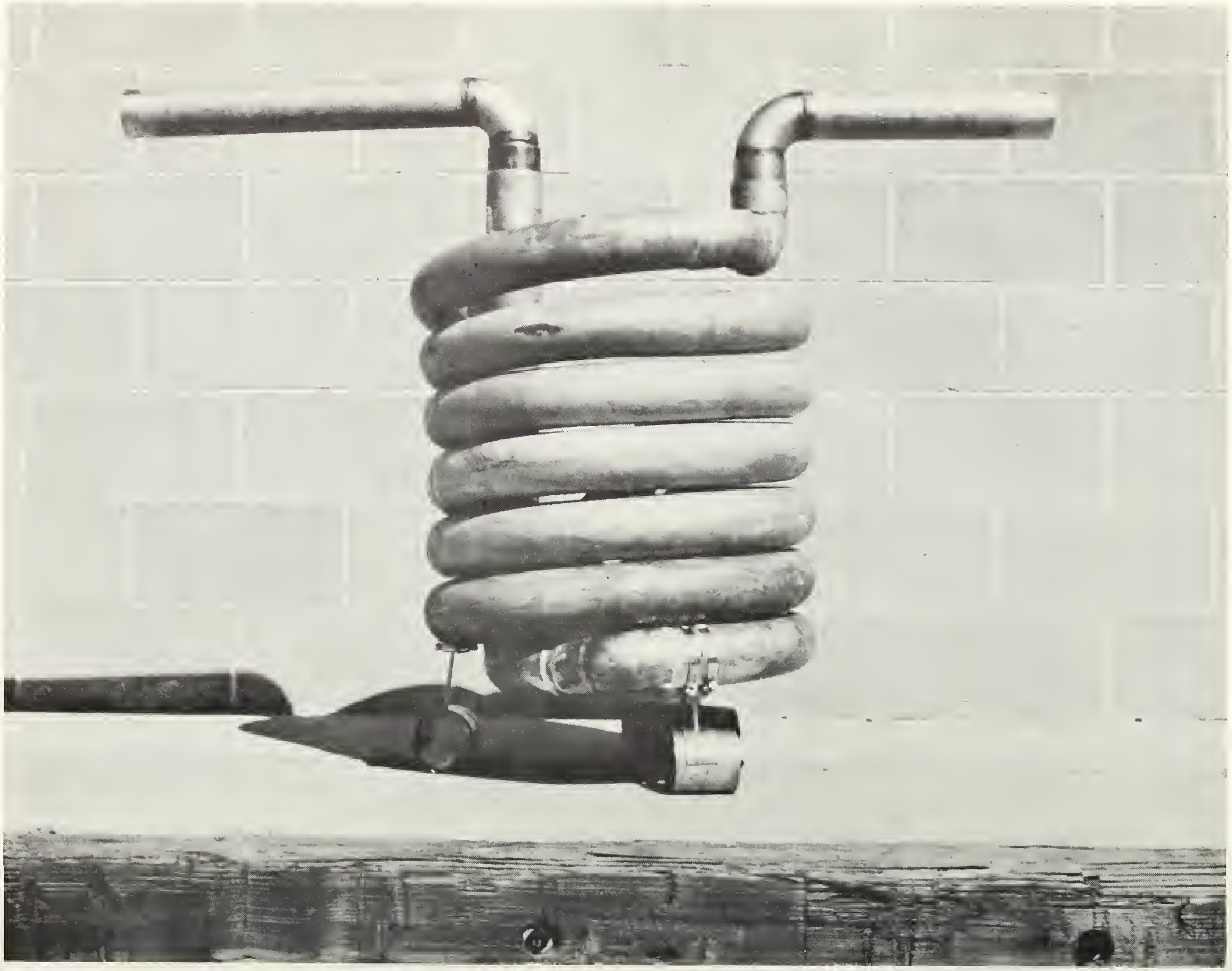


Figure 1. Heat exchanger coil.

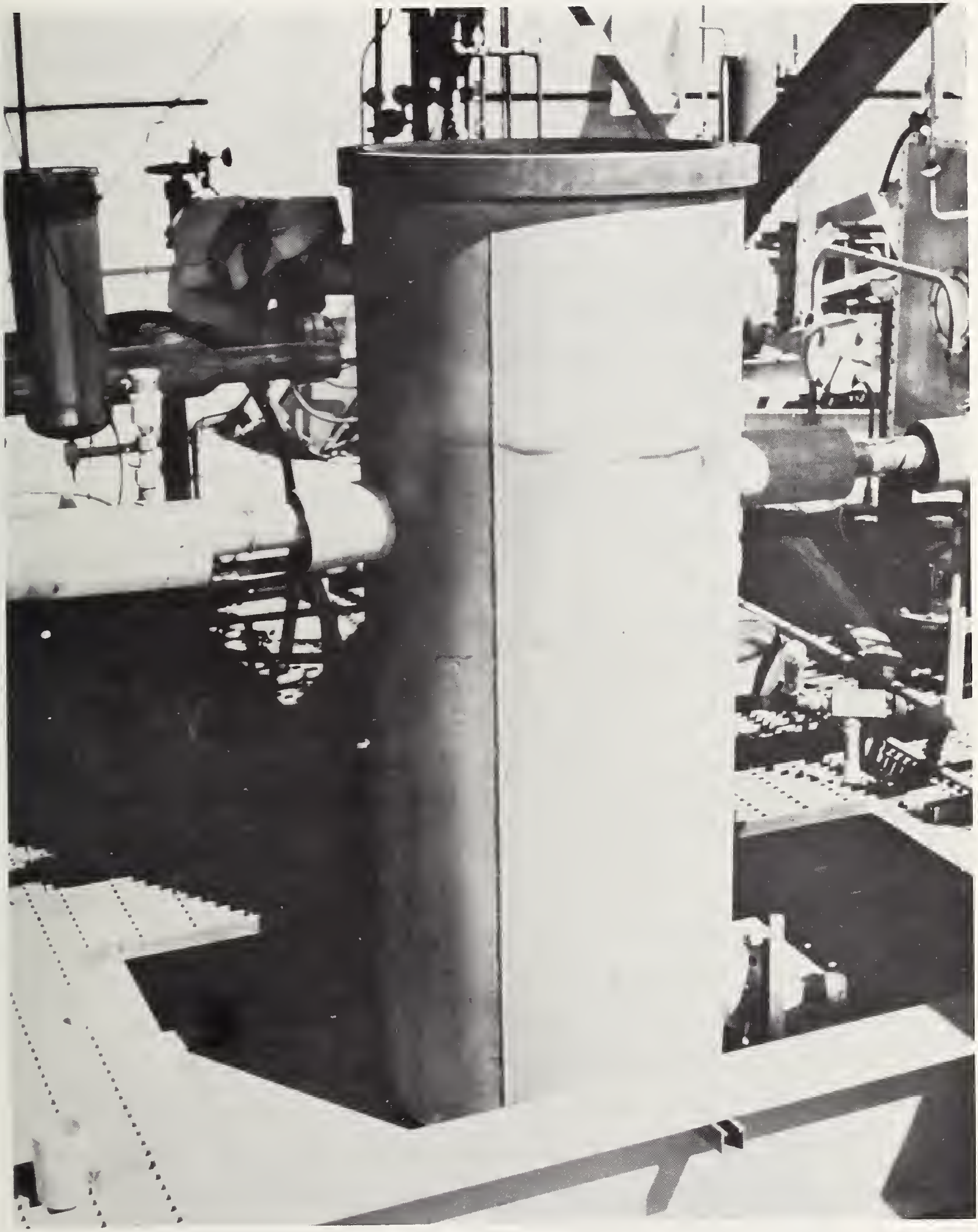


Figure 2. Heat exchanger dewar.

Table 1. Meter Calibration

Meter Size (inch)	Manufacturers Specified Water K-factor (pulses/gal)	Measured Water K-factor (pulses/gal)	Error (%)	Manufacturers Specified LN_2 K-factor (pulses/gal)	Measured LN_2 K-factor (pulses/gal)	Error (%)	LN_2 K-factor from Water K-factor (pulses/gal)	Error (%)
1-1/2	267.59	254.35	5.21	270	254.97	5.89	256.64	0.65
2	116	117.44	-1.23	117.04	119.27	-1.87	118.51	-0.64

All of the liquid nitrogen data used in determining the error values was obtained on the NBS nitrogen flow facility [NBS Tech. Note 606, 1971].

The error figure in table 1 (last column) results from the best available method of predicting meter performance at this time. No conclusive statements can be made about the difference between the two numbers since the sample size (i. e. 2 meters) is so small. Also the 1-1/2 inch meter is not made using the same scaling laws as are used with the 2 inch and large meters. Therefore, conclusions regarding the appropriateness of various K-factor prediction methods must await additional data on other meters. Another meter will be tested during the next reporting period and the results will be used to further check the prediction methods.

The measured meter K-factor is shown in figure 3. Each water data point represents the average of five individual measurements taken over a period of two days. The liquid nitrogen data points are individual measurements, not averages, and were all taken on one day in the liquid nitrogen flow facility.

The 2 inch meter was also tested in the LNG flow facility with liquid nitrogen and liquid natural gas. Figure 4 shows the results of both the liquid nitrogen and the LNG tests. Here again each data point represents an individual measurement. In figure 4 the meter performance is shown as a deviation, in percent, as a function of volume flow rate. The deviation shown is the deviation of the vortex meter from a turbine meter. The vortex meter was installed in series with the turbine meter but was several feet downstream. This arrangement does result in the vortex meter having slightly less dense liquid flowing through it as compared to the turbine meter. The effect of the density difference results in a positive deviation between the meters and may account for most of the apparent positive bias shown in figure 4. Although minor refinements of the data are possible as time goes on and more data are obtained, it is not expected that further data analysis will materially change the overall results shown in figures 3 and 4.

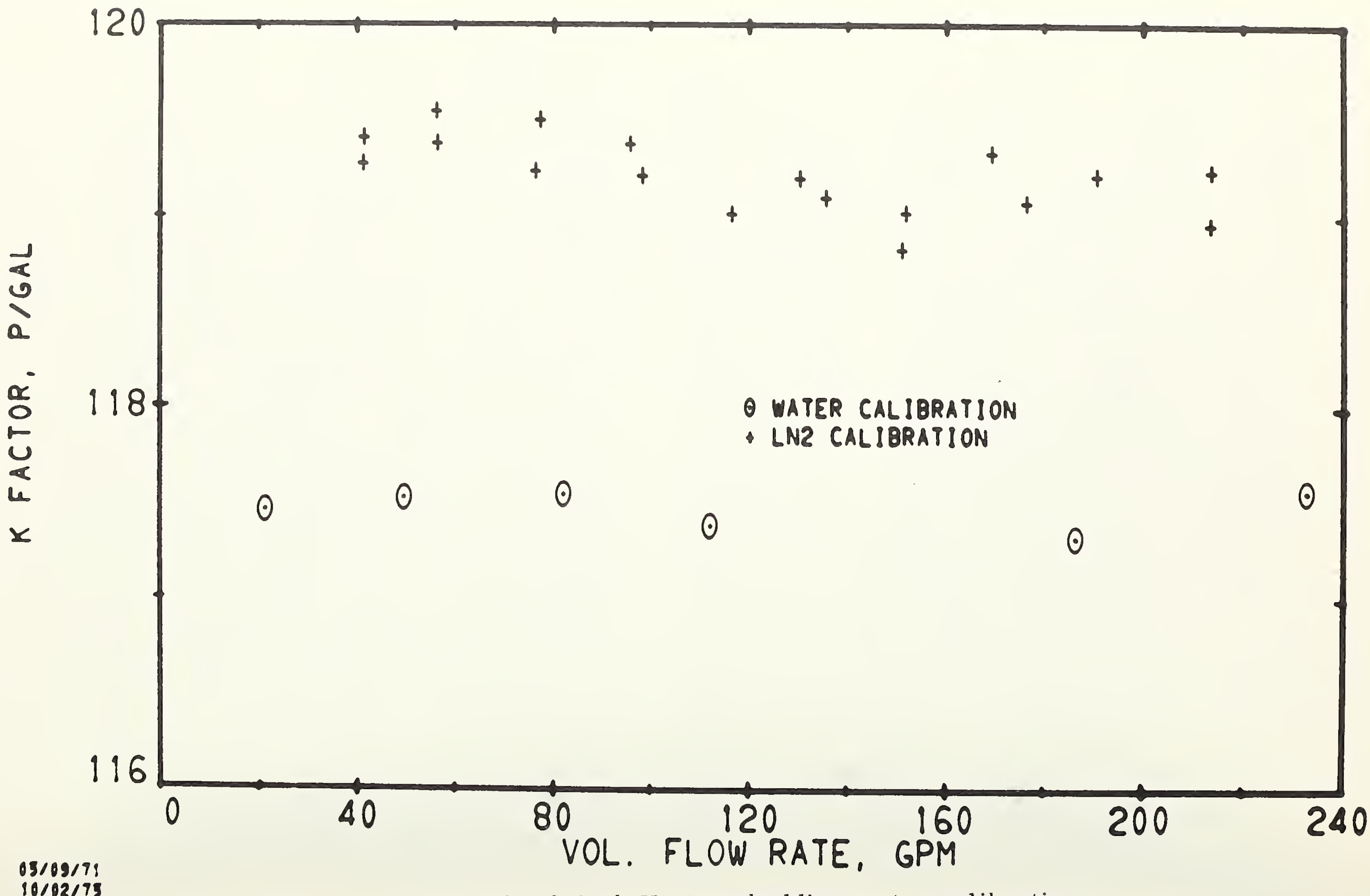


Figure 3. 2-inch Vortex shedding meter calibration.

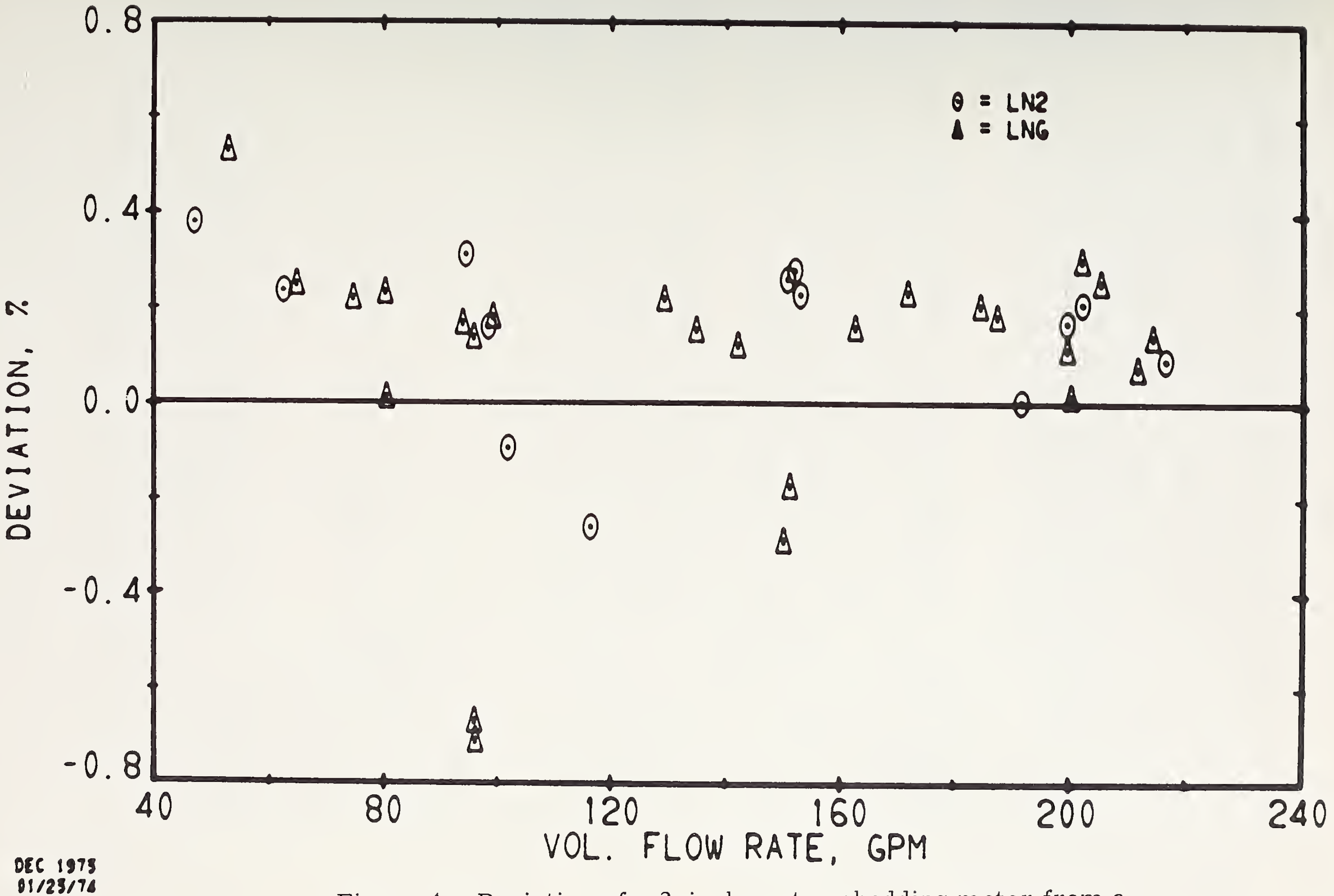


Figure 4. Deviation of a 2-inch vortex shedding meter from a 2-inch turbine meter, LNG facility.

One minor operational point which must be considered in using the vortex meter in various liquids is the vortex counting sensor. The meter used in the tests reported here incorporated a thermistor sensor and it was necessary to have two thermisters of different electrical characteristics to cover the temperature range of the three fluids - water, liquid nitrogen and LNG. The same sensor was used in liquid nitrogen and LNG but an adjustment in the electronics was necessary. This adjustment is easily made but is very important and must be performed with care.

8. Problem Areas. The amplifier used in the load cell output circuit (weigh system) of the LNG flow facility has failed, so tests are limited to comparing one meter to another. Before replacing the amplifier a determination will be made on the effectiveness of changing the method of read out. If the system can be upgraded by modifying the present arrangement then the amplifier replacement will be worked into the modifications.

Flow control at low flow rates continues to be a problem. Better control could be obtained by changing the flow characteristics of the control valve. If the valve stem and plug are removable a modified unit will be installed.

At this time we do not expect these problems to significantly perturb our schedule.

9. Funding. (as of 1/19/74)

Man years expended	0.3
Value of equipment purchased (no major purchases)	
Total cost (1973)	35 K$
Balance on hand	0

10. Future Plans. An expanded program designed to incoporate the results of current experiments into a heating value measurement system for flowing LNG will start early in January 1974. This expanded program (funded at a 2-man-year level by PRC) has been divided into the following four separate tasks:

(1) Flowmetering

(2) Densimetry

(3) Calorimetry

(4) System integration

Table 2 lists the expected progress in each task during the next reporting period.

Table 2.

Program Schedule

Task	First Quarter	Second Quarter
Flowmetering	1. Purchase 4" meter. 2. Calibrate 4" meter on water.	1. Calibrate 4" meter on liquid nitrogen.
Densimetry	1. Purchase densimeter. 2. Assemble calibration equipment.	1. Calibrate densimeter statically on pure liquids methane, ethane, propane, and nitrogen.
Calorimetry	1. Secure calorimeter.	1. Install calorimeter at LNG facility.
System integration	1. Install flowmeter in LNG facility.	1. Install densimeter in LNG facility.

1. Title and Principal Investigators. LNG Density Reference System - Ben Younglove.

2. Cost Center Number. 2751361

3. Sponsor Project Identification. AGA-LNG-Density Reference System

4. Introduction. The emphasis of the LNG effort of NBS is in providing technical support to industry in meeting the energy needs of our economy with natural gas.

The density reference system will evaluate the ability of commercially available instruments to measure densities of LNG. Density is an essential measurement in performing total energy content determinations of natural gas reservoirs. While this effort is oriented towards metrology the output from cost center 2751364 will provide basic reference data on pure liquids and mixtures which will serve as density standards.

5. Objectives. This research will provide a system for evaluating density measurement capability of commercially available meters. We will evolve a density reference system capable of generating accurate densities for this evaluation. From the commercial meters we will attempt to select one capable of performance as a transfer standard in order to provide traceability of accuracy to field density measurement systems.

The first year will be devoted to construction and testing of the density reference system. In the second year we will concentrate on evaluation of commercial meters while the final year will involve selection testing and application of the transfer standard.

6. Background. In early 1973 a proposal was made to the American Gas Association for research in several areas of LNG technology to be done at this installation. Part of this program was the density reference system. Initital scheduling indicated for the first year of work, starting in April to be design, fabrication, and testing of a density system. Work actually commenced in August as a result of staffing difficulties. Since this initiation, we have conducted extensive study on the feasibility of various techniques for such a system

deciding finally on an application of Archimede's principle (see 7. below). Construction has begun on the various components of the system and the automatic weighing head plus a precision gas balance for mixture determination are on order.

7. Program and Results. After an extensive study of various methods of density measurement the approach was chosen of using the results of the Densities of Liquefied Natural Gas program (cost center 2751364) as primary source densities. A density monitoring device to be installed in the actual density reference system will provide a more immediately available source of accurate densities. The performance of the density monitor will be evaluated using the results of the NBS Densities of LNG program as they become available. The density monitoring device will be a weight by immersion device (Archimede's principle). The weight of a piece of single crystal silicon (density 2.32900 g/cm^3 at 25°C and 1 atmosphere) will be determined for the conditions of no buoyant force (vacuum). For the temperatures of interest this will be used with the weight of the silicon in the actual test liquid and with the computed density of silicon under the appropriate temperature and pressure to determine the density of the liquid mixture.

The device or devices under evaluation will be immersed in the same liquid at the same time and in close proximity to the density monitor. A measurement of temperature, pressure, and mol fraction of the constituents will allow computation of density from the NBS Densities of LNG program. The continuous reading of monitor weight will signal the attainment of equilibrium.

Accurate measurements of density will also require several auxiliary parameters be measured such as temperature, pressure, and volume of the gas spaces above the liquid.

Work has started on parts required for the construction of the density reference system. An accurate and automatic weighing head for the density monitor has been ordered. This weighing head should have an overall accuracy of 0.001 gram and a dynamic range of 20 grams. It will be self-balancing and have an automatic readout. Internal counterbalancing will allow the silicon crystal to be 125 grams.

A weight loader has been built which will allow loading known weights onto the density monitor balance under actual operating conditions so that its performance can be periodically verified. The loader will also allow loading onto the balance, two weights of equal mass but different densities so that the gas density in the volume about the balance, can be measured. This is one of the auxiliary variables necessary in accurate density determination.

A high precision gas balance, needed for preweighing of the constituents of the test mixture, has been ordered. This balance is capable of weighing 50 kg to high accuracy.

We have been in contact with several field densimeter manufacturers who will be providing meters for our evaluation and expect delivery of the first meters for testing soon.

8. Problem Areas. As mentioned under 6. above work began late on this project and the principal investigator has now completed six months of work on it. At this point we see some minor delays caused by long delivery times of some purchased equipment, but within the usual uncertainties of prediction of research task duration, we feel that the originally proposed first year objectives will essentially be met by 1 August 1974.

More serious is the fact that the construction of the density reference system appears to be costing more than originally estimated. Thus, based on the current costs in 9. below and our projections, we feel that our expenditures in the next six months will bring the total to between $80,000 and $85,000 instead of the original $60,000 estimate for the first year's work. Apart from the usual inflation rate this is probably due to the need to build a slightly more sophisticated apparatus than originally envisioned and to unforeseen purchase costs, primarily the high precision gas balance, the cost of which ($9624) is being shared equally with cost center #2751364.

9. Funding. (as of 1-19-74)

Man year expended	0.5 approx.
Value of equipment purchased	7,900
Total Cost	37,358
Balance on hand	22,642

10. Future Plans. First three month period. Continue construction of cryostat, sample holders, cooling system, vapor pressure system, temperature and pressure measuring systems and associated measuring systems. Construct container for the weighing head. Take delivery of weighing head. Test density monitor balance with silicon weight in liquid water to verify behavior in liquid of accurately known behavior.

Second three month period. Complete construction of cryostat cooling system, etc. Depending on progress made at this time, make preliminary test of monitor with liquid nitrogen.

1. Title. Liquefied Natural Gas Technology Transfer
   Principle Investigator. D. B. Mann

2. NBS Cost Center. 2750401

3. Sponsor Project Identification. Maritime Administration, Project 55-330-15-011.

4. Introduction. The NBS support of the Maritime Administration (MarAd) LNG ship program is divided into two areas under a common contract. These are an experimental program (NBS Cost Center 2750430) and the subject cryogenic technology transfer. In addition to those objectives listed below this program provides a cohesive structure for the coordination of the NBS LNG program.

5. Objectives. Cryogenic Technology Transfer is designed to provide cryogenic technical information, data, and advice to the Maritime Administration (MarAd), its contractors and other agencies performing work of interest to, or for, MarAd in the design, development, testing, construction and operation of LNG ships and ship components.

6. Background. The Merchant Marine Act of 1970 restructured federal maritime policies to make bulk carrier vessels, such as tankers and LNG ships, eligible for construction and operating subsidies. In December 1973 the keel was laid for a 926 foot long LNG vessel carrier at Quincy, Mass. The keel laying initiated the construction of the first LNG tanker to be built in the United States. American ship builders have orders for a total of 13 of these complicated ships. Various future projections indicate a total of from 25 to well over a 100 ships will be required to handle LNG importation within the next 10-15 years. LNG marine technology is presently foreign dominated. As a matter of fact, many of the ships being constructed in U. S. shipyards are using designs under license from foreign industrial

groups or governments. LNG is a cryogenic fluid and the massive technology developed over the past 15-20 years in cryogenics as applied to industrial gases and the aerospace effort provides a resource which could be applied profitably to improving the U. S. competitive position in the construction and operation of LNG shipping. Because of its historical association with broad based cryogenic technology over a period of 20 years, the NBS Cryogenics Division was requested to provide support to the MarAd LNG ships program in order to aid in the transfer of cryogenic technology where it could enhance the effectiveness of maritime LNG shipping. Therefore, on April 17, 1973 we submitted a work statement which was confirmed by the establishment of a program in May.

7. Program and Results. (1 July to 31 December 1973) In the initial phases of the LNG Cryogenic Technology Transfer program emphasis was placed on establishing the level and degree to which we could interface with MarAd, MarAd research centers (NMRC), and MarAd contractors. Progress therefore is measured as specific responses to MarAd and MarAd contract requests and NBS generated output felt necessary for the overall program.

7.1. Data and Information - LNG. In order to establish the degree of existing knowledge in this specialized field of LNG, a series of literature searches have been made utilizing the NBS Cryogenic Data Center Data Retrieval System. This system contains over 80,000 references on cryogenic subjects. Searches of this reference system have resulted in six bibliographies on the properties of solids, a bibliography on liquefied natural gas processes (general), a bibliography on liquefied natural gas processes (selected subject matter), a bibliography on methane and a bibliography on methane mixtures. (See references 1-10)

These bibliographies reflect the state of the art (to 1973) of liquefied natural gas and are the logical first step in establishing an LNG information center.

7.2. Mass Gauging of Spherical LNG Storage Containers. We were able to establish, in this particular case, a parallel objective to a existing NASA sponsored program for the gauging of total mass of a cryogenic fluid contained in a spherical cryogenic vessel. The technique being explored for NASA involves exciting the cryogenic container at rf frequencies and observing the change of the resonant modes with amount of mass contained within the vessel. The first step in applying this technique to maritime LNG ships was the obvious one of scaling. Therefore a simple experiment utilizing a dry, empty 50-foot diameter liquid oxygen tank was conducted. On the basis of the results of these tests, it was suggested that this device has the potential of being easily added to existing tanks for both primary and backup gauging.

7.3. Consultation. Consulting and advisory services are provided whenever needed, and we have the advantage of drawing on a variety of capabilities and experience, on short notice, for problems of limited scope. Examples of such services provided during the reporting period are (a) data and comments on a MarAd-AiResearch Corporation contract for "Maritime Closed Gas Turbine Engine Program". (b) Data, opinions and comments on MarAd-Booze-Allen Applied Research "LNG Technology and Transport Study". NBS provided a review of a portion of the contract involving risk analysis of second generation LNG ship designs. (c) Establish contact and a basis for a working relationship with the National Maritime Research Center-Galveston, Texas. Exchange visits of personnel from Boulder and NMRC-Galveston were made in August and September and a continuing dialogue is being maintained with NMRC staff to aid in their definition of program objectives. (d) Maritime Research Information Service, we are presently providing input to this service from our Cryogenic Data Center.

Details of these responses by NBS are documented in the above referenced progress report to MarAd. In addition, included in the progress report was a section outlining future activities within the present contract and a suggested scope of work which may be extended beyond the current contract period. This section is therefore a result of information developed since May 1973 which more clearly defines the position of the NBS Cryogenics Division within the MarAd program and should be considered as a guide to the content of our contributions in the near future. As indicated the progress report is presently under review by the Maritime Administration.

8. Problem Areas. Major problem area under this program is the definition of content and scope. MarAd has a number of separate current advisory studies, the results of which are necessary for defining their position in the LNG marine technology. Until these decisions by MarAd are made, NBS will continue to provide information and assistance of the type outlined above.

9. Funding. July 1 to December 31, 1973

Labor	$ 31.0 K
Other Costs	5.0 K
	$ 36.0 K
Remaining	$112.0 K

10. Future Plans. The purpose of the progress report issued in December was to define present level of effort and to suggest a structured future plan for the period 1 January to 30 June 1974. As a result no definite schedule for this period is possible until a response from MarAd is obtained.

1. Title and Principle Investigators: Federal Power Commission Consultation -- D. B. Chelton 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 will provide consultation and advisory services to the Federal Power Commission on the cryogenic safety and the design aspects of several current applications before the FPC for authorization of LNG terminal and storage facilities. These services cover 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 results and status of those facilities presently under the jurisdiction of the Federal Power Commission and subject to our review are outlined in the following table.

   Elements of the facilities that are subject to review are the land-based cryogenic storage tank components, bounded by the tanker or barge, the vaporizer and the liquefaction units (if any). These include, but are not limited to the transfer lines, the storage tanks, the vaporizers and the process piping as it interacts with the storage tanks. It is essential that the reviews cover the operation, maintenance and emergency procedural philosophies for each terminal. Based upon these studies, reports are submitted to the Staff of the FPC setting forth the technical evaluations and conclusions on each proposal. In addition, NBS may provide expert witnesses on behalf of the Staff of the FPC in any hearings on the aforementioned applications.

   Emphasis is 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 must be assessed. The basis of review includes various codes and standards, prior experience, precedent and engineering knowledge.

   A News Release issued by the Federal Power Commission entitled "FPC Authorizes East Tennessee Natural Gas to Build $10 Million LNG Facility" is attached.

7. Funding:

Total Funding FY 74	$57,000
Expenses July 1 - December 31, 1973	$20,000
Man Years of Effort	0.3

8. Future Plans. At the present time there are several pending applications, but information is not yet available. It is anticipated that additional facilities will be reviewed as applications are made to the Federal Power Commission.

FEDERAL POWER COMMISSION

NEWS RELEASE WASHINGTON, D.C. 20426

IMMEDIATE RELEASE
JANUARY 7, 1974 No. 19952
Docket No. CP73-336
East Tennessee Natural Gas Company

FPC AUTHORIZES EAST TENNESSEE NATURAL GAS TO BUILD $10 MILLION LNG FACILITY

The Federal Power Commission has issued an order authorizing East Tennessee Natural Gas Company, of Knoxville, Tenn., to build a $10,045,000 liquefied natural gas plant with an above-ground storage tank and related facilities.

The plant, to be located near Kingsport, Tenn., is designed to liquefy 5,500,000 cubic feet of natural gas daily for storage in a holding tank with the capacity equivalent of 1.2 billion cubic feet of gas and send-out design rate of 100 million cubic feet daily. A new 1,100-horsepower gas turbine compressor will be installed at a new compressor station near Bristol, Tenn.

East Tennessee plans to use the LNG facility to provide an interim and long-term supplemental winter service to its existing customers, beginning this winter.

Pending completion of the storage facility, the company has arranged to provide an interim supplemental winter service by using Chattanooga Gas Company's existing LNG storage facility during the 1973-74 and 1974-75 winter heating seasons. Chattanooga is a customer of East Tennessee.

The project will convert, by use of the LNG facilities, summer valley gas from Tennessee into LNG that can be readily stored during the summer months for subsequent regasification and delivery during the winter heating season. It can then be made available for high priority uses by existing customers.

(over)

The Commission said it recognized that there is potential danger to the public associated with storage and handling of LNG, as there is with other flammable liquids and gases. However, it said, for this particular facility in this particular location, the risk to the public's safety is not considered significant.

The National Bureau of Standards, under FPC contract, concluded that the proposed facilities constructed and operated in the manner set forth in the application "can reasonably be expected to function safely." In addition, NBS said that "all practicable care has been taken by East Tennessee Natural Gas Company and its contractors in designing a facility embodying sufficient safeguards (including appropriate fire protection and prevention systems) to eliminate or reduce to acceptable levels the impact of credible accidents."

The Commission said that an independent assessment by its own staff indicated that the type of accident that would expose the general public to greatest danger would be the quick release of all stored LNG to the diked area around the tank which, under unique meteoroligical conditions, could result in an ignitable plume of natural gas extending about a mile.

However, the Commission said, this would appear to be an extremely unlikely event. No cryogenic tanks of this type have ever failed in this manner and it is difficult to postulate how such a failure would occur, the Commission said.

However, to reduce this extremely low risk even further, the FPC is requiring East Tennessee to develop accident contingency plans, to file various safety reports with the Commission, and to comply with all pertinent Federal, State, and local safety regulations.

-FPC-

For further information
call 386-6102 (Area Code 202) DC-114

FPC CONSULTATION - LNG FACILITY REVIEW

Applicant	Location	Type Facility	Storage Facility	Status		
				Site Tour	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	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	10/30/73	Complete
El Paso Natural Gas Co.	Plymouth, WA	Peak Shaving	1-348,000 barrel 6.0 MMCFD liquefier	10/31/73	10/31/73	Complete
East Tennessee Natural Gas Co.	Kingsport, TN	Peak Shaving	1-348,000 barrel 5.0 MMCFD liquefier	**	11/29/73	Complete
Transco Terminal Co.	Bridgeport, NJ	Import Terminal	3-600,000 barrel	1/23/74	1/23/74	In Process
Southern Energy Co.	Savannah, GA	Import Terminal	4-400,000 barrel	1/24/74	Scheduled	In Process
Alabama-Tennessee Natural Gas Co.	Greenbrier, AL	Peak Shaving	1-117,000 barrel 2.0 MMCFD liquefier	**	Scheduled	In Process
Trunkline LNG, Inc.	Lake Charles, LA	Import Terminal	3-600,000 barrel	Scheduled	*	In Process
Chattanooga Gas Co.	Chattanooga, TN	Peak Shaving	1-348,000 barrel 10.0 MMCFD liquefier	*	*	In Process
Tennessee Natural Gas Co.	Nashville, TN	Peak Shaving	1-290,000 barrel 5.0 MMCFD liquefier	*	*	In Process

* to be determined
** NBS visit not scheduled

1. <u>Title.</u> LNG - Dual Fuel Auto

<u>Principle Investigator.</u> J. M. Arvidson

2. <u>Cost Center Number.</u> 2750590 (Reimbursable)

3. <u>Sponsor Identificaton.</u> Joint NBS and General Services Administration Requisition Number 0F4KE023, Case Number 66551.

4. <u>Introduction.</u> The work described relates to the general area of transfer of technology based on Division experience in the handling of liquefied combustible gases, instrumentation and systems analysis.

5. <u>Objective</u>. To establish the degree of hazard to passengers and auto on the release of liquefied natural gas in the trunk area of the standard GSA dual fuel (natural gas and gasoline) sedan.

6. <u>Background</u>. The General Services Administration (GSA) dual fuel automobiles are equipped to run on gasoline or natural gas. In the initial GSA program the natural gas was compressed and carried in high pressure cylinders, which in sedans were located in the trunk space. To take care of accidental leakage, a large vent was installed in the roof of the passenger compartments, with two small air vents installed in the top of the trunk space. More recently, most of the dual fuel installations have been installed with liquefied natural gas (LNG) carried in an insulated tank at low pressure in the trunk compartment.

Natural gas has a density less than air and therefore is buoyant and will rise at temperatures above about 151 K. It was anticipated that vents provided would be adequate for dilution of explosive concentrations of methane gas in the trunk and passenger compartments under conditions of operation. This was believed to be the case even if very cold gas was vented (at a temperature of less than 157 K) as the amount of the methane gas vented at this lower temperature would be minimal, would be heated rapidly above 157 K and then vented normally.

A recent explosion of a sedan, believed to be caused by migration of methane gas from a trunk area to the passenger area - raised the question of the functional adequacy of the high level vents. In other words, can a combustible mixture of cold methane gas (at a temperature of less than 157K) migrate from a leakage area in the trunk to the passenger compartment, and if so, can additional venting, relocation of vents, or other methods be incorporated in the sedan to eliminate this hazardous situation?

GSA has requested the Cryogenics Division of NBS to perform tests, analyze data, and make recommendations for the modification (if any) to be made in the vent system or any other aspect, method or design that would minimize the concentration of methane gas (or LNG vapor) in the trunk or passenger area to well below the lower explosion limit (at least to 50% LEL).

7. Program and Results. (1 July - 31 December 1973) In response to the request from GSA a work statement was prepared on September 7, 1973 and an inter-agency agreement between NBS and GSA was authorized by GSA on the 4th of October 1973.

On September 26, 1973 a GSA furnished dual fuel automobile was delivered to NBS Boulder. The vehicle was a 4-door sedan, license number G11-50627. The vehicle was driven from San Diego, California by Mr. Cruz J. Avila, who is maintenance manager of the San Diego Motor Pool. The vehicle had 33,933 miles on it and was in good condition.

Two modifications were made to this vehicle on the LNG system that are unlike the accident vehicle: (1) a fill and vent line connection cap with a plastic tube vent to outside the vehicle and (2) the air cleaner for the engine has been placed on the opposite side of the engine (right) and the intake duct has been extended. This was done in order to make room for the additional valves and switches included in the modification kit.

Prior to testing, the car was placed in an outdoor test site. The windshields (front and back) were removed; battery was removed; side windows were rolled down; the vehicle was electrically grounded; and all openings were sealed with a double layer of approximately 6 mil plastic. The gas tank, LNG tank and carburetor were emptied and purged with gaseous nitrogen. The roof vent of the vehicle was shielded from minor air currents by a four-sided box (open at the top). It was shown during the tests that the placement of this shield had no influence on the experimental data. A purge and methane injections system was designed to provide a precise flow of methane into the trunk area. To initiate the test, a pre-determined amount of methane, at various flow rates and temperatures (ambient, 200 K and 121 K) was released into the trunk space at the fill-vent line location and allowed to diffuse into the rest of the vehicle. A combustible gas detector, thermocouple power supply, recorder and other instrumentation were located in an instrument shack approximately 20 feet from the test car. Sample tubes from within the vehicle were run to the combustible gas detector. These tubes consisted of copper tubing (3/8-inch diameter) in 50-foot lengths to insure that all sensing points had equivalent response times. Eight sample points were located within the vehicle on a plane running through the vertical center line. Samples were taken above the front seat at roof level, at chest level in the front seat and at floor level in the front seat. Additional samples were taken at the inlet to the roof vent, chest level of the back seat and floor level in the back seat. Two sensors were located in the trunk area, one at floor level and one above the LNG tank.

All sensing locations were equipped with thermocouples at approximately 1/4-inch from the inlet end of each tube. They were installed primarily for low temperature methane testing to determine whether the cold gas migration will occur at floor level. As each test progressed, a strip chart recording of the gas concentration and temperature was made. A liquid nitrogen cooled heat exchanger was used to pre-cool the gaseous methane for low temperature tests.

Calibration of the combustible gas detector was performed as recommended by the manufacturer and, in addition, by use of a water displacement, 5% mixture of methane and air (100% LEL). At periodic intervals throughout the entire testing program, both methods of calibration were employed to insure instrument reliability.

Detailed results of the testing have been compiled in a preliminary progress report that was sent to the sponsor (GSA) on December 21, 1973. In summary, three flow rates of methane (0.5, 0.24, and 0.15 scfm) were introduced into the vehicle in the trunk area at the fill and vent of the LNG tank. In each case, a total volume of from 8 to 15 scf of methane was used. These flow rates were repeated for three different temperatures (ambient, 200 K and 121 K).

As a result of these tests, it was shown that hazardous conditions can exist at various locations within the vehicle; their degree depending on variables such as methane flow rate, total volume of gas released, vehicle disposition (stationary or moving), etc. For most cases the LEL was reached quickly. After the flow of methane was stopped, the concentration rate of decay was very slow. It was surprising to note that for some tests over 40 minutes was required for the concentration level of methane to fall below the LEL. No significant differences were found between the circulation and diffusion characteristics for ambient, 200 K and 121 K methane. Within the limits of reproducibility the test results at all three temperatures may be compared independent of methane inlet temperature. Thermocouples located at the sensing points also show essentially no change in temperature within the test vehicle.

Review of the progress report by the sponsor is still in progress.

8. Problem Areas. It was assumed that the most hazardous condition under which the vehicle would operate with liquefied natural gas as a fuel would be when the vehicle was stationary and closed (windows, doors, etc.) for an extended period of time. Although the reproducibility of the tests was remarkable, it was determined that slight wind conditions in the neighborhood of the car could effect the test results. Future testing in a controlled environment should improve test reproducibility.

The method of sampling the car interior for combustible gas mixtures involves continuously removing the sample during the period of test. This was a function of the particular type of combustible gas analyzer used in the test. A combustible gas detector having the sensor detectors located at the sample point has been ordered and received, but the testing of this method of sampling has not been completed at this date. A comparison should be made to show the validity of the sampling technique.

9. Funding. This was a cooperative effort between the National Bureau of Standards and the General Services Administration.

Labor	$ 8.5 K
Other	2.5 K
	$10.5 K

10. Future Plans. Preliminary discussions with the sponsor indicate that they desire to continue the investigation and a program is being outlined to improve the venting characteristics of the sedan.

NBS-114A (REV. 7-73)

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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.)*

Fourteen cost centers supported by six other agency sponsors in addition to NBS provide the basis for liquefied natural gas (LNG) research at NBS. This integrated progress report to be issued in January and July is designed to:

1) Provide all sponsoring agencies with a semi-annual and annual report on the activities of their individual programs.
2) Inform all sponsoring agencies on related research being conducted at the Cryogenics Division of NBS-IBS.
3) Provide a uniform reporting procedure which should maintain and improve communication while minimizing the time, effort and paper work 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)*

Cryogenic; liquefied natural gas; measurement; methane, properties; research.

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American Gas Association
1515 Wilson Boulevard
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LNG Density Project Steering Committee
(in cooperation with the American Gas Association)

Pipeline Research Committee
(American Gas Association)

Federal Power Commission
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Washington, D. C. 20426

General Services Administration
Motor Equipment Research & Technology Division
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U. S. Department of Commerce
Maritime Administration
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