DOE/CH/10984

Final Report

on the

Development of a Liquid to Compressed Natural Gas (LCNG) Fueling Station

for

The Department of Energy
Contract No. DE-AC02-99CH10984

prepared by

CVI
A Division of CHART Industries
Columbus, Ohio

June 30, 1999

This report satisfies the requirements of DOE contract DE-AC02-99CH10984, paragraph 2A.

DISCLAIMER

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Acknowledgments

This program was performed under the auspices of the Department of Energy (DOE) and the Brookhaven National Laboratory (BNL). The DOE contracting officer was Mr. Keith Adkins of the Chicago Operations Office. The DOE contracting officers technical representative was Ms. Patrice Brewington also with the Chicago Operations Office.

The BNL technical representative was Mr. James Wegrzyn located in Upton, New York.

Work was performed by CVI located in Columbus, Ohio. CVI's program manager was Mr. John Bonn while Mr. Joseph Moore acted as Project Engineer.

Installation services were provided by Hughes Electric.

The underground LNG fueling station utilized by this effort for the installation and demonstration phase of the program was contributed by Waste Management at the W.H. Martin landfill site in Washington, Pennsylvania. Special recognition is given to Mr. Ben Woods, Mr. Jerry Simmons and Mr. Dave Long for their efforts and cooperation without which this program could not have been successfully completed.

Table of Contents

1.0 Program Objective and Background

This program had as its objective the development and demonstration of equipment and processes to produce compressed natural gas (CNG) from liquefied natural gas (LNG) for heavy duty vehicular applications. The interest for this technology is a result of the increased use of alternative fuels for the reduction of emissions and dependancy on foreign energy. An abundant source of natural gas is available in the United States. Technology of the type developed under this program is critical for establishing natural gas as an economical alternative fuel.

CNG has been in use as an alternative fuel for some time, however, several problems prevent its widespread use. First is the available infrastructure for refueling natural gas powered vehicles. Current refueling stations are large, costly and expensive to maintain. Second is the time required to refuel a typical CNG fuel tank requiring several hours to realize a complete fill using a standard cascade system. Third, although intangible, are the aesthetics of a typical CNG refueling station where large compressors, high pressure gas storage containers and complicated piping and control systems present the public with a "high technology" impression thus slowing acceptance of CNG as a common vehicular fuel.

CVI has developed technology for refueling heavy duty vehicles with LNG. More specifically, a refueling station was developed that stored the LNG in underground cryogenic tankage thus making the storage tank essentially the same as gasoline tanks, i.e., not in view of the public and thus more transparent. This had the additional benefit of reducing the area required for the equipment due to reduced setback distances from buildings and property lines required by fire regulations. Additionally, the location of controls and critical safety devices below grade provides for enhanced safety. This station has the capability of fueling LNG at a rate of up to 60 gallons per minute at a delivery pressure of up to 300 psig. The LNG saturation pressure can be increased by as much as 100 psi during the transfer process from storage tank to vehicle tank using an electric heater. This is sometimes called "on-the-fly conditioning". The system provides a single hose fill and a simple control panel for user operation. The dispenser is the only device that is visible in the fueling area.

CVI also has as a standard product a high pressure cryogenic liquid pump capable of producing up to 6000 psig at discharge. A logical extension to the underground storage technology developed in the effort just described would be to adapt the high pressure pump to the underground storage to generate high pressure LNG that could be warmed to ambient temperature then delivered to a dispenser for fueling CNG powered vehicles. Storing and pressurizing LNG as compared to CNG has several benefits. First, LNG is significantly less expensive than the equivalent energy volume of pipeline gas. Second, it is far more efficient to pump liquid to pressure than to compress a gas. It requires nearly an order of magnitude more energy to compress methane gas to the same pressure as compared to its energy equivalent incompressible liquid form. Third, the equipment required to pressurize the cryogenic liquid is far less costly both in terms of capital expenditure and maintenance costs. Fourth, fuel is stored as a low pressure liquid with high pressure gas made on demand rather than storing large amounts of high pressure gas resulting in an inherently safer station. Fifth, the fuel made from LNG is significantly more pure thus eliminating the deleterious effects of moisture and heavy hydrocarbons on vehicle engines and/or reducing or eliminating the equipment required to extract these contaminates from the fuel.

This program seeks to demonstrate the benefits just described by developing technology that will produce CNG from LNG.

2.0 Program Approach

The general approach of the program was to develop an extended high pressure cryogenic pump that is capable of producing discharge pressures on the order of 4000 psig by adapting current technology that exists at CVI. This pump would be placed in an existing underground LNG storage tank and used to pump the stored LNG to high pressure. The high pressure liquid is piped to a vaporizer that utilizes ambient air as the heat source to warm the LNG to a gas near ambient temperature. The warm gas is then piped to a standard, commercially available CNG dispenser.

Since LNG is not odorized, a commercially available odorant injection system was used to inject standard odorant into the high pressure warm gas line exiting the vaporizer, prior to reaching the dispenser.

Large high pressure storage cylinders are not required as the high pressure gas is produced on demand by the pump from LNG. Instead a relatively small volume of storage, typically called a buffer storage system, is provided to absorb boiloff gas that is left from the warming of LNG left within the piping and vaporizer after the filling cycle is complete. This buffer volume prevents the required relief devices from opening during normal operation thus minimizing any loss of fuel.

A Process and Instrumentation (P&I) diagram is shown in the Appendix that describes the process. A plan view of the physical arrangement (General Arrangement) of the major system elements integrated within an existing underground LNG fueling station is also shown in the Appendix. This station is located at the W.H. Martin landfill site owned by Waste Management in Washington, PA and is the location where the equipment was installed.

3.0 Scope of Work

The scope of work is described below. The work is divided into several tasks, each being described separately.

3.1 Task I - Design of an Integrated LCNG Fueling Station

This task consisted of performing the engineering and design, producing the fabrication drawings and installation documentation and performing the fabrication of the components required to create and install all ancillary components of a fully operational LCNG station with the exception of a high pressure pump.

3.2 Task II - Procurement of CNG Equipment

This task procured the equipment and raw materials necessary for fabricating the equipment defined in Task I.

3.3 Task III - Design, Testing and Fabrication of a High Pressure Pump

This task performed the design, engineering, procurement, fabrication and testing functions necessary to modify and proof test an existing high pressure pump design such that it could be used in a deep sump, equivalent to pumping from an underground storage tank.

3.4 Task IV - Installation of the LCNG Equipment

This task performed the installation of the equipment produced in Tasks I, II and III.

3.5 Task V - Startup and Testing of the LCNG Equipment

This task performed the startup, debugging and operational checkout (commissioning) of the equipment installed in Task IV.

3.6 Task VI - As-Built Drawings and Test Reports

This task generated as-built drawings based on field modifications that occurred during commissioning of the system and produced interim and final reports that documented the results of this effort.

4.0 Results

A summary of the effort required to complete each task is described below.

4.1 Task I - Design of an Integrated LCNG Fueling Station

The overall station design was based on current practice for CNG stations, adapted for the use of LNG as the stored fuel. Current CNG stations are built and installed per National Fire Protection Agency (NFPA) standard 52 "Compressed Natural Gas (CNG) Vehicular Fuel Systems Code" that covers CNG fueling stations. The basis for the design for each major subcomponent is discussed below.

4.1.1 Vaporizer

The vaporizer is a commercially available device, sized by the vendor for a duty cycle that will allow 5 minutes of operation once an hour at a flow rate of 3.5 GPM of LNG (300 SCFM) without exceeding a 20 °F approach temperature. The vaporizer is rated for a 3500 psig maximum allowable working pressure in accordance with ANSI B31.3. It is a finned tube ambient type mounted on an aluminum framework.

4.1.2 Odorizer

The odorizer is a commercially available device designed to inject standard mercaptan odorant into a high pressure gas line. It consists primarily of an odorant storage vessel and a pneumatically operated piston pump. It is capable of injecting odorant at the recommended rate of 0.75 lb / MMcf into the high pressure line that pipes gas to the dispenser. The odorizer is controlled by turning the supply air pressure to the pneumatic pump on or off using a solenoid valve that is controlled by the existing fueling station programmable logic controller (PLC).

4.1.3 Buffer System

The buffer system was designed to absorb boiloff gas produced from LNG remaining in the piping after a fill cycle to reduce or eliminate piping relief devices from opening under normal operating conditions. The boiloff gas stored by the buffer system is used to "prefill" a vehicle before using liquid from the storage tank. A typical filling cycle first allows the pressure within the buffer system to equalize with the vehicle tank(s). The buffer system is then isolated from the fill piping and the high pressure pump starts to complete the fill. Once the fill is complete, the liquid storage is isolated from the piping then the buffer system is opened to absorb the remaining high pressure gas and liquid in the piping, thus recharging the buffer system such that the process may repeat. This also has the added safety feature of maintaining the piping at a lower pressure during nonfilling periods.

The buffer system is sized to limit the line pressure to 1000 psig under normal operating conditions between filling operations. This consists of two (2) high pressure cylinders with an internal volume of approximately 1.5 cubic feet each. The system is designed in accordance with ANSI B31.3 with a MAWP of 3600 psig. It also contains instrumentation for monitoring pressure in the filling line and buffer tanks and incorporates a pressure transducer that communicates with the existing station PLC to provide line break and over pressure detection.

4.1.4 Dispenser

The dispenser is a commercially available device designed to dispense natural gas at a maximum rate of 1000 SCFM at 3600 psig. It is a single hose dispenser with a mass flow meter that will communicate with the existing station PLC that will accumulate the total fuel dispensed. It also provides a 4 to 20 mA signal for the gas line pressure that will serve as the shutdown or fill stop parameter that is monitored by the existing station PLC. It is suitable for fueling vehicles to 3600 psig using a standard NGV1 fueling connection.

4.2 Task II - Procurement of CNG Equipment

All items as defined in Task I were procured per standard CVI operating procedures.

4.3 Task III - Design, Testing and Fabrication of a High Pressure Pump

The existing design of a standard CVI high pressure LNG pump was modified such that it could be used in a deep sump or well. This consisted of extending the cold working end of the pump such that the pump inlet was at the bottom of the tank. The pump works most efficiently with the maximum amount of net positive suction head (NPSH) and is designed to run at cryogenic temperatures, thus the requirement for locating the working end at the bottom of the tank. This required the redesign of the pushrod and extension spool from a length of nominally 2 feet to 11 feet.

Consideration was given to the compression loads imposed on the pushrod during maximum operating conditions. The diameter of the pushrod had to be increased dramatically in addition to being guided at its center. This was required not so much as to prevent catastrophic buckling but to limit the amount of deflection to what is normally experienced in the standard pump, the standard pump design serving as a baseline of what is historically known to be reliable and durable. Excessive deflection, while possibly not being the cause of the pump to work entirely, would reduce the life of piston rings and bearing surfaces in the pump.

The pump was fabricated, assembled and tested in a specially designed vacuum jacketed sump that would accommodate the length of the pump. The component parts that would actually be installed in the field were used in the test. The pump was tested in accordance with CVI specification 105440-9910 included as a reference in the Appendix. The pump performed extremely well. Disassembly and inspection after the test revealed no excessive wear indicating that the new design should exhibit equivalent reliability and durability as the original design. This of course can only be verified by extensive field testing that is not a part of the current scope of work. The pump was reassembled with new wear items such as piston rings and shaft seals and prepared for shipment.

4.4 Task IV - Installation of the LCNG Equipment

The equipment was installed during the period from June 11 through June 25. Mechanical installation consisted of pouring concrete foundations for the vaporizer, odorizer, buffer system and CNG dispenser, setting the equipment on its foundation, installation of interconnecting process tubing, valves and the various control devices and connection of the existing air supply to those devices requiring air. Electrical installation consisted of installing rigid conduit and wiring rated for Class I, Div. 1, Group D (explosion proof) to each device from the existing LNG electrical panels within the LNG dispenser that were prewired for this equipment. Installation was governed by NFPA 52 that invokes the National Electrical Code (NFPA 70) for electrical installation.

4.5 Task V - Startup and Testing of the LCNG Equipment

The PLC program was simulated and checked for proper operation prior to downloading to the existing PLC used to control the existing LNG dispenser. The simulation included checking all process scenarios for proper output response given all anticipated combinations of inputs and verification of proper response in the event of an emergency situation such as over pressure, line break or the pressing of an Estop button.

The installed equipment was first checked out by individually checking the proper operation of each device prior to running the high pressure LNG pump. All safeties were verified including the emergency stop (Estop) circuits.

Once individual components were verified, the system was run to fill the buffer system tanks. The system operated as anticipated. The buffer tanks were vented to atmosphere and refilled to verify proper operation.

To further verify proper operation of the system a CNG powered vehicle was filled. The vehicle was a pickup truck owned by the local Columbia Gas service group in Washington, PA. The truck was fitted with cylinders rated at 3600 psig with a total capacity of 1083 standard cubic feet (SCF) of methane. The filling cycle began with the cylinders at approximately atmospheric pressure. The truck was successfully filled at the rated flow of 3.5 GPM (3500 SCFH) to a pressure of 3600 psig in 3 1/2 minutes from the initial pressure just mentioned. The truck was started and it operated normally.

4.6 Task VI - As-Built Drawings and Test Reports

Fabrication drawings were updated after equipment was successfully demonstrated to reflect its as-built and working configuration. One interim report dated June 10, 1999 and this final report contain the testing results of this effort and thus serve as the test reports mentioned in the statement of work.

5.0 Conclusions

This program has successfully demonstrated the equipment and processes required to produce compressed natural gas (CNG) from liquefied natural gas (LNG) for heavy duty vehicular applications. It should be noted that the unique approach of this effort, namely underground LNG storage, should enhance the acceptance of this alternative fuel owing to the simplicity, relatively low capital, installation and maintenance costs and "transparency" of this method of fueling CNG vehicles of all duty types.

6.0 Recommendations

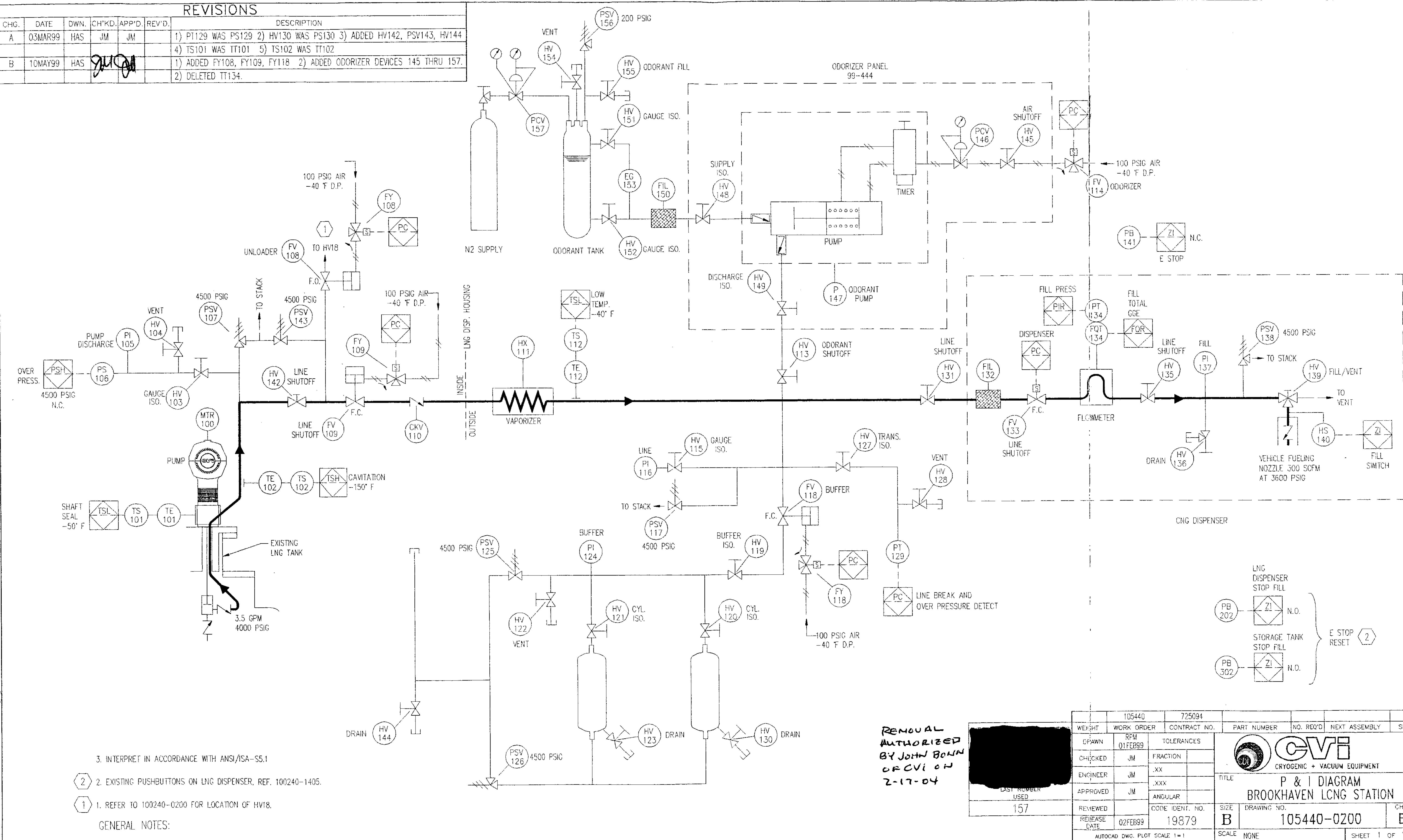
It is recommended that the reliability and durability of the system should be verified, primarily in the area of the high pressure pump developed in this effort. This piece of equipment is the key to utilizing underground storage and must be thoroughly evaluated and verified as a highly reliable device before entry into the consumer market. A two phase verification process is proposed, the first phase would run extensive durability and endurance testing of the high pressure pump in a laboratory environment, the second would be to put the verified design in a high use CNG station for use by the public or a fleet environment for a protracted period of time with close monitoring of system performance.

Appendix

CVI Drawing 105440-0200 “P&I Diagram”
CVI Drawing 105440-0010 “General Arrangement”
CVI Drawing 105440-9910 “Pump Test Procedure”
Photographs

REVISIONS

CHG.	DATE	DWN.	CH'KD.	APP'D.	REV'D.	DESCRIPTION
A	03MAR99	HAS	JM	JM		1) PT129 WAS PS129 2) HV130 WAS PS130 3) ADDED HV142, PSV143, HV144
						4) TS101 WAS TT101 5) TS102 WAS TT102
B	10MAY99	HAS	JM	JM		1) ADDED FY108, FY109, FY118 2) ADDED ODORIZER DEVICES 145 THRU 157.
						2) DELETED TT134.



3. INTERPRET IN ACCORDANCE WITH ANSI/ISA-S5.1

2. EXISTING PUSHBUTTONS ON LNG DISPENSER, REF. 100240-1405.

1. REFER TO 100240-0200 FOR LOCATION OF HV18.

GENERAL NOTES:

REMOVAL AUTHORIZED BY JOHN BONN OF CVI ON 2-17-04

[redacted]

LAST NUMBER USED
157

WEIGHT	WORK ORDER 105440	CONTRACT NO. 725094	PART NUMBER	NO. REQ'D	NEXT ASSEMBLY	SIZE
DRAWN	RPM 01FEB99	TOLERANCES	CVI CRYOGENIC + VACUUM EQUIPMENT			
CHECKED	JM	FRACTION				
ENGINEER	JM	.XX	TITLE P & I DIAGRAM BROOKHAVEN LCNG STATION			
APPROVED	JM	.XXX / ANGULAR				
REVIEWED		CODE IDENT. NO. 19879	SIZE B	DRAWING NO. 105440-0200		CHG. B
RELEASE DATE	02FEB99		SCALE NONE		SHEET 1 OF 1	

AUTOCAD DWG. PLOT SCALE 1=1

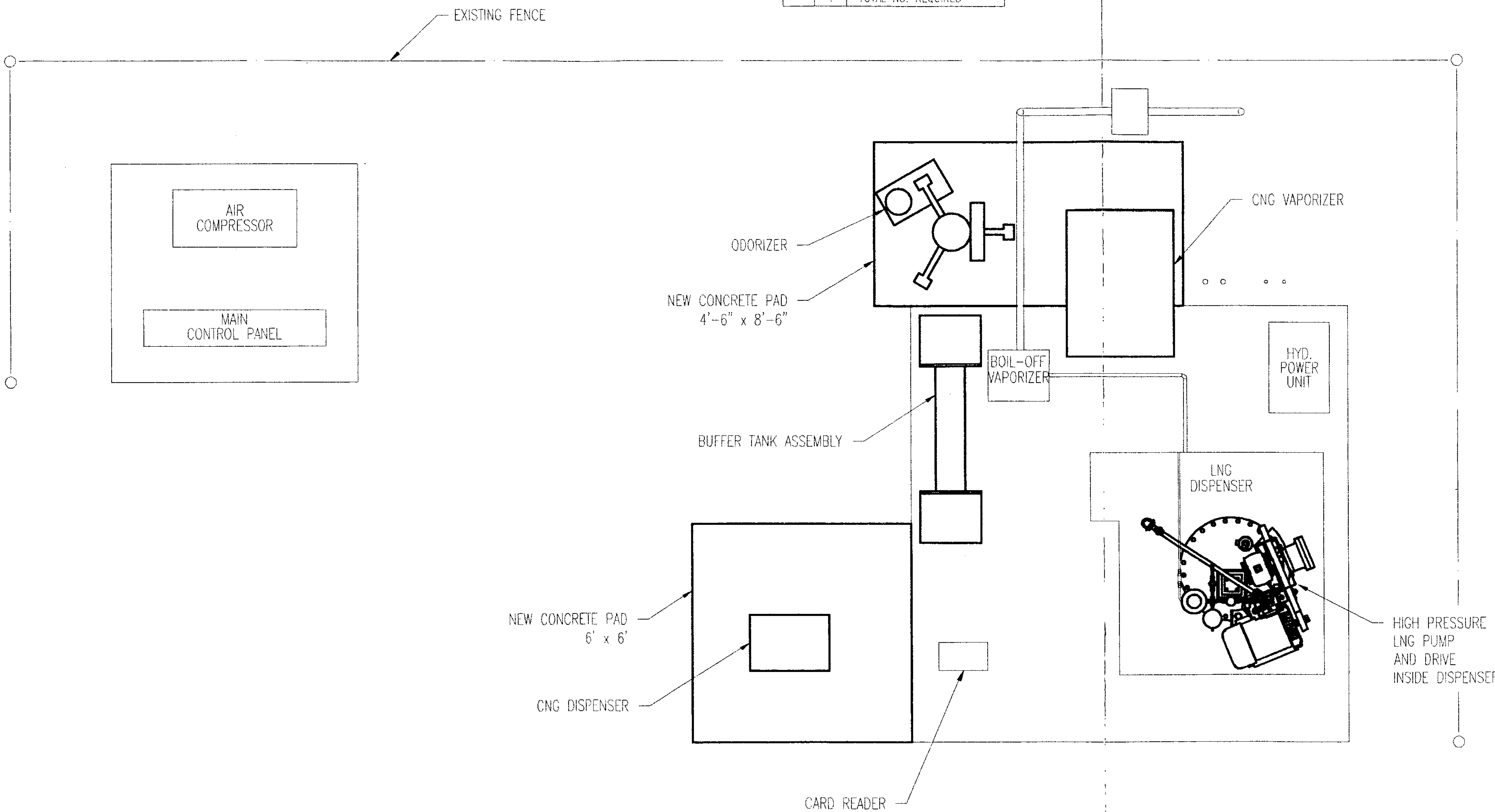
105440-0200 SH. 1 (B)

REVISIONS

CHG.	DATE	DWN.	CH'KD.	APP'D.	REV'D.	DESCRIPTION

BILL OF MATERIAL

NO. REQ'D. -1	TOTAL NO. REQ'D	ADV. PROC.	DET. LOC.	AB NO.	ITEM	PART NUMBER	DWG. SIZE	DESCRIPTION	MATERIAL
1	1				1	105440-0100	B	EQUIPMENT FOUNDATION	
1	1				2	105440-0210	B	MECHANICAL INSTALLATION	
1	1				3	105440-0410	B	ELECTRICAL INSTALLATION	
					4				
					5				
1	TOTAL NO. REQUIRED								



105440-0010 SH. 1 (N/C)

GENERAL NOTES:

1. HEAVY LINES INDICATE NEW ITEMS ADDED ON THIS CONTRACT. LIGHT LINES INDICATE EXISTING ITEMS.
2. REF. P & I DIAGRAM 105440-0200.

[redacted]

REMOVAL AUTHORIZED BY JOHN BONN 2-17-04

WEIGHT	WORK ORDER	CONTRACT NO.	PART NUMBER	NO. REQ'D	NEXT ASSEMBLY	SIZE
	105440	725094				

		TOLERANCES	
DRAWN	Rc 5-7-99	FRACTION	
CHECKED	[signature]	.XX	
ENGINEER	[signature]	.XXX	
APPROVED	[signature]	ANGULAR	
REVIEWED		CODE IDENT. NO. 19879	
RELEASE DATE	5-10-99		

AUTOCAD DWG. PLOT SCALE 1=40

CVI CRYOGENIC + VACUUM EQUIPMENT

TITLE: GENERAL ARRANGEMENT BROOKHAVEN LCNG STATION

SIZE: B | DRAWING NO.: 105440-0010 | CHG.: N/C

SCALE: NONE | SHEET 1 OF 1

REVISIONS							
LTR	DESCRIPTION	RELEASE DATE	INITIAL AND DATE			
			CHGD	CHKD	ENGR	APPD
A	Modified Section 2.10 to include determining the time required to pump the sump empty.	5/7/99	JAM	[signature]	[signature]	[signature]

WEIGHT	WORK ORDER	CONTRACT #	PART #	# REQD	NEXT ASSEMBLY	SIZE

PRPRD HAS	DATE 4/22/99	TITLE PUMP TEST PROCEDURE		CVI Incorporated
CHCKD JM	DATE 4/22/99			
ENGNR JM	DATE 4/22/99			SIZE A / CHG A
APPRVD JM	DATE 4/22/99	RELEASE DATE 4/22/99	DRAWING # 105440-9910	
APPRVD	DATE		SCALE NONE	SHEET 1 OF 3

PUMP TEST PROCEDURE

1.0 Installation

1.1 Assemble the pump test station per 105440-9907.

1.2 Connect a 1/2" (minimum) LN2 line from the bulk tank to the lower sump connection. The line must have a cryogenically rated extended stem or VJ shutoff valve in line to allow control of the liquid flowing to the sump.

1.3 Connect a 1/2" (minimum) vapor return line from the top sump connection back to the vapor space of the bulk LN2 tank. This line must have a cryogenically rated extended stem or VJ valve to allow isolation of the sump from the bulk tank. Also, "tee-in" a valve in the vapor return line to allow the sump to be blown down once isolated from the bulk tank. Install a 375 psig (maximum) relief valve in the vapor return line to protect the sump.

1.4 Connect 480 VAC, 3 phase power to the motor using an appropriate start/stop station and motor starter. Refer to motor nameplate for power requirements.

Once connected "bump" the motor to ensure proper rotation direction - counterclockwise when viewed from the pulley end of the motor.

1.5 Connect an existing test stand used for testing high pressure pumps to the discharge line to allow control and monitoring of the pump discharge pressure. Pipe the discharge outside.

2.0 Testing Procedure

Do not allow the pump to run at any time if mechanical failure, binding or excessive noise develops during any portion of the testing below.

2.1 Fill the sump with liquid and allow to soak until temperatures are equilibrated.

2.2 Hand rotate the pump flywheel to ensure there is no binding.

2.3 Fully open the valve on the pump test stand so no discharge pressure will be developed when the pump is turned on.

2.4 Cross your fingers and turn on the pump.

2.5 If everybody is still alive, allow the pump to run for 5 minutes with no discharge line pressure. Turn the pump off, allow the pump to stop, then restart the pump. Repeat this 3 times. Stop the pump and inspect the pushrod / crosshead connection for any signs of unusual deformation or looseness.

2.6 Restart the pump and adjust the valve on the test stand until a 1000 psig discharge pressure is developed. Allow the pump to run at this pressure for approximately 1 minute.

2.7 Adjust the pump discharge pressure to 2000 psig and allow the pump to run for approx. 1 minute.

2.8 Adjust the pump discharge pressure to 3000 psig and allow the pump to run for approx. 1 minute.

2.9 Adjust the pump discharge pressure to 4000 psig and allow the pump to run for a minimum of 30 minutes. Inspect the pushrod gas seal area for any signs of leakage during the run.

[redacted] REMOVAL AUTHORIZED BY MR JOHN BONN ON 2-17-04	SIZE A	DRAWING # 105440-9910	CVI Incorporated
		CHG A	SHEET 2 of 3

2.10 To estimate the liquid head required to operate the pump simultaneously start a timer then shut the liquid supply off to the sump. Using a tachometer determine the actual flywheel RPM. Note the time elapsed when the pump begins to cavitate. Allow the pump to empty the sump. Shut off the pump once the sump is emptied.

2.11 Close the vapor return line valve to the bulk tank then blow down the sump to atmospheric pressure. Close the blowdown valve and allow the sump to warm to room temperature.

2.12 The pump test stand may be disconnected from the pump discharge line, if required. Seal all openings on the pump to prevent ingress of moisture or other contamination.

3.0 Disassembly and Inspection

The following tasks must be completed in a clean area. Refer to the pump assembly drawing 105440-5100. Cleanliness of the parts must be maintained or recleaning must occur per the pump assembly drawing. Inspection to be performed by Engineering by comparing items to new, unused parts.

3.1 Disconnect the pushrod (item 34) from the crosshead of item 1 and remove the pushrod gas seals (item 2) for inspection. Install new seals and reassemble.

3.2 Once the pump/sump has completely warmed to ambient temperature remove the pump from the sump.

3.3 Disassemble the cold end cylinder (item 7) and inspect the piston, rings, seals (items 6, 10, 12) and cylinder ID for excessive wear.

3.4 Remove the extension spool lower half (item 33) such that the bearing at the center (item 28) may be inspected for excessive wear.

3.5 Install a new extension spool bearing, piston rings and seals.

3.6 Reassemble the extension spool and cold end cylinder per the pump assembly drawing.

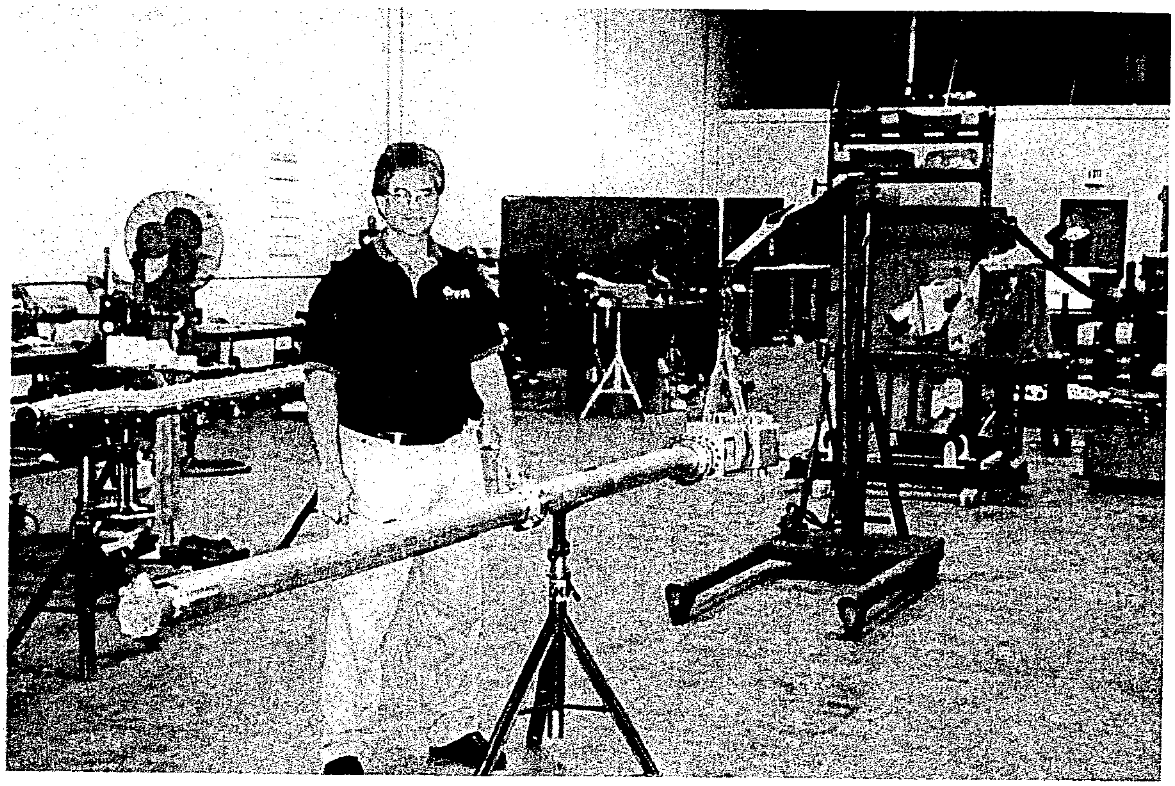
3.7 Bag the cold end and seal all openings for storage / shipment.

4.0 Modifications

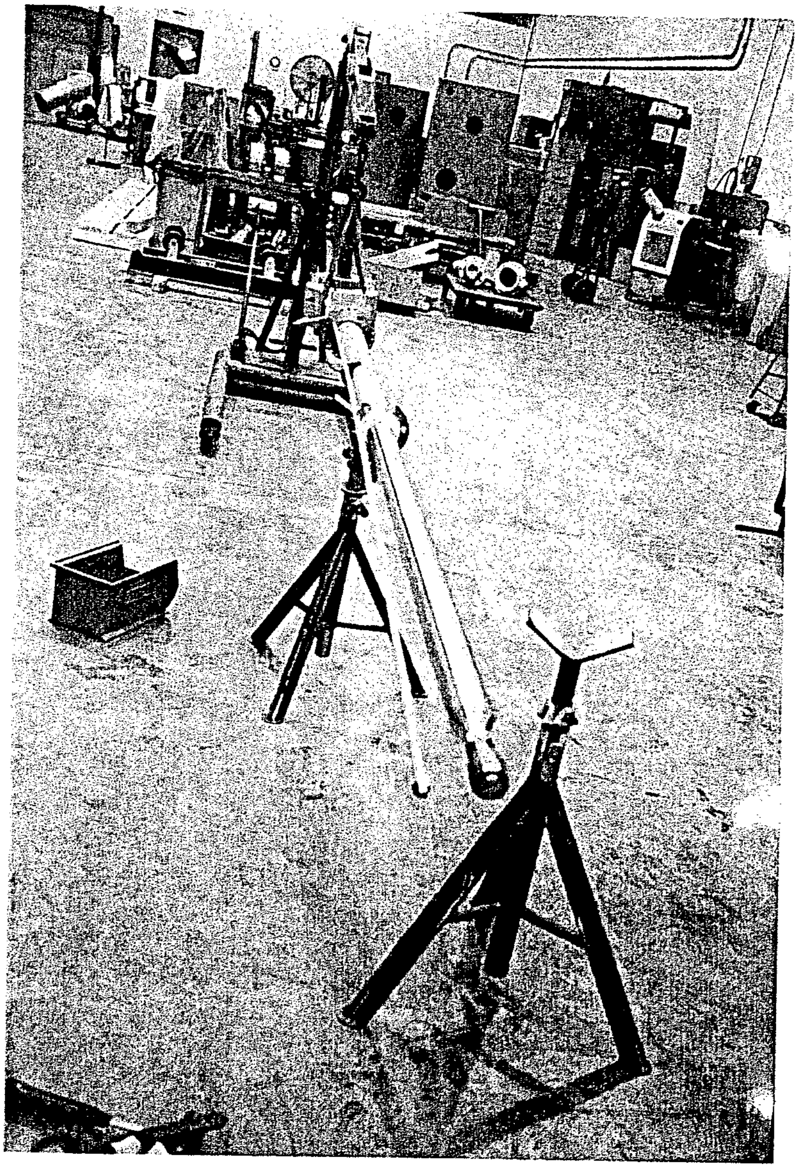
This procedure must be repeated if there are any modifications to the pump.

5.0 Documentation

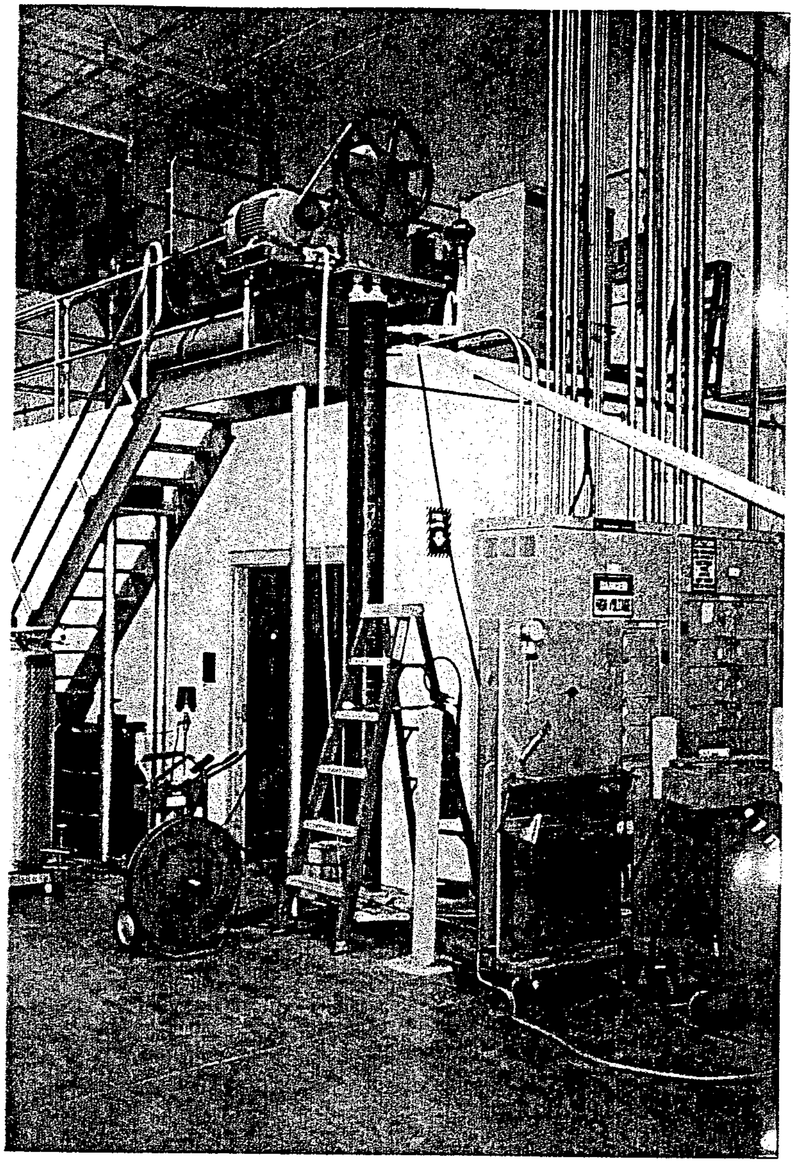
Indicate completion of this procedure and acceptance of pump performance by signing the traveler.



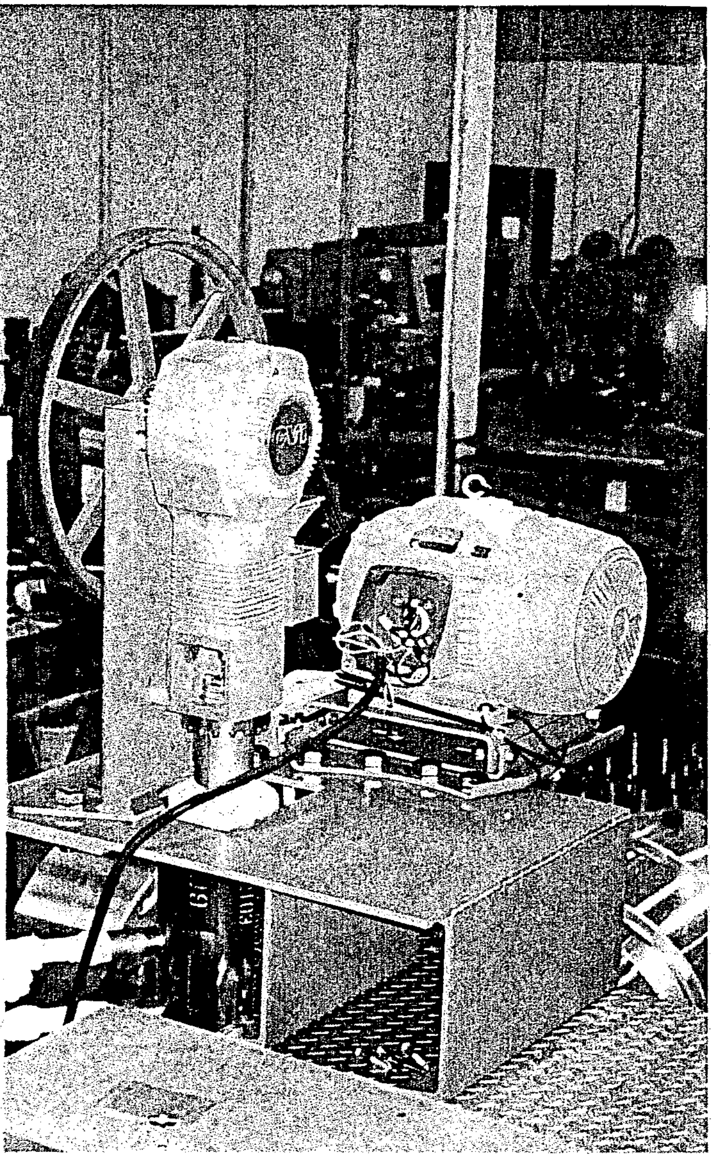
EXTENDED HIGH PRESSURE PUMP ASSEMBLY

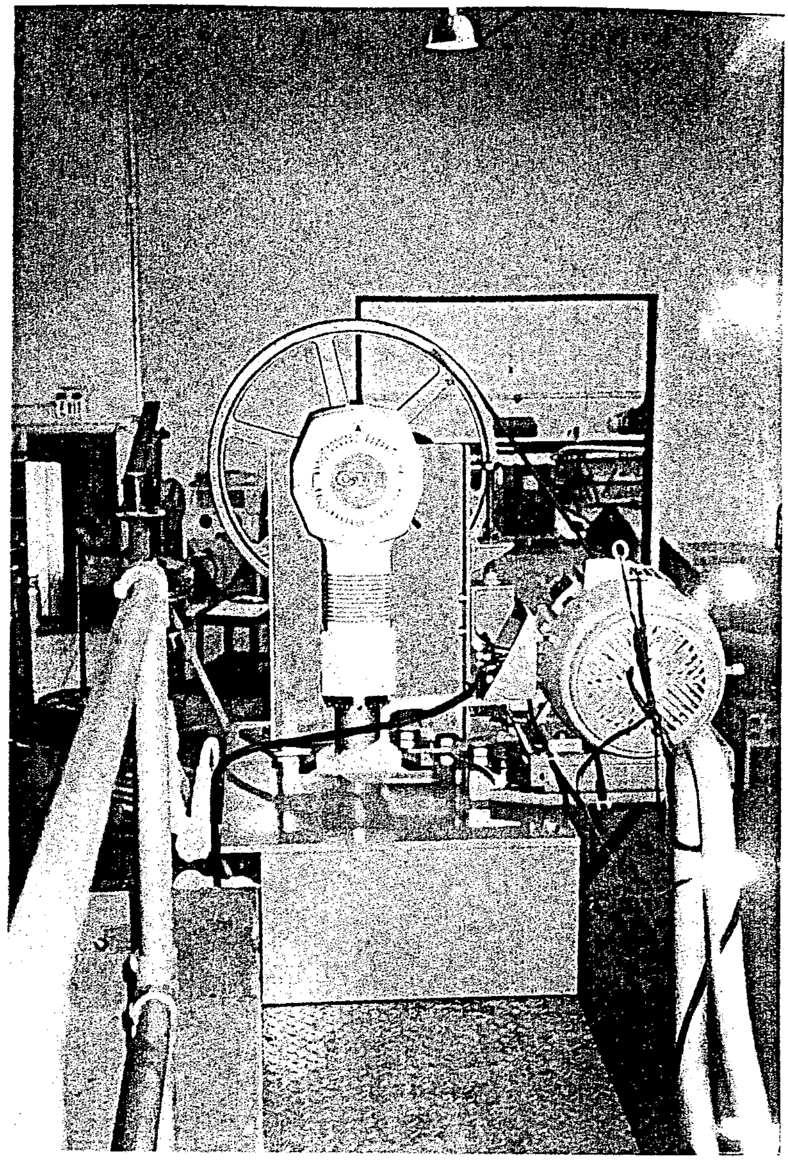


EXTENDED HIGH PRESSURE PUMP
PARTIALLY DISASSEMBLED TO
SHOW PUSHROD AND PISTON END.



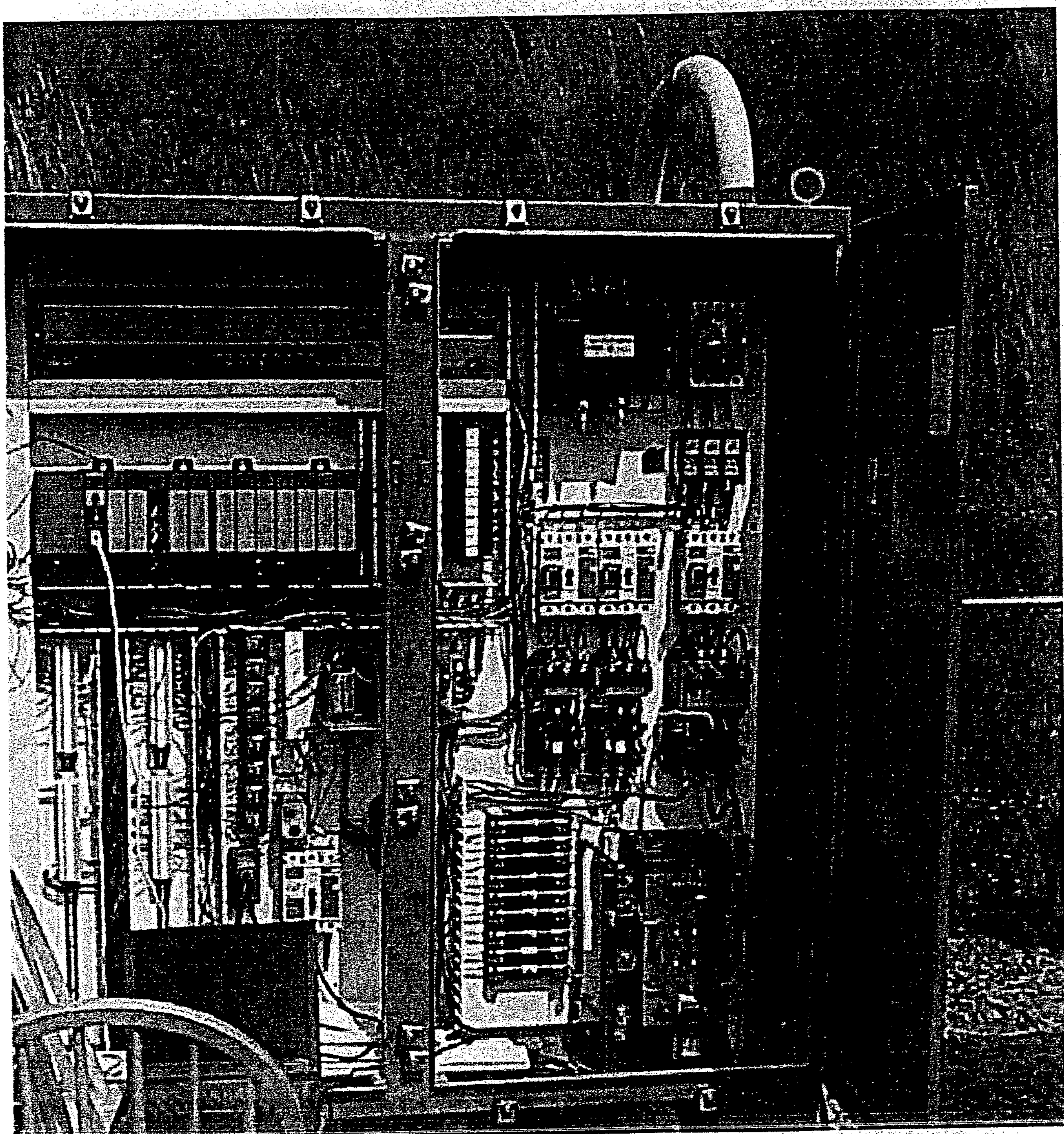
PUMP SHOP TEST



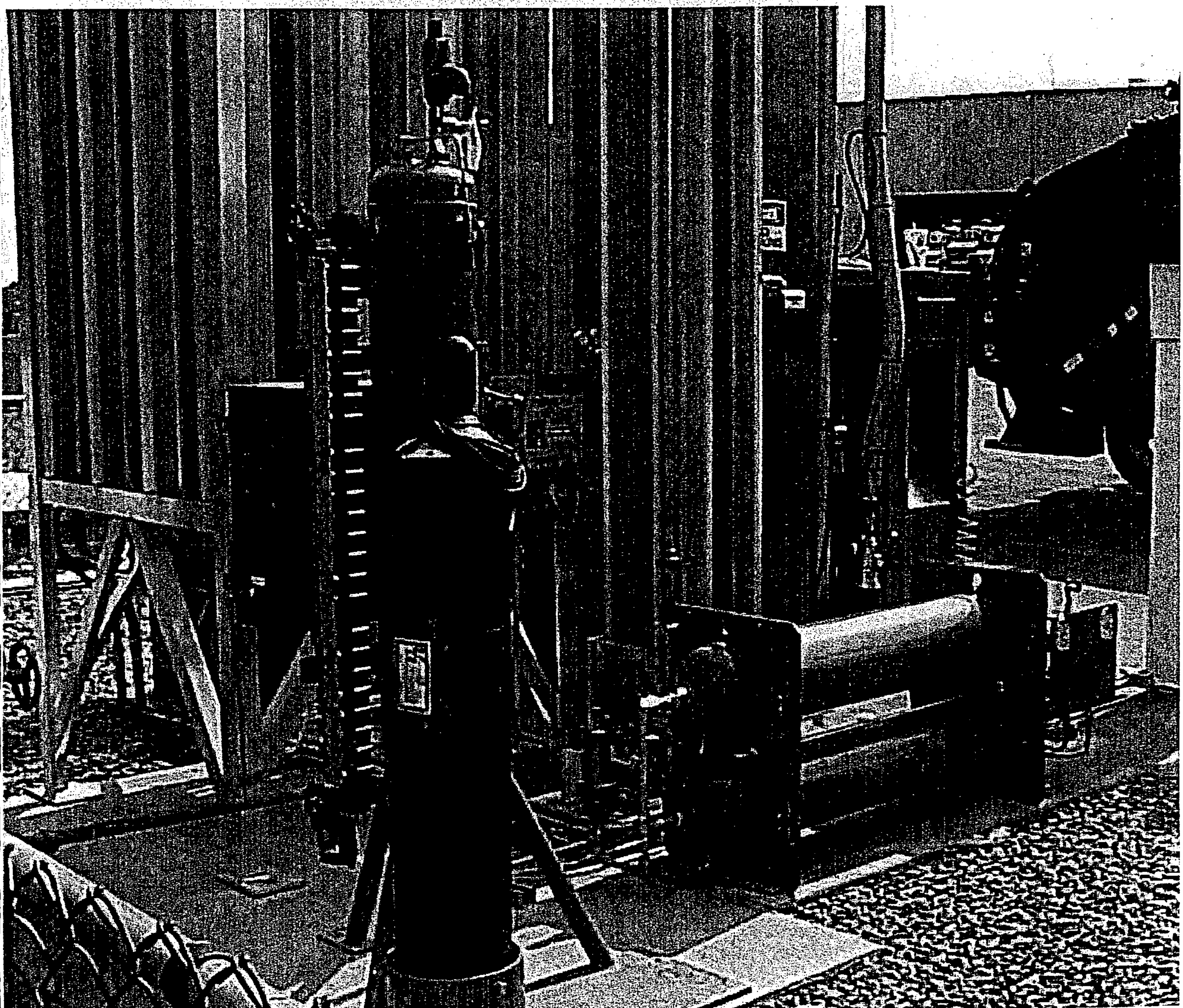


PUMP DRIVE END ASSEMBLY - SHOP TEST

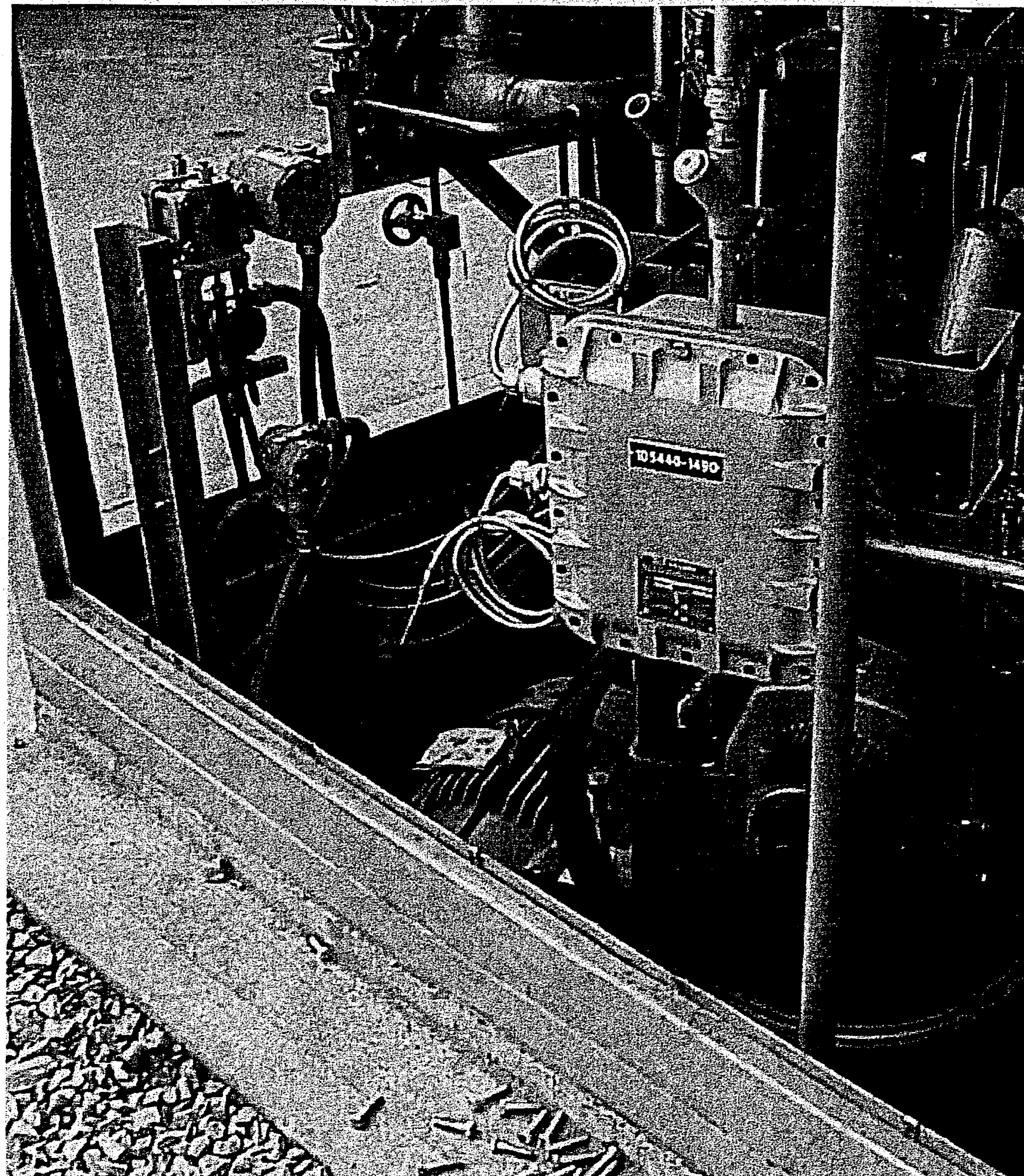
INSTALLATION IN PROGRESS - CNG DISPENSER
AND EXISTING CARD READER



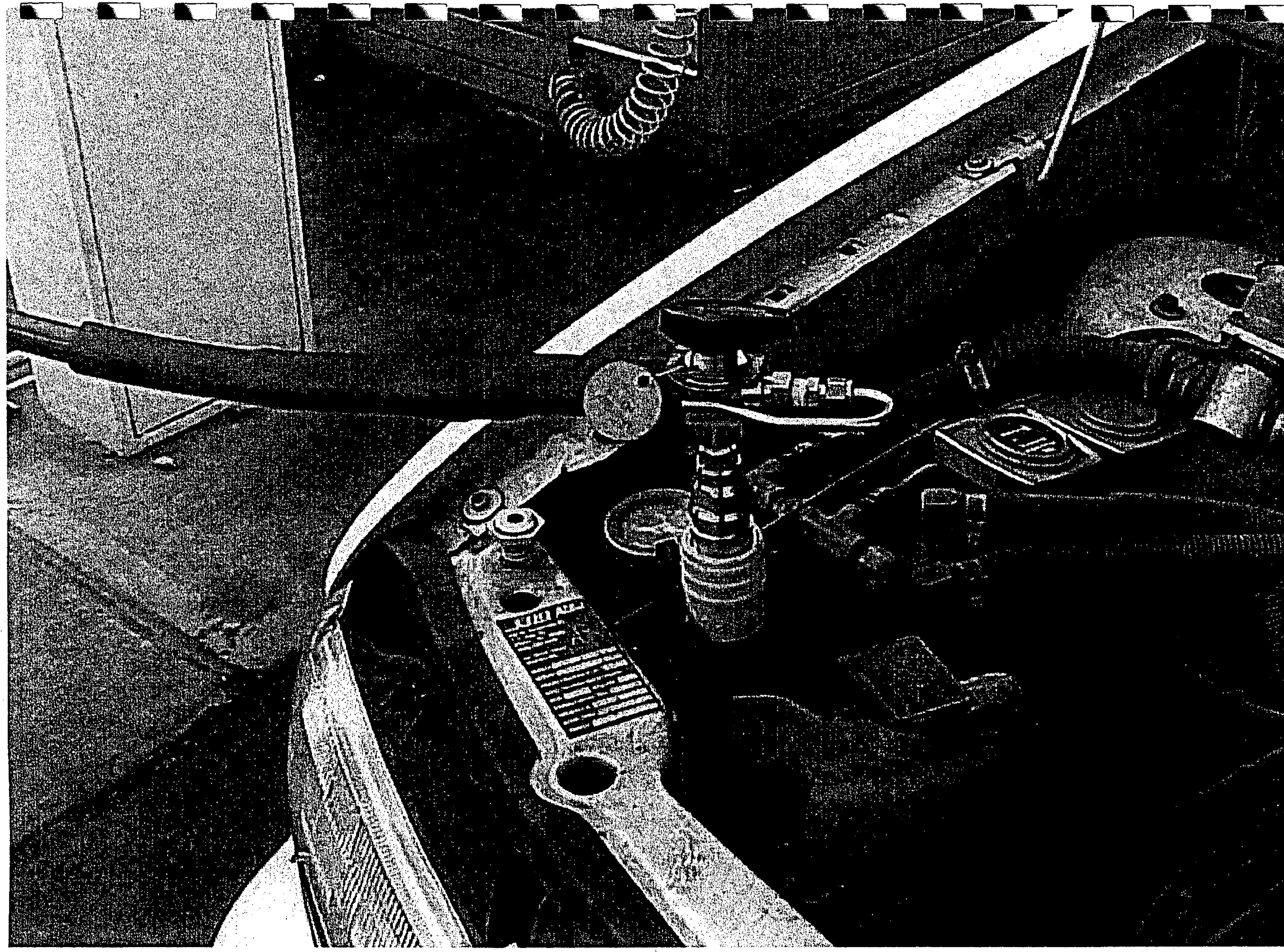
WORK IN PROGRESS - MAIN CONTROL PANEL MODIFICATIONS



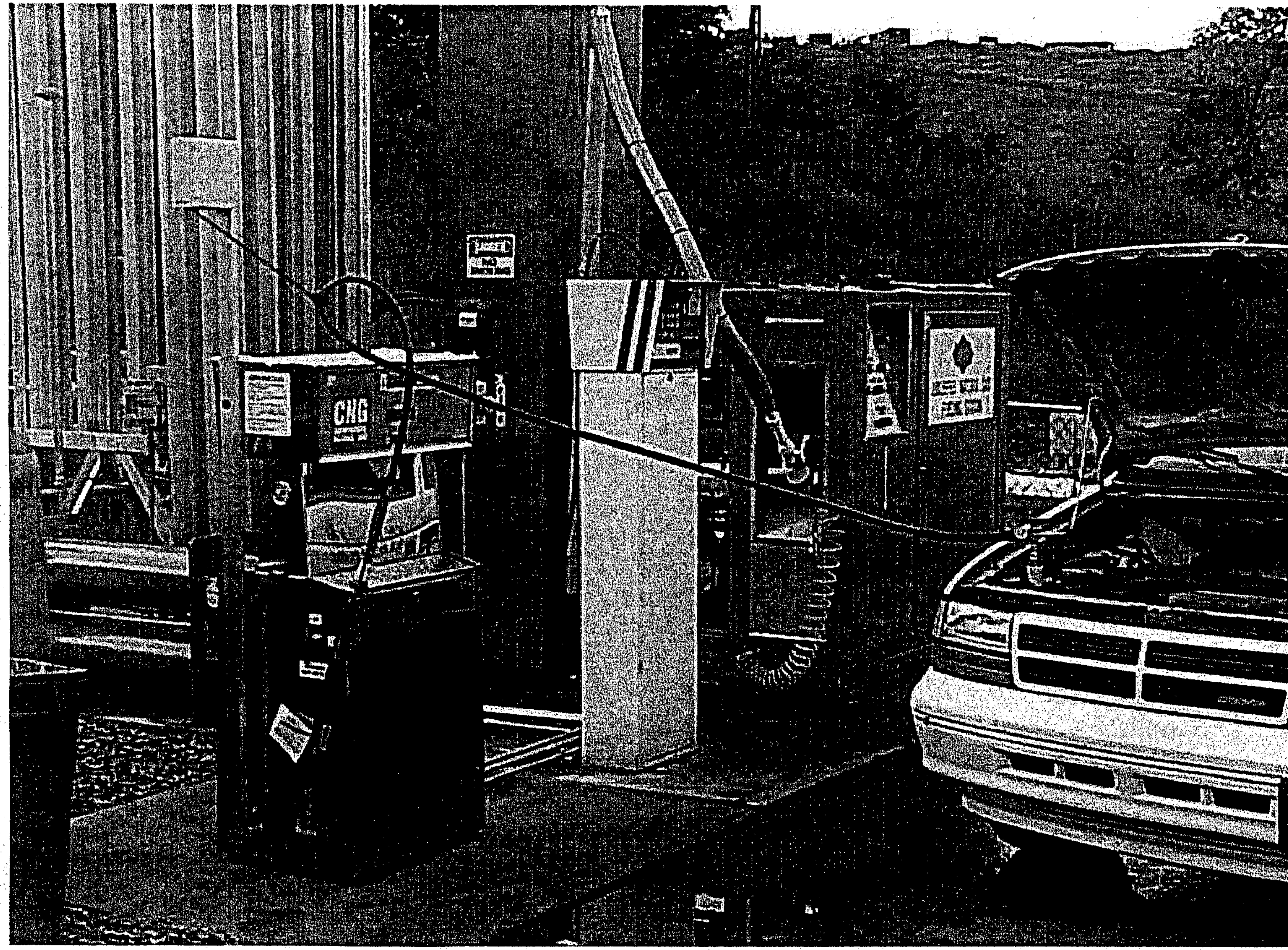
INSTALLATION IN PROGRESS - ODORIZER, BUFFER ASSEMBLY AND VAPORIZER



ON SITE PUMP TEST - PUMP INSTALLED INSIDE LNG DISPENSER



VEHICLE FILLING - HOSE CONNECTION



FINAL INSTALLATION AND FILLING DEMONSTRATION