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Liquid Transfer Cryogenic Test Facility—Initial Hydrogen and Nitrogen No-Vent Fill Data

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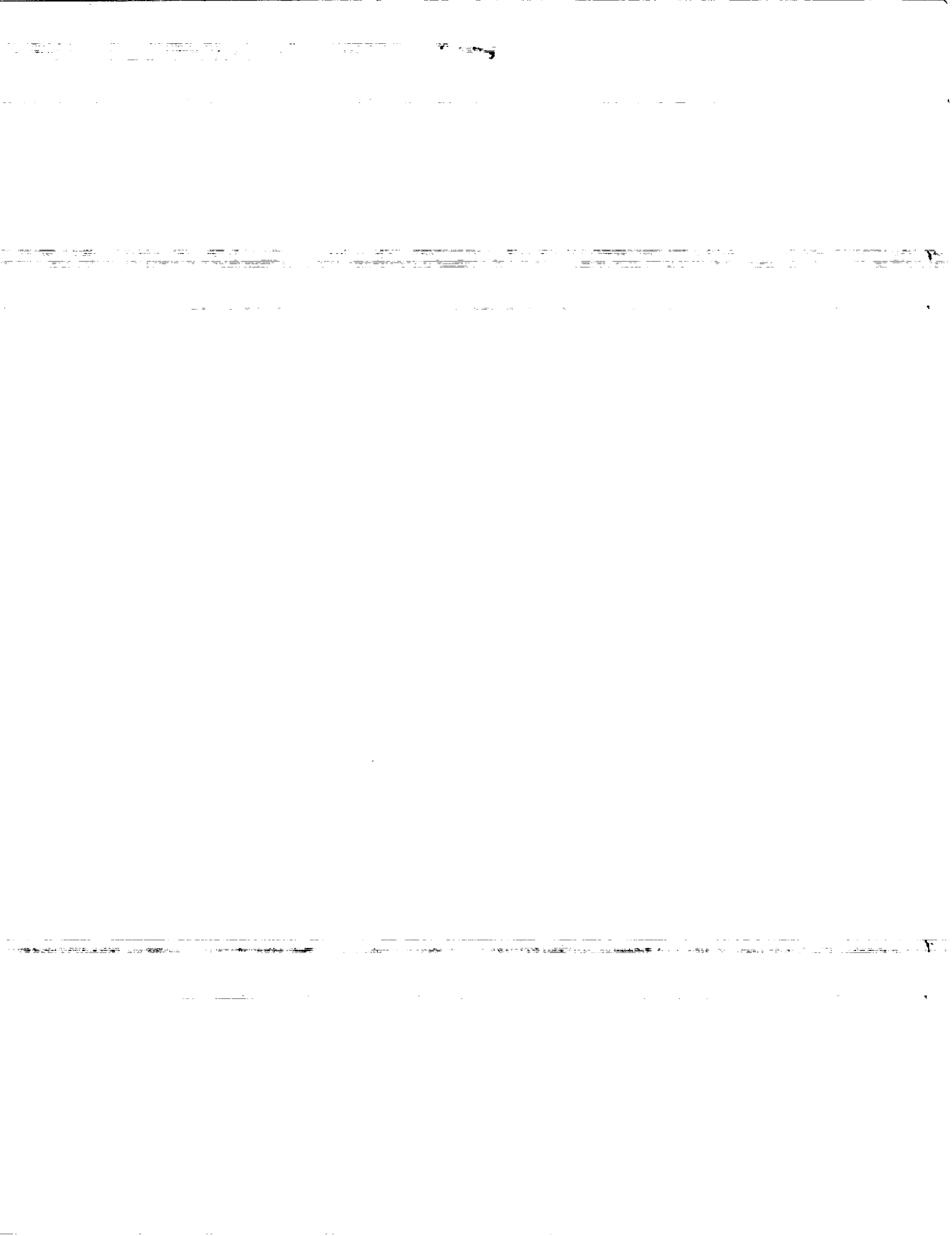Analex Corporation
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ABSTRACT

The Liquid Transfer Cryogenic Test Facility is a versatile testbed for ground-based cryogenic fluid storage, handling, and transfer experimentation. The test rig contains two well instrumented tanks, and a third interchangeable tank, designed to accommodate liquid nitrogen or liquid hydrogen testing. The internal tank volumes are approximately 18, 5, and 1.2 cubic feet. Tank pressures can be varied from 2 to 30 psia. Preliminary no vent fill tests with nitrogen and hydrogen have been successfully completed with the test rig.

Initial results indicate that no vent fills of nitrogen above 90% full are achievable using this test configuration, in a 1-g environment, and with inlet liquid temperatures as high as 143 °R, and an average tank wall temperature of nearly 300 °R. This inlet temperature corresponds to a saturation pressure of 19 psia for nitrogen. Hydrogen proved considerably more difficult to transfer between tanks without venting. The highest temperature conditions resulting in a fill level greater than 90% were with an inlet liquid temperature of 34 °R, and an estimated tank wall temperature of slightly more than 100 °R. Saturation pressure for hydrogen at this inlet temperature is 10 psia. All preliminary no vent fill tests were performed with a top mounted full cone nozzle for liquid injection. The nozzle produces a 120 degree conical droplet spray at a differential pressure of 10 psi. Pressure in the receiving tank was held to less than 30 psia for all tests.

1

INTRODUCTION

The resupply of cryogenic propellants in orbit is one of the technologies being addressed by the Cryogenic Fluids Technology Office (CFTO) of the NASA Lewis Research Center (ref. 1). One method under study for transferring liquid cryogens from one tank to another is the no vent fill technique. This method involves chilling the receiving tank to a predetermined average wall temperature, and then filling the tank without venting.

The CFTO has created analytical models to simulate the no vent fill process (ref. 2). In an effort to assist in verification of these models prior to planned in-space experimentation, a facility for ground based cryogenic testing was constructed. This facility has the capability to perform a variety of experiments involving the storage, handling, and transfer of cryogenic fluids. Specific tests currently planned for the Liquid Transfer Cryogenic Test Facility include no vent fill, tank chilldown, fluid mixing techniques for pressure control, and tank pressurization (ref. 3).

This report presents a detailed description of the Liquid Transfer Cryogenic Test Facility and its associated systems and instrumentation. Techniques employed for acquisition and reduction of the test data are also outlined. Finally, results of preliminary no vent fill tests with nitrogen and hydrogen are presented and discussed.

EXPERIMENTAL RIG DESCRIPTION

The Liquid Transfer Cryogenic Test Facility is located in Cell 7 of the Cryogenic Components Laboratory (CCL-7) [1] of the NASA Lewis Research Center. A photograph of the installed test rig is shown in figure 1. Operation and monitoring functions are performed in a remotely located control room, which is separated from the testing area by earth embankments. Video cameras provide continuous viewing of the rig from several nearby vantage points. The facility is designed to accommodate both nitrogen and hydrogen testing. All safety precautions required for hydrogen testing are incorporated in the rig design and test procedures.

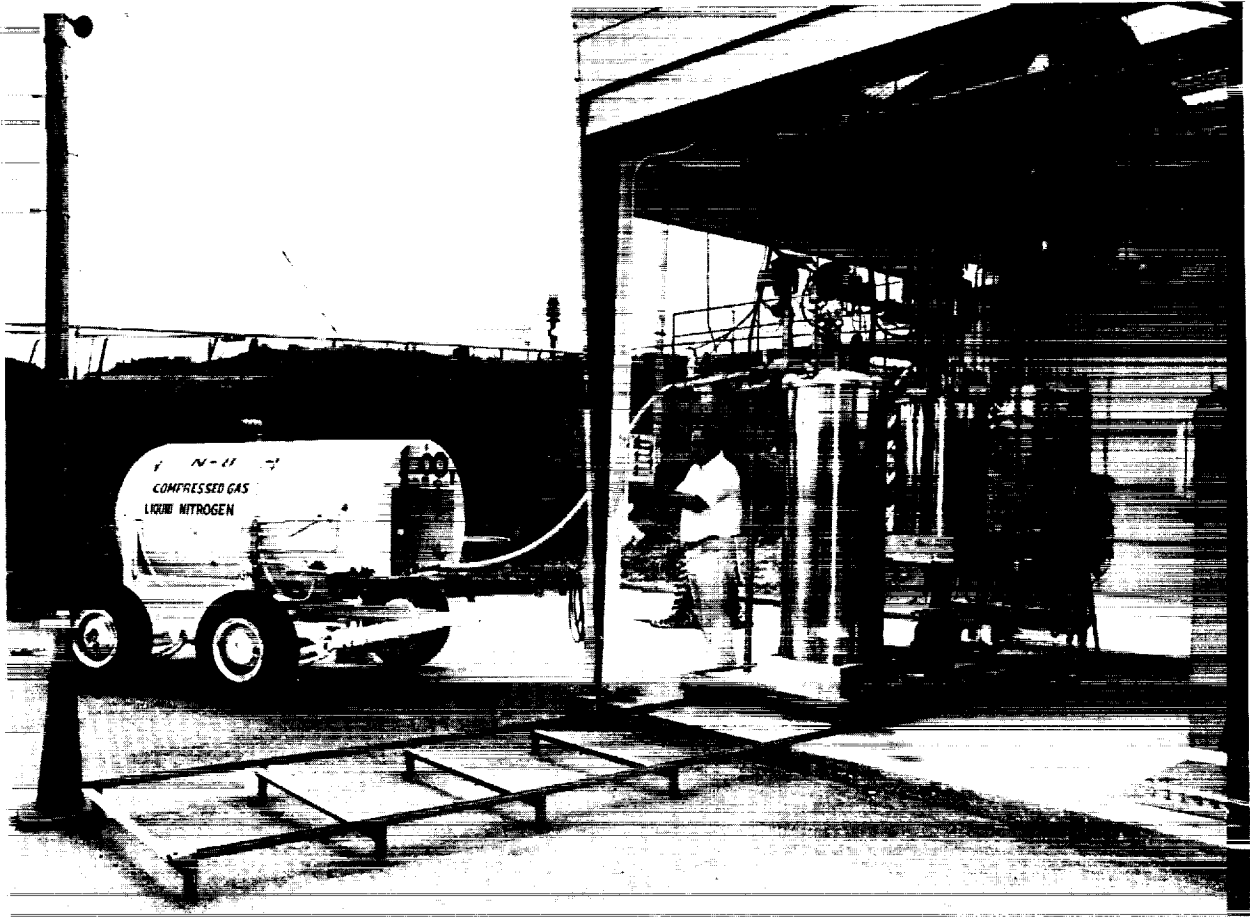[1] Formerly the Fracture Mechanics Laboratory (FML).

Figure 1: Photograph of the CCL-7 test cell

Hardware

Fluid handling in the CCL-7 facility is performed with a supply dewar and two interchangeable receiver dewars. Liquid cryogen is loaded into the supply tank[2] from an adjacent portable dewar, and thermally conditioned prior to the initiation of a test.

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[2] The terms "dewar" and "tank" are used here interchangeably.

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A schematic of the supply and one of the receiver tanks as they are installed in the test facility, is presented in figure 2.
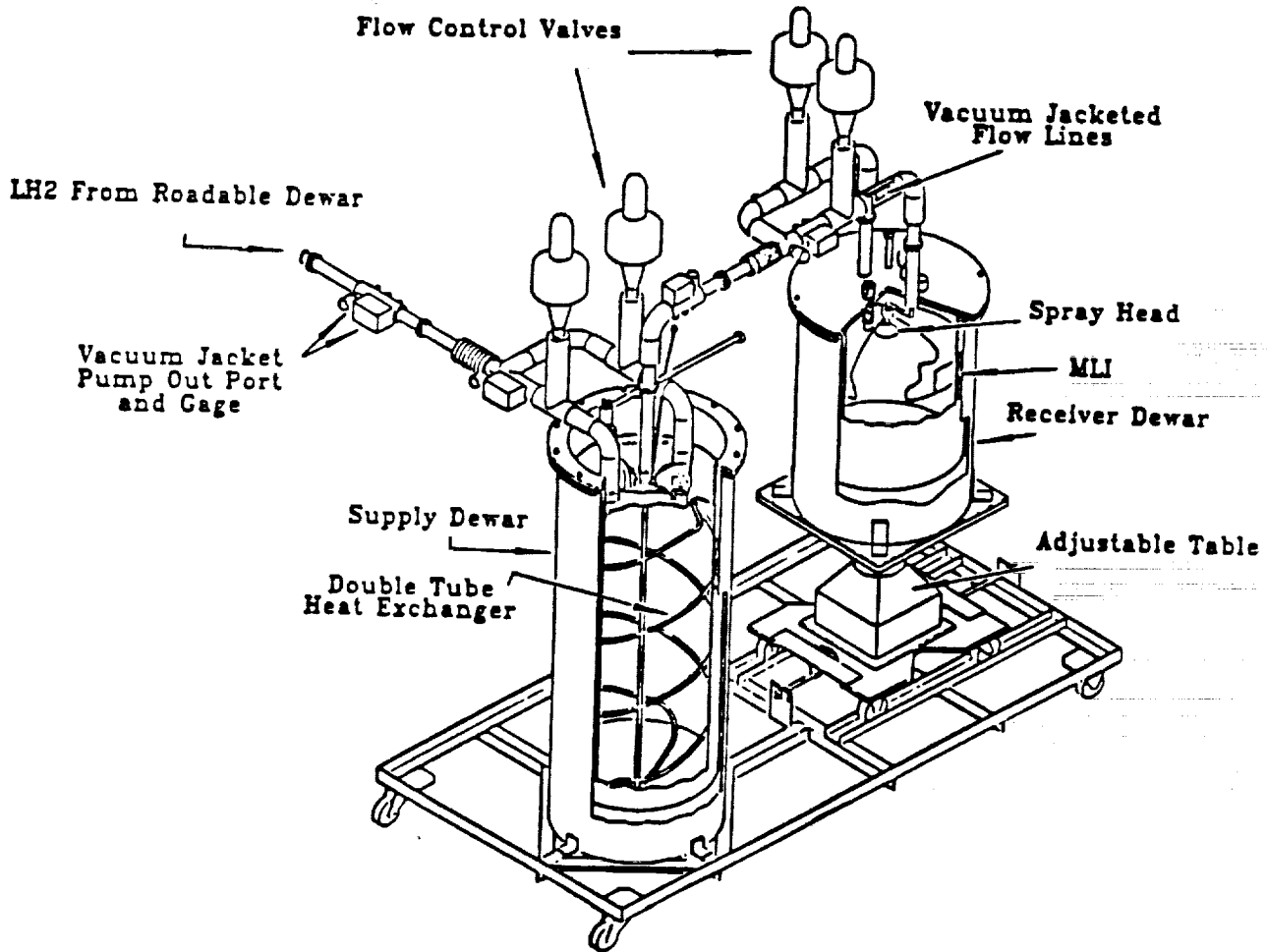
Figure 2: Supply and large receiver tanks as installed in CCL-7

Supply dewar. The supply dewar is a vacuum jacketed stainless steel tank containing multi-layer insulation (MLI) within the vacuum annulus. The dewar is composed of a cylindrical main body with an overall height of 60 inches, and a mating lid assembly. The main body is open at the top for insertion of the lid, and has an inside diameter of 22 inches. Both the main body and lid are

flanged to accommodate a bolted, double o-ring joint. The top of the lid contains piping and instrumentation penetrations, and is recessed to allow application of foamed insulation. Internal volume of the supply tank is approximately 18 cubic feet.

A Thermodynamic Vent System (TVS) is installed within the supply tank to provide an alternative means of thermally conditioning the fluid[3] prior to a test. The TVS is a tube-in-tube counterflow heat exchanger coiled around the inside perimeter of the tank. A preset fraction of the incoming liquid during a fill of the supply dewar is expanded through a Joule-Thompson valve, and the resulting vapor enters the inner tube of the TVS. The remainder of the inlet flow, controlled by a separate valve, remains in liquid form and enters the annular space between the concentric tubes at the opposite end of the TVS. Consequently, saturated vapor within the inner tube, at reduced temperature and pressure, extracts heat from the liquid counterflow and subcools the incoming cryogen. If desired, the Joule-Thompson valve can be completely bypassed.

Two more liquid line penetrations are installed for cryogen transfer between tanks. One line is connected to a dip tube within the supply tank for pressurized liquid transfer to the receiver tank. The second penetration is a liquid return line from the receiver tank.

In addition to the liquid lines, the supply tank lid accommodates two vent lines. One line is dedicated to the TVS, while the other provides venting to the tank. Piping for gaseous pressurant and burst disk pressure relief is connected to the tank line. The vent line is also used to route instrumentation leads from within the tank test volume. A final penetration is used for the liquid level probe.

Sensor leads located in the vacuum annulus of the tank are brought through a separate, hermetically sealed connector in the tank outer wall. The outer wall also has a pump out port, vacuum gauge connector, and a vacuum burst disk.

Receiver dewars. The receiver dewars are of similar construction as the supply dewar. The large receiver, with an overall height of 32 inches and an inside diameter identical to the supply dewar (22 inches), has an internal volume of approximately 5 cubic feet. In contrast, the small receiver has an overall height of 24 inches and inside diameter of 12.5 inches, resulting in an internal volume of 1.2 cubic feet. The lid assembly of both receivers is composed of a short cylindrical section with an inverted dome bottom. The assembly is evacuated and insulated with MLI to minimize heat transmission through the dome from the environment. Figure 3 presents a photograph of the large receiver lid.

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[3] The primary method of conditioning the liquid cryogen is by controlling the tank pressure, and thus the saturation conditions within the tank.
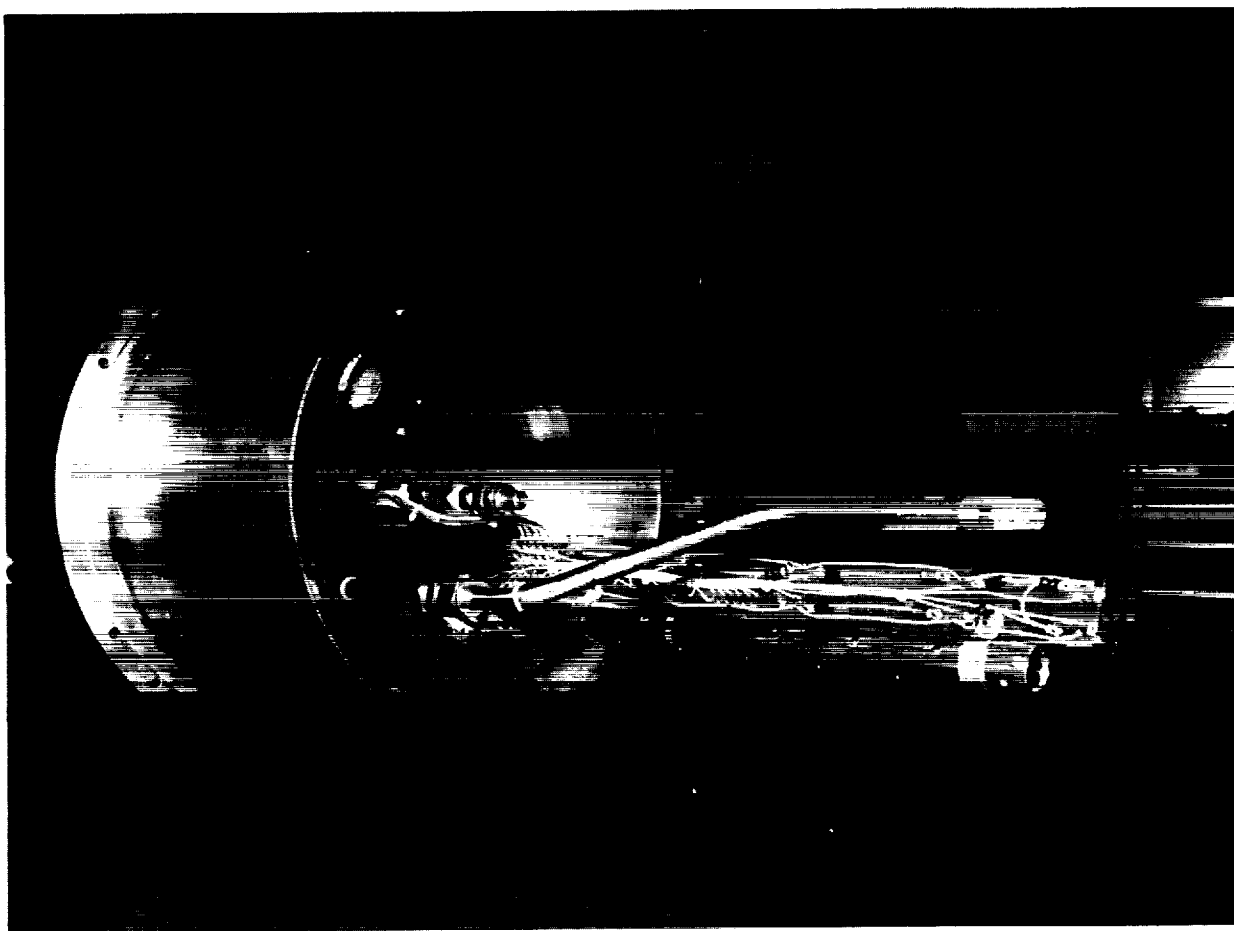
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Figure 3: Photograph of the large receiver lid assembly.

With the lid in place, the interior walls of the assembled receiver tanks form a cylindrical storage volume with domed ends. Piping penetrations include one line for venting, pressurization, and burst disk pressure relief. Two liquid lines are supplied for various liquid transfer configurations.

6

An additional penetration is provided for the liquid level probe. Routing methods for the instrumentation leads are identical to those for the supply tank.

Piping systems. Liquid lines are constructed of stainless steel, and vacuum jacketed or foam insulated throughout the rig. The rig is capable of transferring liquid cryogen between all of the dewars using a variety of fill configurations. One of the liquid lines of the large receiver is used for transfer of liquid back to the supply dewar following a no vent fill. A connection off this line also provides a means of directly dumping the liquid to atmosphere. Liquid line valves are pneumatically actuated and vacuum jacketed. Control electronics and power supplies for all the valves in the system are located in sealed, nitrogen purged cabinets.

The vent system is composed of stainless steel lines connected to each tank and the TVS. An air ejector system provides sub-atmospheric pressure control in the vent lines to as low as 2 psia. The system is comprised of four converging-diverging nozzles and one two stage nozzle, all connected in parallel. Service air at 120 psig supply pressure flows through the nozzles. The vent gas enters the nozzle upstream of the throat area, and is subsequently entrained in the air flow. Vent line control valves are pneumatically operated and explosion proof. Because the valves are not designed for cryogenic temperature service, finned pipe sections are located just downstream of the tanks to insure near ambient vapor temperatures within the vent lines before reaching the control valves.

Pressurization with helium, hydrogen, or nitrogen (during liquid nitrogen tests), is available for the supply and receiver tanks. A simplified piping schematic of the test rig is given in figure 4.

Structural systems. Structural support for the rig assembly is provided by a steel channel frame with casters. The casters ride in a hard mounted track which provides a means of moving the tanks during installation and change-out activities. The receiver tank is attached to a manually operated pneumatic support stand. The stand permits vertical and horizontal adjustment of the receiver tank. Since the two receiver dewars are of different size, this stand is needed to allow modular change-out of the dewars without modifying the associated system connections.

Piping systems for the rig are either self supported or mounted to the building structure of cell 7. A condensate trough is installed below any uninsulated piping which may become cold enough to liquify the ambient air. Overhead cable trays support all electrical lines used for control and instrumentation.
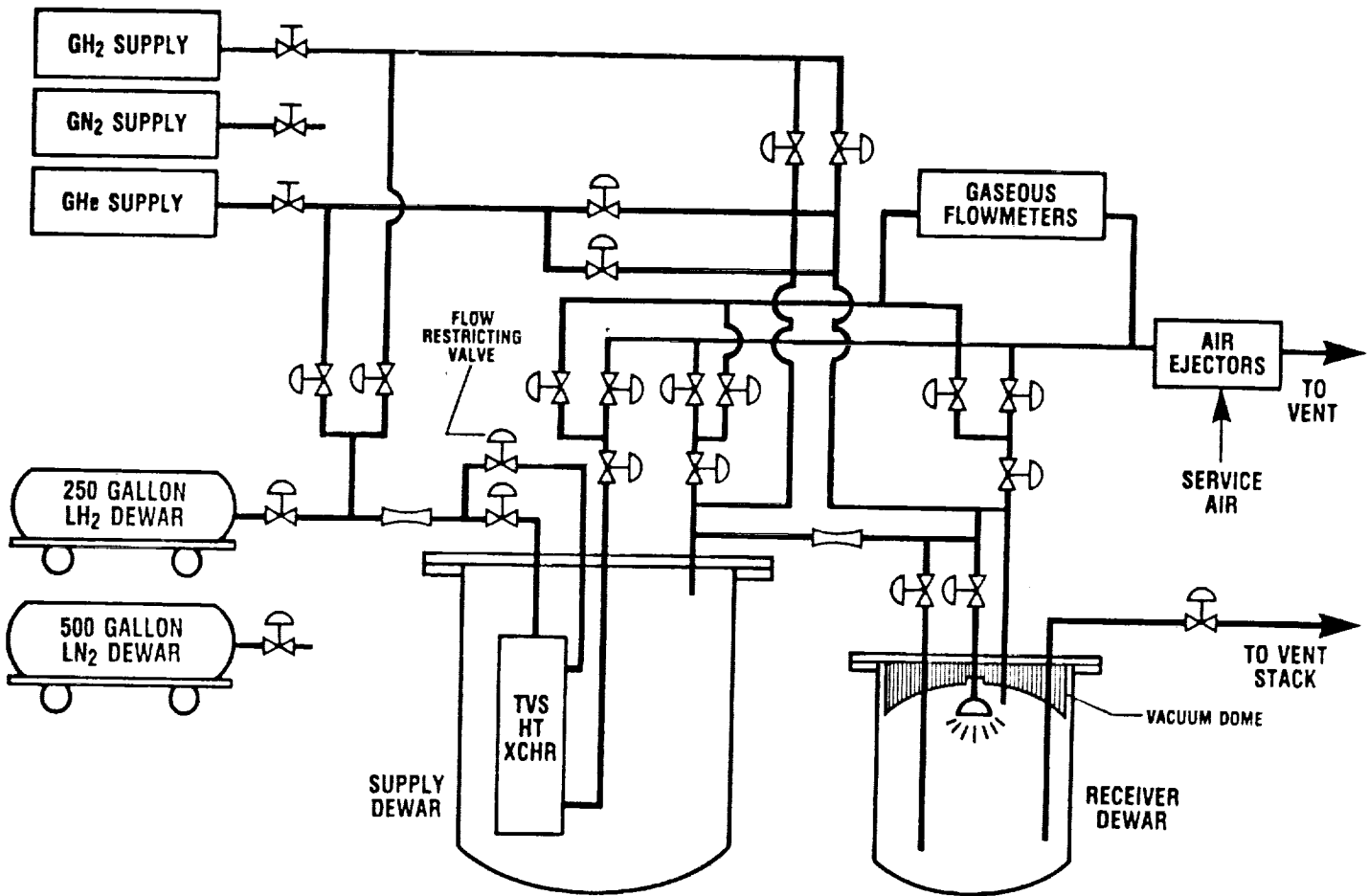
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Figure 4: Simplified piping schematic of CCL-7 test rig

Instrumentation

All power supplies and terminal blocks located within the test cell are enclosed in nitrogen purged cabinets. Rig instrumentation lines are routed to the control room via shielded cabling. In the control room, sensor readings are monitored with panel mounted LED and LCD displays, as well

as on the dedicated microcomputer screen while the data acquisition software is operating. A photograph of the control console is shown in figure 5.
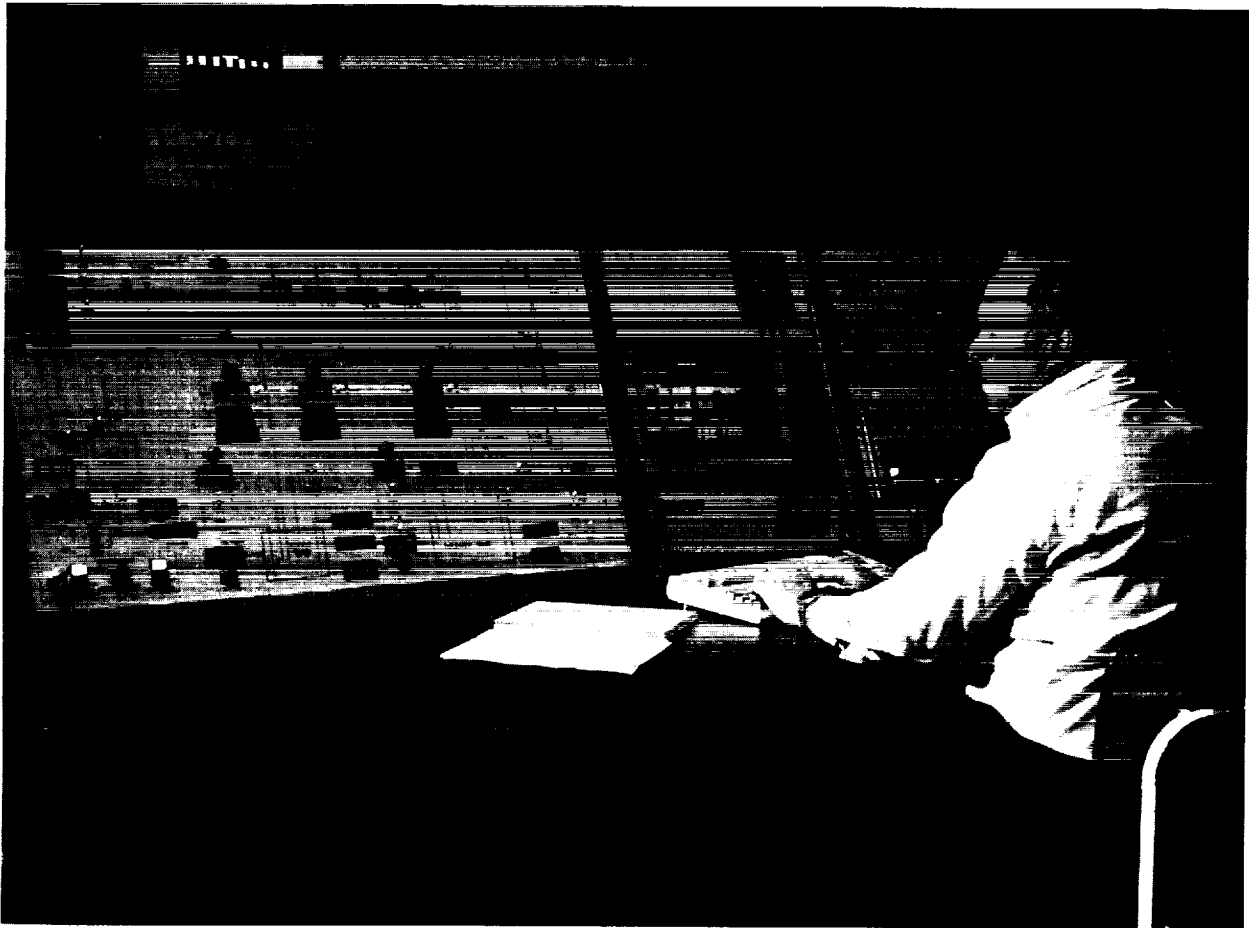

Figure 5: Photograph of the CCL-7 control console.

Temperature measurement. Temperature sensors are positioned throughout the rig on all tanks and selected lines and components. Temperature measurements are obtained with thermocouples and silicon diodes, and thermistors are utilized to indicate the presence of liquid or vapor. Figure 6 illustrates temperature sensor and thermistor locations for the supply and large receiver tanks.
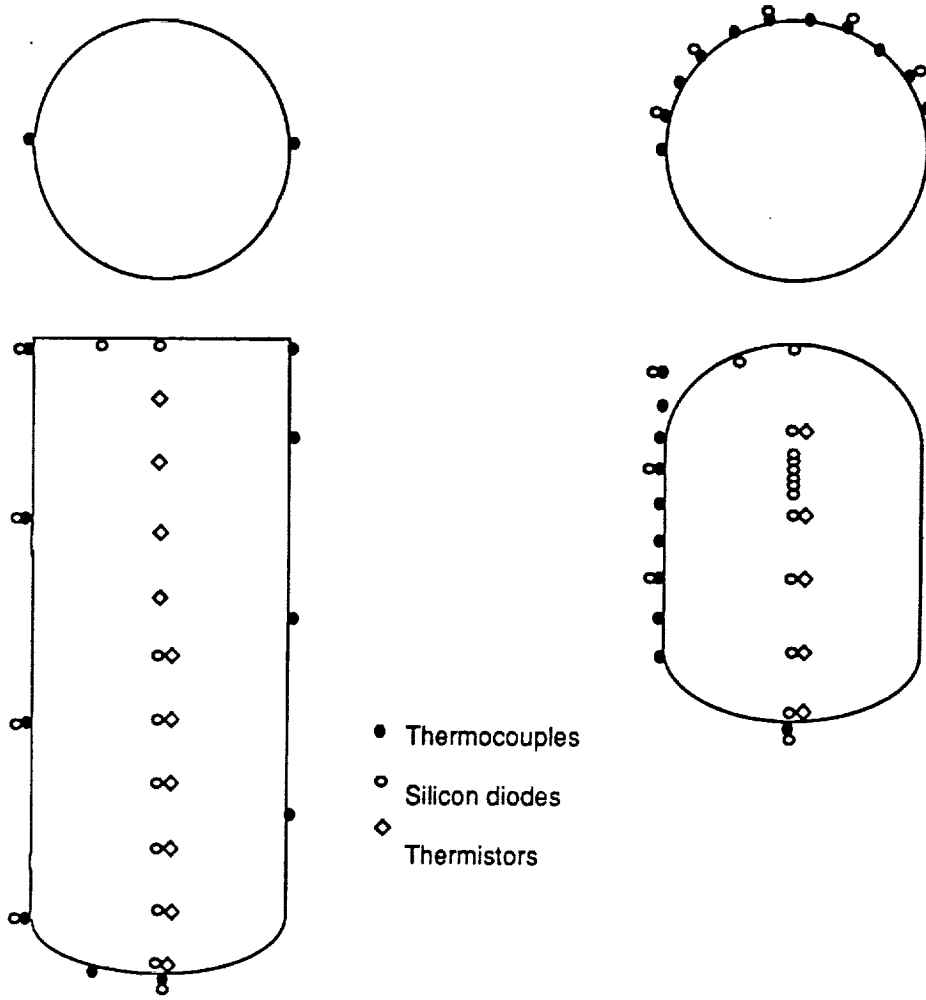
Supply Tank   Large Receiver Tank

Figure 6: Approximate locations of temperature sensors and thermistors for the supply and large receiver tanks.

Tank wall thermocouples and silicon diodes are located in the annular vacuum space of the supply and receiver tanks, and are mounted to the inner tank wall. The supply tank contains four

thermocouples[4] vertically spaced on the wall, two at the tank bottom, and an additional four thermocouples positioned 180 degrees circumferentially from the original array. Four silicon diodes are mounted in the same location as the first array of wall thermocouples, and one diode is positioned at the bottom of the tank. Two final silicon diodes are located on the inside lid of the supply tank.

Similarly, the large receiver tank contains 10 thermocouples vertically spaced on the tank wall along the same circumferential angle. At two different vertical heights, 21 thermocouples are placed around the tank wall in three inch circumferential increments. Fourteen silicon diodes are mounted next to selected thermocouples, and an additional two diodes are located on the inside lid. The small receiver is comparably instrumented with a total of 19 thermocouples and 7 silicon diodes.

Within each tank is an instrument tree containing silicon diodes and thermistors at varying heights. This tree is in direct contact with the tank contents, whether liquid or vapor. The supply dewar contains a total of 6 silicon diodes and 10 thermistors on the instrument tree. Alternately, both the large and small receivers have 11 silicon diodes and 5 thermistors each. Five of the tree diodes for the large receiver are located near the 70% height level, and spaced 0.25 inches apart. A similar diode array is installed in the small receiver near the 50% height level.

In addition to the tank wall and tree temperature measurements, other temperature sensors are placed in key locations throughout the rig. Thermocouples are positioned on the flange of each tank, and on all tank and TVS vent lines. Additional thermocouples monitor the liquid dump, valve prechill, and receiver tank return lines. Silicon diodes are mounted on the tank/TVS inlet and outlet lines, as well as on all venturi flowmeters.

Before testing, the tank wall mounted sensors were individually checked for proper location and operation. Other temperature sensors were validated during checkout tests.

Pressure measurement. Pressure transducers installed on the vent lines of both tanks and the TVS provide continuous internal pressure data on these components. Total pressure and pressure differential measurements are also available on all venturi flowmeters. Finally, a pressure sensor is installed in the exhaust line of the air ejectors.

Proper operation of all the pressure sensors was confirmed prior to testing. Calibrations were performed and checked, when indicated, with a portable flow control unit and pressure gauge.

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[4] All rig thermocouples are type T (copper-constantan)

Flow measurement. Mass flowrate through the liquid inlet lines of the supply and receiver tanks is calculated with venturi flowmeters. The flowmeters are instrumented with temperature and pressure taps as previously described. The combined vent line, which is connected to the vent lines of both tanks and the TVS, also utilizes a venturi flowmeter for mass flow measurements. One of the tanks or the TVS can be isolated to vent through the flowmeter to obtain a flowrate measurement for that component. Four additional thermal conductivity type mass flowmeters in varying sizes of 0.5, 5.0, 50.0, and 400.0 standard liters per minute, are also connected to the combined vent line in parallel. Vent flow can be channeled to any one of these mass flowmeters.

All flowmeters were calibrated prior to operation.

Liquid level. Liquid height as a percentage of total tank height is measured via a capacitance level probe. The probe is constructed of an outer and inner pipe which form an annular space where liquid and vapor accumulates. Holes are drilled in the outer pipe to allow inflow of cryogen into the annular space. The probe is mounted vertically within the tank, and capacitance measurements of the space between the pipes are made. The magnitude of the capacitance reading for a particular fluid is an indication of the fraction of liquid versus vapor resident in the annular space. In this way, the probe provides a measurement of the liquid height within the tank.

Each tank is equipped with a level probe. The probes were calibrated according to manufacturer instructions, and then checked using an open dewar of liquid nitrogen. Zero and span adjustments were made after submerging the probes into the LN_2 at 100%, 50%, and 0% of full length. Separate calibration settings were established for nitrogen and hydrogen. A final adjustment of the receiver probe was made with both fluids by comparing probe measurements with thermistor readings taken during no vent fills, liquid outflows, and quiescent boiloff tests. The thermistors indicated contact with either liquid or vapor at the discrete levels of 20%, 40%, 60%, and 80%. Discrepancies between the probe and thermistor readings at all heights was found to be less than +/- 2.5% for nitrogen, and +/- 5.4% for hydrogen.

DATA ANALYSIS

Data Acquisition

Measurements in the form of voltage signals from the various sensors at CCL-7 are transmitted to a multiplexer in the control room. The multiplexer performs an analog-to-digital (A/D) conversion of the voltage signals, and transmits the data for each channel to a dedicated microcomputer. Data

acquisition is controlled by the microcomputer which sends channel address and instrument gain information to the multiplexer needed for conversion and transmission of the data. Finally, a data acquisition program written in C language converts the digitized signals to a scale of integer counts. Nominally, 240 channels of data are taken on the test rig.

Data conversion. The data acquisition program performs several key functions required for operation of the rig. One function of the program, as mentioned previously, is the collection and conversion of the channel signals to a consistent system of integer counts. Manipulation of the data by the acquisition program is performed with the converted count values.

Count values are then changed to engineering units as needed in one of two ways. The first method is a look-up table based on manufacturer data for the instrument. The program enters the table with the measured count, and extracts the corresponding engineering value. This method is used for the thermocouples, silicon diodes, and thermistors.

The remaining instrumentation is converted using the full scale, and calibrated zero and span values of the sensor as follows,

$$\text{eng units} = K \ \frac{(\text{counts - zero})}{(\text{span})} \ (\text{full scale}) \tag{1}$$

Where K is a factor of ten used to set the decimal point in the final calculated value. Equation (1) is used for the pressure transducers, thermal conductivity type flowmeters, and capacitance level probes.

Data display. After converting the measured counts to engineering units, the data acquisition program performs a second primary function; data display. Real time monitoring of the rig instrumentation is available from LED and LCD indicators on the control panel, and the CRT monitor of the microcomputer. The control panel contains information on pertinent operational parameters such as system pressures, temperatures, and valve status. In addition to the LED/LCD displays, the control panel contains toggle switches, selector knobs, and continuously adjustable dials for control of system valves and fluid routing. Sensor display values are continuously updated by the data acquisition program. Instrumentation and control power buttons are also located on the panel, along with an emergency power-off button.

Data display on the microcomputer monitor consists of four separate screens. The first screen provides general sensor information on the overall rig including component temperatures and pressures, tank liquid levels, and venturi flowmeter temperatures and pressures. Displayed venturi flowmeter pressures are a running average of 64 samples in order to smooth out fluctuations in

13

instantaneous measurements. The second screen contains information specific to the supply dewar, along with integrated flowrate values for the two tanks and the TVS from the vent flowmeters. Supply tank thermistors, and wall and tree temperatures are included on this screen. The third screen indicates receiver tank parameters such as thermistors, and wall and tree temperatures. Also given on this screen is the receiver tank pressure, and an estimate of the average tank wall and instrument tree temperatures. A final screen contains miscellaneous data including vent temperatures for both tanks and the TVS.

Data storage and retrieval. A third key function of the data acquisition program is recording selected data for later retrieval. At the desired time, the rig operator selects a sampling rate and initiates the data recording function. The data acquisition program creates a binary file and writes a calibration header to the file containing information for converting the data to engineering units. After writing the calibration information, the program begins recording all count values for each data channel at the prescribed sampling rate. In addition to the channel data, the updated zero values for the vent flowmeters are written to the file to record any zero recalibrations performed during the test. A separate text file is also created to record any comments inputted during the test from the keyboard. At the completion of an experiment run, the operator ends the data recording session, and both the data and comment files are closed. The files remain resident on the microcomputer hard disk for future copying and/or archiving.

The fourth function of the program is retrieval of the recorded data for step-wise examination. The retrieval function recreates the four computer screens, and displays data for a given sample time or data set. Many editing features are available including instant recall of a particular data set, and incremental stepping forward or backward in time with any specified step size. An option is also available for displaying the data by engineering units, counts, or channel identification.

Lastly, the data acquisition program performs several utility functions needed for operation of the rig. These functions include control and calibration of the multiplexer, zero recalibrations of the vent flowmeters, calculation of an average instrument tree and wall temperature, and recording of the flowmeter switch positions and isolated vent line components.

Data Reduction

After a test run, the binary data file is copied to a floppy disk and transported to an office microcomputer for data reduction. The data reduction program, which is also written in C language, uses the calibration data at the beginning of the file to convert the data to engineering units. Calculated parameters such as fill level and mass flow are then computed. The following

description pertains to the reduction of no vent fill test data.

Calculated parameters. Fill level of the receiver tank is derived from the capacitance level probe readings by transforming the percent height measurement to percent fill level by volume. The bottom dome of the large receiver is an elliptical hemisphere, the mid-section is cylindrical, and the top dome is a spherical segment. Equations describing the volume of each of these tank sections as a function of axial height have been generated to transform the percent height measurement to percent full by volume.

Mass flow rate through the liquid venturi flowmeters is calculated from the fluid conditions measured at the flowmeter. Fluid density is primarily a function of temperature for the anticipated testing conditions. Therefore, a linear relation for both nitrogen and hydrogen density as a function of temperature only was derived. Discharge coefficients for the flowmeters are extrapolated from water calibration curves. A fitted exponential equation is used, and the Reynolds number is evaluated with either hydrogen or nitrogen properties, as appropriate.

Final data records and plotting. After calculating the mass flows and liquid levels for each time increment, the reduced data is written to four text files in tabular form. The first file contains general information on the receiver dewar including pressure, fill level, inlet liquid flowrate, and inlet liquid temperature. Included in the second file is instrument tree temperatures, while the third file has wall temperature data. The final file of tabular data contains tree temperature measurements from the array of silicon diodes located near the 70% height level. Each file also has the data set number and elapsed time recorded.

These generated tables are copied to floppy disks for distribution and subsequent editing. Data from the tables is also used to plot various test parameters. A sample of some of these plots is presented in the "Results and Discussion" section.

An estimate of the average initial tank wall temperature is calculated for inclusion in selected data plots. The average temperature is arrived at by assuming a linear temperature distribution in the tank wall, based on temperatures measured by the mounted sensors. The tank wall is then divided into sections, and associated wall volumes are calculated. Linearized temperature data for each section is weighted based on the volume for that section. The final average wall temperature is then calculated as an arithmetic mean of these weighted temperatures.

TEST PROCEDURE

Prior to full scale testing, a number of pretest activities were performed to characterize the system and verify its operational readiness. Liquid nitrogen was loaded into the rig, and all components were tested for leaks. Instrumentation was checked and adjusted where necessary for proper operation.

No Vent Fills

Performance of a no vent fill test involves five sequential steps:

1. System purge: The system is pressurized to 25 psia with gaseous helium and checked for leaks. The helium is then vented through the air ejectors. This purge cycle is repeated a total of four times, with leak detection performed on the first cycle only.

2. Filling the supply dewar and conditioning the cryogen: The supply dewar is filled from the roadable dewar with enough liquid to perform the planned test. With the supply tank filled, the liquid is thermally conditioned using either the TVS, or by adjusting the tank pressure. When using tank pressure to set the liquid saturation temperature, the tank is pressurized with gaseous pressurant for conditions above atmospheric. Conversely, the air ejector system is utilized for achieving pressures below one atmosphere.

3. Prechill of the transfer line: With the cryogen conditioned to the desired temperature, the supply tank is pressurized for liquid transfer. The transfer line and associated components (e.g. valves, fittings, etc.) are then prechilled with a low flowrate of liquid.

4. Receiver tank chilldown: The receiver tank pressure is reduced below atmospheric with the air ejectors. A charge of liquid is then loaded into the receiver tank with the vent valve closed. The vent remains closed while the liquid boils, thus removing heat from the tank walls. When the tank pressure reaches a predetermined maximum or stabilizes, the vent valve is opened. Additional cooling is achieved as the tank pressure is once again brought below one atmosphere using the air ejector system. The resulting charge-hold-vent cycle is repeated until the tank wall temperature is reduced to the desired starting condition.

5. No vent fill: In the final step, the liquid cryogen is transferred from the supply to the receiver tank until the receiver is filled, or until the pressure reaches a predetermined maximum value.

RESULTS AND DISCUSSION

To date, four nitrogen and five hydrogen no vent fills have been performed with the CCL-7 rig. All tests have been conducted using a 120 degree full cone nozzle spraying liquid droplets from the top of the large receiver tank. A sketch of this filling configuration is presented in figure 7.
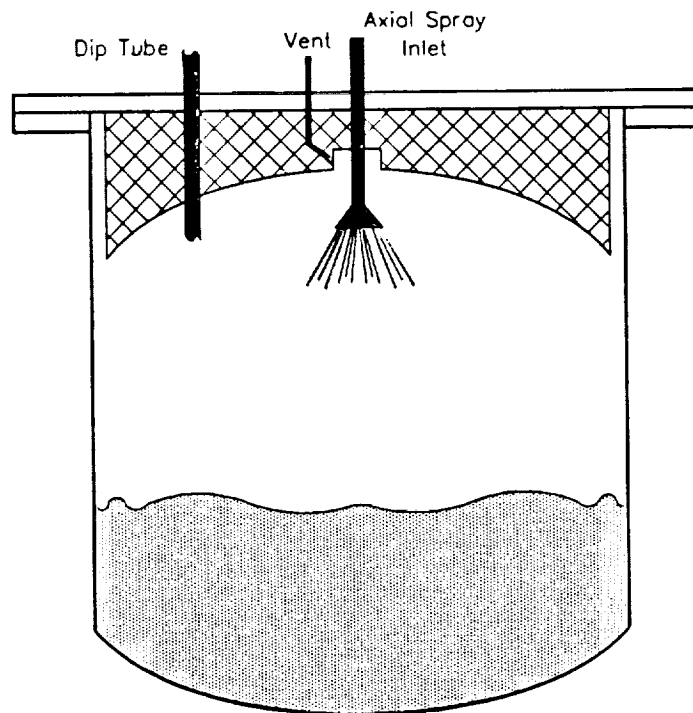

Figure 7: Fill configuration used for no vent fills in CCL-7.

Figure 8 illustrates a plot of the receiver tank pressure as a function of time from one of the hydrogen tests. The liquid inlet temperature for this test averaged 34 °R, with an average mass flowrate of 1.36 lbm/min. The no vent fill was initiated with the receiver tank at 3.6 psia, and an estimated average wall temperature of 103 °R.
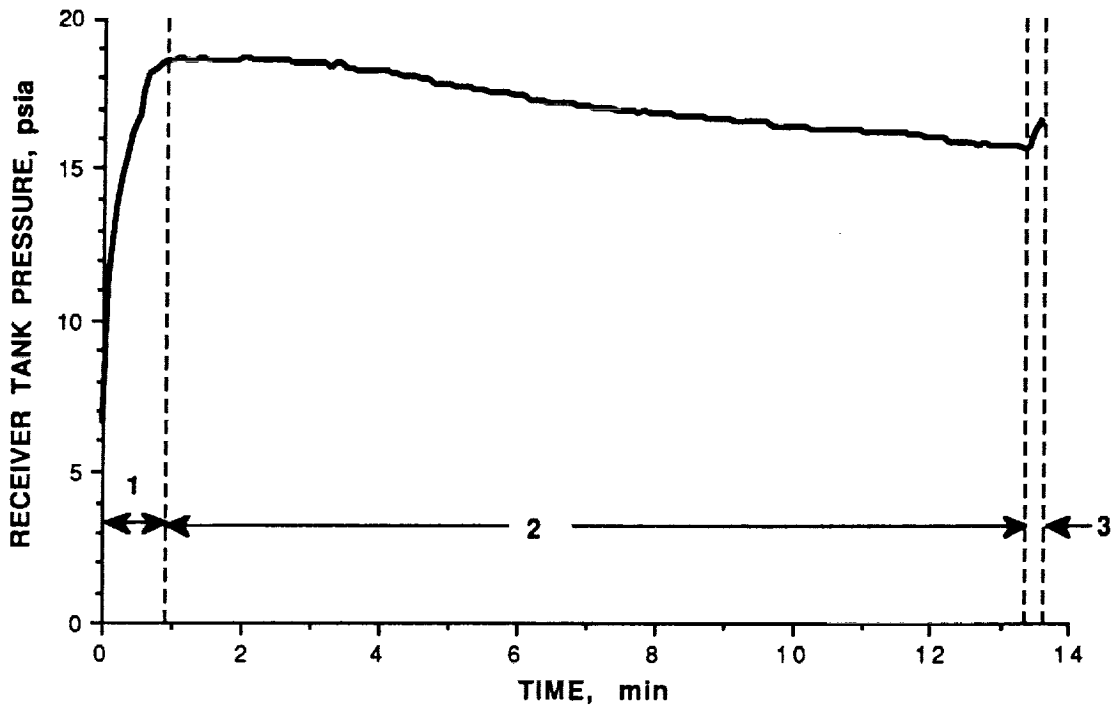
FIGURE 8: Tank pressure as a function of time for hydrogen no vent fill test at CCL-7 (test label H2), and the three distinct pressure regions.

No vent fill tests conducted at CCL-7 exhibit three distinct time dependent pressure regions as indicated by the labels 1, 2, and 3 in figure 8. The first region is a period of rapid boiloff as the incoming liquid spray impinges on the tank wall and absorbs its thermal energy. This region is characterized by a steep pressure rise in the receiver tank. For the test presented, the tank pressure reaches a maximum of 18.7 psia. In the second region, the slope of the pressure curve either decreases or becomes negative for the filling technique employed. At this point in the fill process, boiling of the liquid cryogen decreases, and the effect of ullage vapor condensation onto the incoming liquid droplets becomes more evident. The magnitude and sign of the pressure curve slope in region 2 is dictated by the competing processes of condensation and boiling within the tank. For the test of figure 8, the mass transfer due to condensation is greater than that transferred by boiling, resulting in a gradual pressure decrease with time (i.e. negative pressure curve slope).

The tank pressure at the end of region 2 is 15.7 psia.

18

Region 3 develops as the spray nozzle begins to be submerged by the rising liquid interface. As the nozzle is covered, condensation on the liquid droplets ceases, and the pressure rises suddenly as the ullage is compressed. For this test the final tank pressure reaches 16.6 psia.

A plot of liquid fill level versus time for the same no vent fill test is presented in figure 9. The three previously described regions are marked for reference.
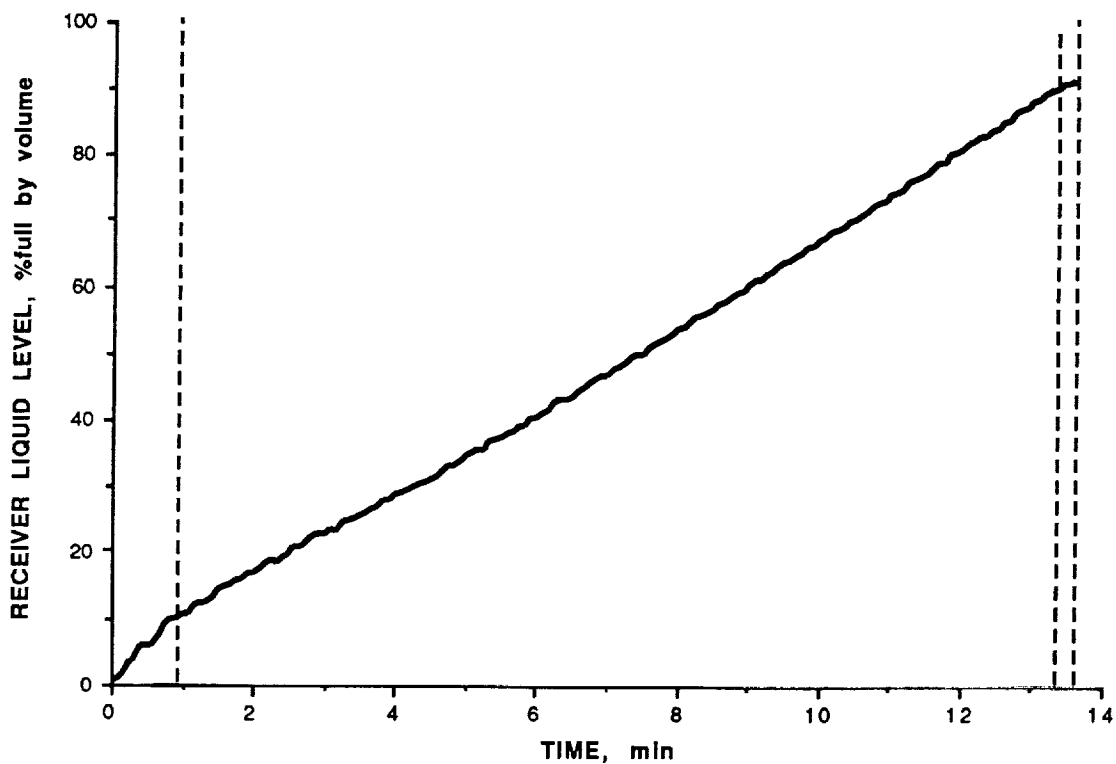

FIGURE 9: Liquid fill level as a function of time for hydrogen no vent fill at CCL-7 (test label H2), and the three distinct pressure regions.

The liquid filling rate of figure 9 decreases with time toward the end of region 1, as indicated by a gradual reduction in the slope of the liquid level curve at this point. The rapid pressure rise in the receiver tank in this region reduces the differential pressure between the supply and receiver tanks, thus lowering the mass flow rate. Liquid level at the end of this region is 10.0%. In the second

region, the liquid level curve is relatively linear, indicating a virtually constant flow rate. A fill level of 89.9% is reached at the end of region 2. Finally, in the last region, The flowrate is reduced as the pressure rapidly rises due to ullage compression. The final fill level for this hydrogen test was 90.8%.

Transient instrument tree temperature data for the first minute of the same hydrogen no vent fill is plotted in figure 10. Plot labels indicate vertical height from the tank bottom, and are nominal.
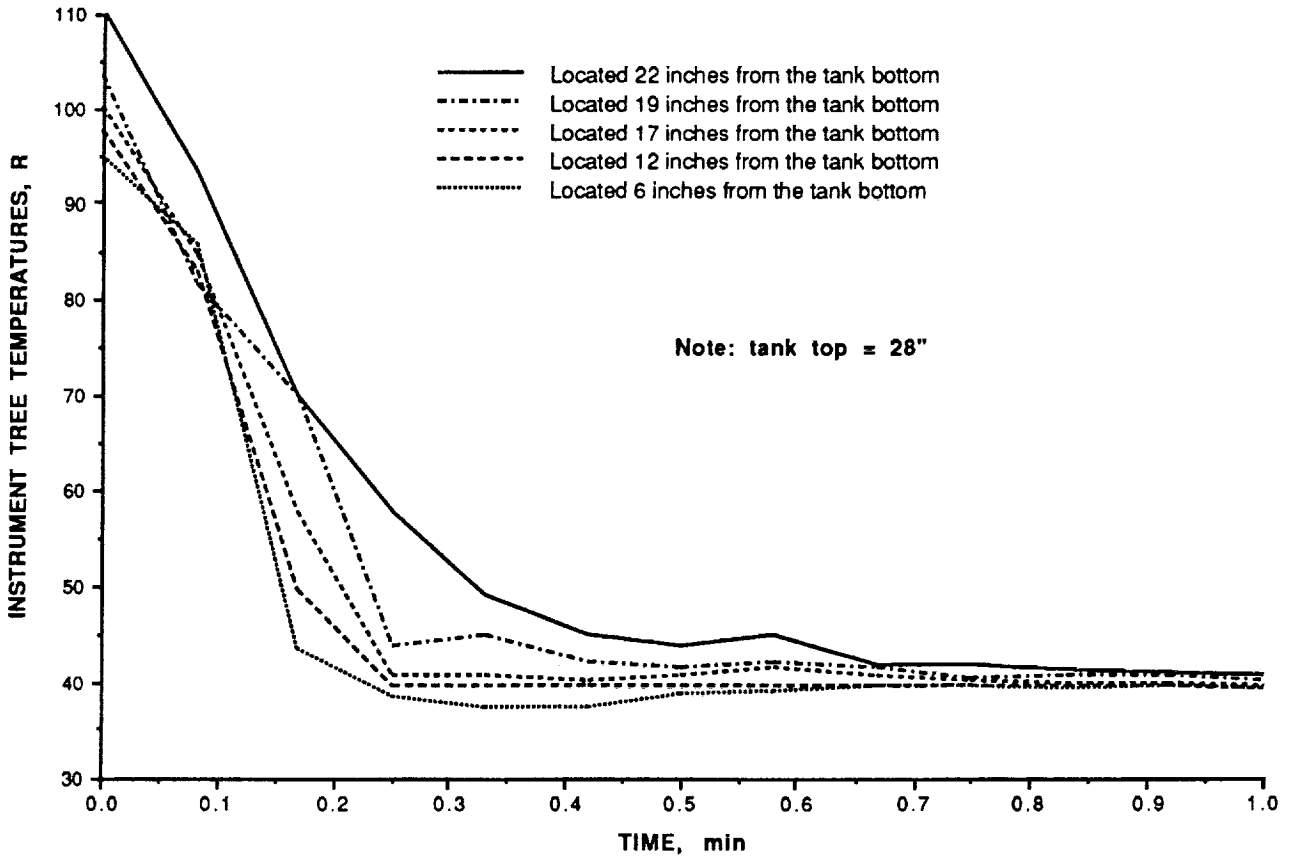

FIGURE 10: Instrument tree temperature data as a function of time for the first minute of hydrogen no vent fill test at CCL-7 (test label H2).

Tree temperatures decrease rapidly during the initial moments of this no vent fill. In fact, one minute into the test, all tree temperature sensors are within 2 °R or less of each other, and remain so for the balance of the test. This behavior is indicative of both the hydrogen and nitrogen fills performed with the inlet spray nozzle configuration. However, the time lag for convergence of the tree temperatures during nitrogen tests is somewhat longer (e.g. five minutes), and the maximum temperature difference between sensors is on the order of 10 °R.

Wall temperature data for this test is presented in figure 11. The upper plot indicates temperature data for the first one minute of the no vent fill, while the lower plot represents the remainder of the test. Once again, plot labels denote nominal height from the tank bottom.

Examination of figure 11 indicates that all but the top two wall sensors drop rapidly in temperature, much like the instrument tree temperatures. Note that the 21 inch and top sensors are located above the point where the inlet spray impinges the wall. Once again, this trend is indicative of all the no vent fills performed to date, with a similar time lag difference between nitrogen and hydrogen tests as noted previously for the tree temperature data.

A composite graph of pressure versus time for all preliminary nitrogen no vent fills performed at CCL-7 to date is presented in figure 12. Table I lists pertinent parameters for these tests.

Table I: Test parameters for nitrogen no vent fills at CCL-7.

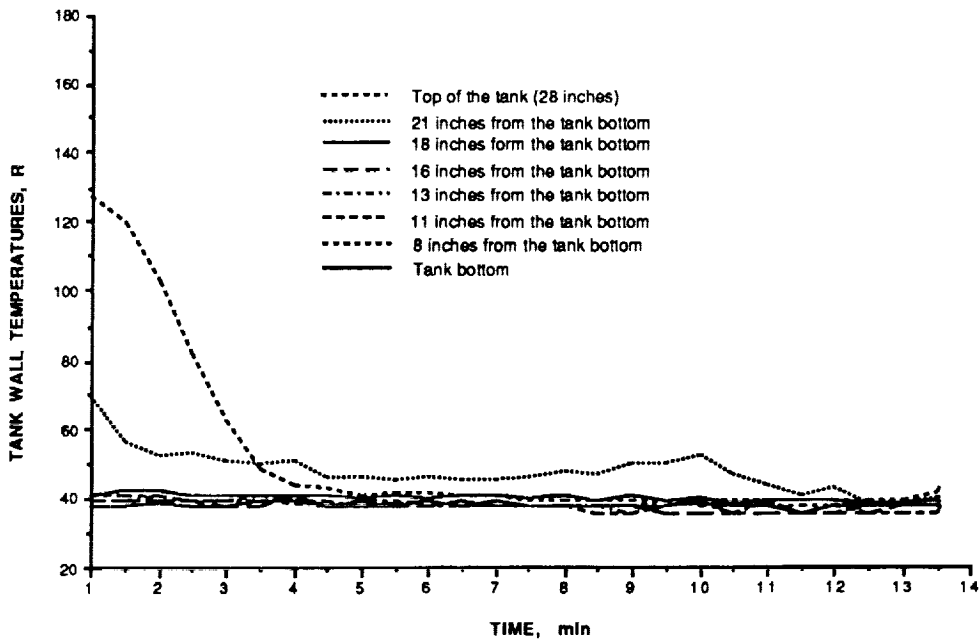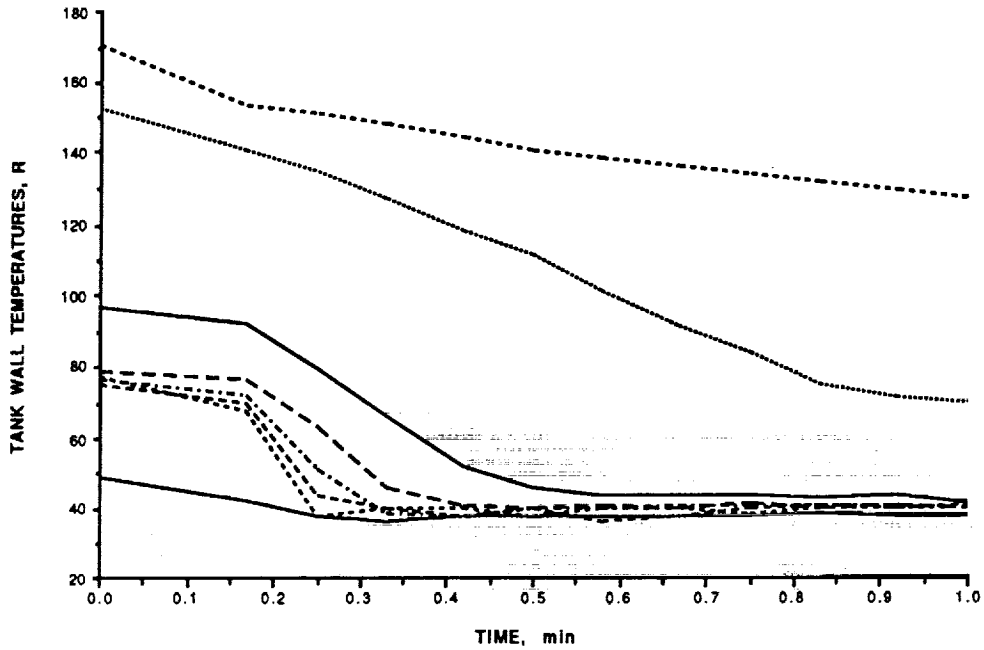| Test label	N3	N2	N1	N4
Liquid inlet temperature, average, °R	122	126	131	143
Initial wall temperature, estimated, °R	299	273	223	176
Inlet mass flowrate, average, lbm/min	11.2	10.7	7.9	7.1
Initial receiver pressure, psia	4.5	3.9	3.6	4.9
Final fill level, %full by volume	97	98	93	90

FIGURE 11: Tank wall temperature data as a function of time for hydrogen no vent fill test at CCL-7 (test label H2).
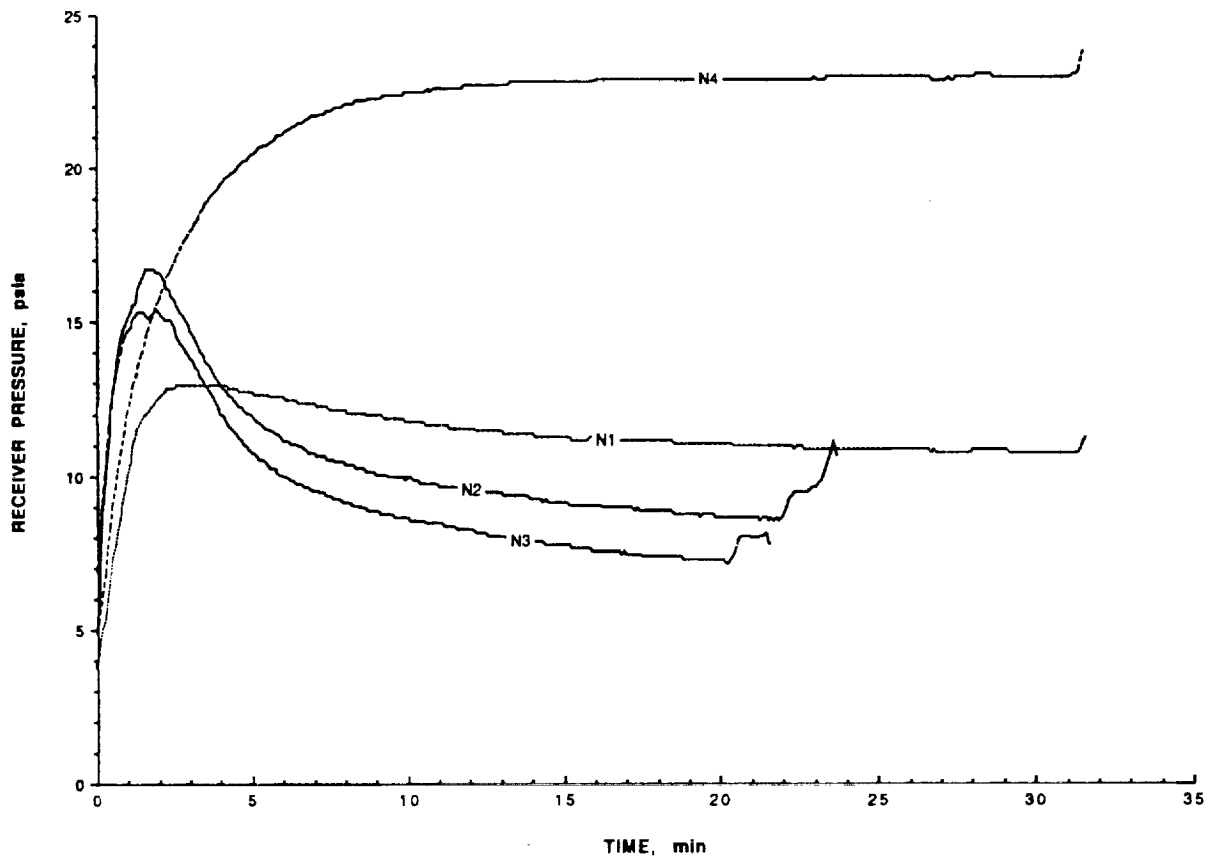
Figure 12: Composite graph of receiver tank pressure as a function of time for nitrogen no vent fills at CCL-7.

The no vent fills represented in figure 12 all exhibit the three pressure response regions described earlier. However, the shape of the curves, and the final tank pressure, vary significantly among the fills as a result of the test conditions. A primary parameter effecting the pressure history in these tests is the inlet liquid temperature. In general, the pressure curve starts to drop in region 2, and the time varying pressure values tend to be less, as the inlet liquid temperature is lowered. Other conditions listed in table I also contribute to the tank pressure response.

At the completion of the no vent fills of figure 12, all liquid fill levels were greater than 90%. For tests N2 and N3, the fill level met or exceeded 97% .

Figure 13 shows a similar composite graph of all the preliminary hydrogen no vent fills performed at CCL-7. Table II presents test conditions for this set of data.

Table II: Test parameters for hydrogen no vent fills at CCL-7.

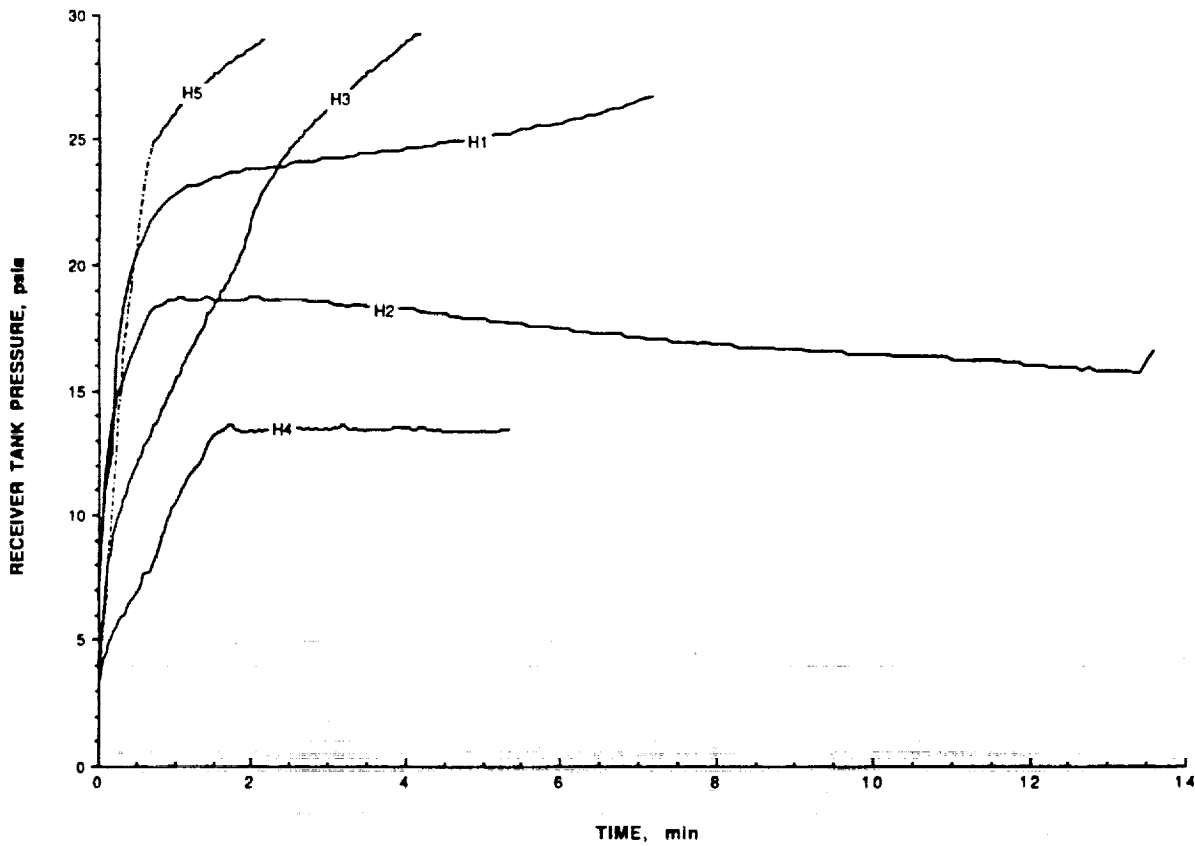| Test label	H4	H2	H1	H5	H3
Liquid inlet temperature, average, °R	34	34	38	39	41
Initial wall temperature, estimated, °R	55	103	111	90	75
Inlet mass flowrate, average, lbm/min	3.05	1.36	1.31	1.28	1.89
Initial receiver pressure, psia	3.1	3.6	3.7	4.0	3.8
Final fill level, %full by volume	86	91	45	14	39

Figure 13: Composite graph of receiver tank pressure as a function of time for hydrogen no vent fills at CCL-7.

24

Examination of the test conditions of table II again indicates that inlet liquid temperature is a driving parameter which dictates the shape and magnitude of the tank pressure curve. Unlike the nitrogen tests, however, high fill levels were difficult to achieve with hydrogen. In fact, test H2 was the only hydrogen no vent fill to reach 90%, with H4 achieving the next highest final fill level of 86%. Since H2 was the singular hydrogen test with a final fill level of 90% or greater, its pressure curve is the only one exhibiting the region 3 pressure rise corresponding to submersion of the spray nozzle.

CONCLUDING REMARKS

The Liquid Transfer Cryogenic Test Facility in CCL-7 provides a versatile tool for experimentation with cryogenic liquid storage, handling, and transfer. With the availability of two well instrumented tanks, and a third interchangeable tank, the test rig is equipped to carry out detailed cryogenic fluid handling experiments in a 1-g environment.

Initial testing completed at CCL-7 with nitrogen and hydrogen indicates that no vent fills in excess of 90% full are achievable with these fluids. Using the described test configuration and procedures, 90% fill levels were accomplished with nitrogen at inlet liquid temperatures as high as 143 °R, and an average tank wall temperature of nearly 300 °R. This inlet temperature corresponds to a saturation pressure of 19 psia for nitrogen. Hydrogen was found to be considerably more difficult to transfer without venting. The highest temperature conditions resulting is a fill level greater than 90% were with an inlet liquid temperature of 34 °R, and an estimated tank wall temperature of slightly more than 100 °R. Saturation pressure for hydrogen at 34 °R is approximately 10 psia. All tests were performed with a top mounted, 120 degree full cone, droplet spray nozzle. Maximum receiver tank pressure was limited to 30 psia.

The shape of the time varying pressure curve for no vent fill tests using the fill technique described is characterized by three distinct regions. These regions are delineated by: 1) an initial steep pressure rise as the incoming liquid boils rapidly due to impingement on the warm tank walls, 2) a sizable decrease and possible sign change of the pressure curve slope as boiling decreases and the effects of condensation of the ullage vapor on the incoming droplets becomes more evident, and 3) a sudden pressure rise as the liquid interface begins to submerge the inlet nozzle. Region 3 develops only in those tests which exceed the 90% fill level by volume for the test configuration employed.

Inlet liquid temperature appears to be a primary parameter effecting the shape and magnitude of the pressure curve for no vent fills with both nitrogen and hydrogen. Other test conditions, however,

also play a role in the pressure history.

Instrument tree temperature data taken during the tests indicates a rapid cooling of the ullage vapor at the start of liquid injection into the tank. The sensors are mounted at varying vertical heights within tank, and quickly converge toward a narrow temperature band as the no vent fill begins. The width of the temperature band, and the time response of the sensors is notably different between hydrogen and nitrogen.

Response of most of the wall mounted sensors is similar to that of the tree temperature indicators. The two exceptions are wall sensors mounted above the point where the inlet spray cone contacts the tank wall. These two sensors react more slowly, presumably from the effects of axial wall conduction and heat transfer with the vapor alone.

REFERENCES

1. DeFelice, D.M., and Aydelott, J.C., " Thermodynamic Analysis and Subscale Modeling of Space-Based Orbit Transfer Vehicle Cryogenic Propellant Resupply", AIAA Paper 87-1764, NASA TM-89921, June 1987.

2. Chato, D.J., "Thermodynamic Modeling of the No-Vent Fill Methodology for Transferring Cryogens in Low-Gravity", AIAA Paper 88-3403, July, 1988 (NASA TM-100932).

3. Papell, S.S., and Nakanishi, S., "Portable Cryogenic Research Test Apparatus Test Plan", Internal report, Cryogenic Fluids Technology Office, NASA Lewis Research Center, Cleveland, OH, July 8, 1988.

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16. Abstract

The Liquid Transfer Cryogenic Test Facility is a versatile testbed for ground-based cryogenic fluid storage, handling, and transfer experimentation. The test rig contains two well instrumented tanks, and a third interchangeable tank, designed to accommodate liquid nitrogen or liquid hydrogen testing. The internal tank volumes are approximately 18, 5, and 1.2 cubic feet. Tank pressures can be varied from 2 to 30 psia. Preliminary no vent fill tests with nitrogen and hydrogen have been successfully completed with the test rig. Initial results indicate that no vent fills of nitrogen above 90% full are achievable using this test configuration, in a 1-g environment, and with inlet liquid temperatures as high as 143 °R, and an average tank wall temperature of nearly 300 °R. This inlet temperature corresponds to a saturation pressure of 19 psia for nitrogen. Hydrogen proved considerably more difficult to transfer between tanks without venting. The highest temperature conditions resulting in a fill level greater than 90% were with an inlet liquid temperature of 34 °R, and an estimated tank wall temperature of slightly more than 100 °R. Saturation pressure for hydrogen at this inlet temperature is 10 psia. All preliminary no vent fill tests were performed with a top mounted full cone nozzle for liquid injection. The nozzle produces a 120 degree conical droplet spray at a differential pressure of 10 psi. Pressure in the receiving tank was held to less than 30 psia for all tests.

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