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Preprototype Nitrogen Supply Subsystem Development

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Life Systems, Inc.

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LIST OF ACRONYMS

A/D	Analog/Digital
APU	Auxiliary Power Unit
BID	Built-in Diagnostic
C/M I	Control/Monitor Instrumentation
CPU	Central Processing Unit
CRT	Cathode Ray Tube
DARS	Data Acquisition and Reduction System
EC/LSS	Environmental Control/Life Support System
EPR	Ethylene Propylene Rubber
EVA	Extravehicular Activity
FTDT	Fault Detection and Trend Analysis
GC	Gas Chromatograph
I/O	Input/Output
NGM	Nitrogen Generation Module
NPC	Nitrogen Purge Controller
NSS	Nitrogen Supply Subsystem
OpC	Operations Controller
OPCON	Operating Mode Control Module
PFC	Power-Failure Control
PM	Pressure Monitor
PWRUP	Power-Failure Control Module
RTE	Real-Time Executive
SOC	Space Operations Center
SYSACT	System Action Word
TeCM	Temperature Controller/Monitor
TSA	Test Support Accessories

SUMMARY

Life Systems, working with the National Aeronautics and Space Administration, is developing a Nitrogen Supply Subsystem based on the dissociation of hydrazine into a mixture of hydrogen and nitrogen. The latter is separated to provide makeup nitrogen to control the composition of spacecraft atmospheres. Recent advances in specific hardware developments have resulted in the design and fabrication of a nominal 3.6 kg/d (8 lb/d) nitrogen generation module. The design integrates a hydrazine catalytic dissociator, three ammonia dissociation stages and four hydrogen separation stages into a 33 kg (73 lb), 14 dm^3 (0.5 ft^3) module. A technique has been devised to alternate the ammonia dissociation and hydrogen separation stages to give high nitrogen purity in the end product stream. Tests have shown the product stream to contain less than 0.5% hydrogen and 10 parts per million ammonia.

The program accomplishments are presented in this Final Report. Specifically, the Report describes the design and development of a test stand for the Nitrogen Generation Module and a series of tests which verified its operation and performance capability. Over 900 hours of parametric testing were achieved. The results from this testing were then used to design an advanced Nitrogen Generation Module and a self-contained, preprototype Nitrogen Supply Subsystem.

The preprototype Nitrogen Supply Subsystem is designed to supply nitrogen at a nominal generation rate of 4.4 kg/d (9.6 lb/d) with a range of 1.4 to 9.1 kg/d (3 to 20 lb/d). It consists of three major components - nitrogen generation module, pressure controller and hydrazine storage tank - and ancillary components. The Nitrogen Generation Module is an advanced version of the module tested in this program and offers several improvements. The most important is the elimination of all sealing surfaces, achieved with a total welded or brazed construction. Additionally, performance was improved by increasing hydrogen separating capability by 20% with no increase in overall packaging size. The advanced module is projected to weigh 28 kg (62 lb), a 15% reduction compared to the current version, and have a smaller envelope. The pressure controller, a design based on prior Life Systems' developments, contains two pressure regulators and two pressure sensors in a single, 3.2 kg (7.1 lb) package.

The mechanical assembly of the Nitrogen Supply Subsystem is projected to weigh 54 kg (118 lb), have an envelope of 56 x 51 x 36 cm (22 x 20 x 14 in) and consume 113 W. A separate control and monitor instrumentation suitable for the next development level was also designed. The results and details of both assemblies are contained within this report.

INTRODUCTION

Future long-term manned spacecraft missions will utilize an atmosphere of nitrogen (N_2) and oxygen (O_2). Space vehicle gas leakage and airlock repressurizations following extravehicular missions necessitate on-board storage of the primary cabin atmospheric constitutents: N_2 and O_2. The N_2 component of the air can be stored as liquid hydrazine (N_2H_4) and the N_2H_4 catalytically dissociated to an N_2 and hydrogen (H_2) mixture. The N_2/H_2 mixture can then be separated to yield the makeup N_2. The byproduct H_2 can be used in the reduction of metabolically generated carbon dioxide (CO_2) in a regenerative Environmental Control/Life Support System (EC/LSS).

This N_2 Supply Subsystem (NSS) concept using liquid N_2H_4 as the stored form of N_2 reduces tankage and expendables weight compared to high pressure gaseous or cryogenic liquid N_2 storage. The advantage of supplying N_2 through N_2H_4 compared to other storage methods is shown in Figure 1. These trade curves are for the National Aeronautics and Space Administration's (NASA's) projected Space Operations Center (SOC), an eight-person mission with a 90-day resupply period. The estimated air leakage rate for the SOC is 5.5 kg/d (12 lb/d) corresponding to the 4.4 kg/d (9.6 lb/d) N_2 leakage rate indicated. At this value, an NSS saves 25 to 35% of equivalent weight compared to gaseous or cryogenic storage. If the H_2 is used for CO_2 reduction, an additional 300 kg (660 lb), or 30% is saved.

Incorporating the N_2H_4-based NSS into advanced missions like SOC will cause no problems and has certain advantages. Hydrazine will be available since it is used for other purposes (e.g., propulsion). Therefore, there are no added special transporting or handling considerations. The technology is simple and mature. The present concept and hardware development, sponsored by the NASA and Life Systems, Inc. (LSI), has progressed to a stage where NSS flight hardware can be available for the SOC or other missions.

Background

The NSS utilizing N_2H_4 catalytic dissociation and N_2/H_2 separation has evolved through NASA sponsorship under Contracts NAS2-7057, NAS2-8732 and NAS2-10096. The concept has progressed from individual N_2/H_2 separator and N_2H_4 catalytic dissociator breadboards through the combination of the separator and dissociator hardware into an engineering breadboard NSS and finally to the operation of the breadboard NSS as part of an integrated, experimental Air Revitalization System. Included in these activities was the development of a staged NGM which integrates the dissociation and separation processes into a single unit. Staging is employed (i.e., alternate separation and dissociation stages) to eliminate ammonia (NH_3) contamination of the product N_2 stream.

During an earlier program[1] Life Systems identified two attractive N_2 generation systems based on the catalytic dissociation of N_2H_4. In the first system, liquid N_2H_4 was catalytically dissociated to yield an N_2/H_2 gas mixture. Separation of the gas mixture to yield N_2 and byproduct H_2 was accomplished using a Polymer-Electrochemical N_2/H_2 Separator.[2,3] In the second system, the N_2/H_2 product gas from the dissociator was separated in a palladium/silver (Pd/Ag) N_2/H_2 Separator.

The above referenced program culminated in the successful design, fabrication and testing of an N_2H_4 catalytic two-stage Pd/Ag Separator. Based on the results of this program it was recommended that an N_2 generation system, and subsequently an NSS, be developed based on N_2H_4 catalytic dissociation and the Pd/Ag method of N_2/H_2 separation.

(1) References cited are at the end of this report.

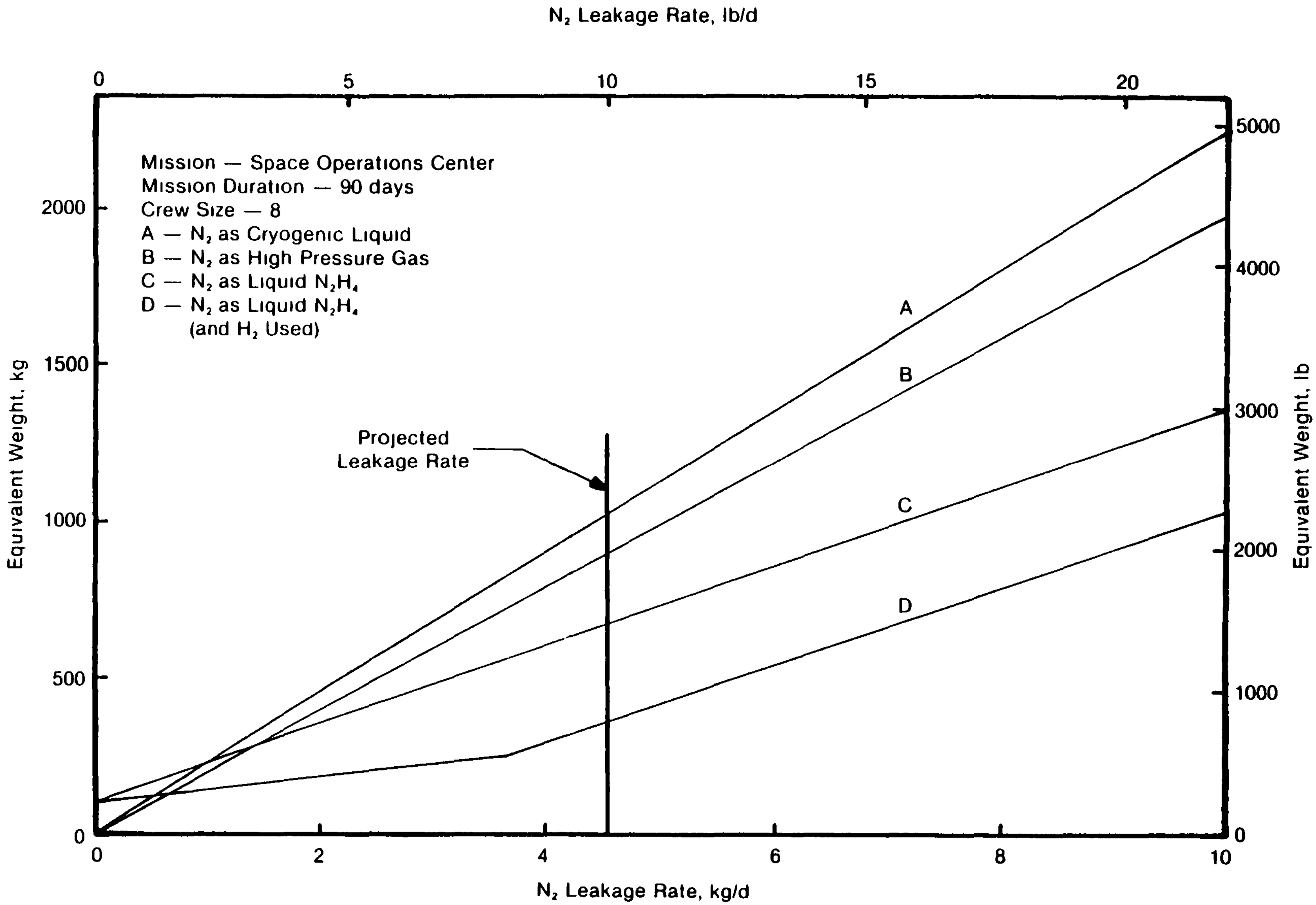

FIGURE 1 CANDIDATE NITROGEN SOURCE TRADE-OFF

During a following program,[4-6] LSI developed and tested various components of the NSS including a N_2 Generation Module (NGM), N_2H_4 storage and advanced instrumentation. Tests were conducted to support the development of the NGM and to advance NSS technology. The current program continues the NSS development by designing a preprototype NSS using an advanced NGM and computer-based instrumentation. This development step is based on additional characterization and parametric testing of the prior NGM and incorporation of certain improvements in its design.

Program Objectives

The objectives of the current program were to develop a preliminary design of a preprototype NSS including an advanced NGM with passive thermal control and optimized reactor/gas separation stages. Prior to beginning the preprototype hardware design, existing NGM hardware was tested to generate the technology data base required for an advanced NGM design. This advanced NGM was then incorporated in the preprototype NSS design.

Program Organization

To meet the above objectives the program was divided into five tasks plus the documentation and program management functions. The five tasks were:

1. Design, fabricate and checkout an NGM test stand to support characterization and parametric testing of an existing NGM.

2. Accumulate an NGM data base using the NGM previously developed under Contract NAS2-10096.

3. Design an advanced NGM based on the results of prior testing and having goals of passive thermal control and elimination of mechanical sealing surfaces.

4. Design a preprototype NSS including the advanced NGM, N_2H_4 storage and feed mechanism, ancillary components and advanced Control/Monitor Instrumentation (C/M I).

5. Complete the design of the NSS Test Support Accessories (TSA) needed to simulate NSS and spacecraft interfaces and resources.

Report Organization

This Final Report covers the work performed during the period June, 1980 through May, 1982. The following two sections present the technical results grouped according to (1) NGM Development and Testing and (2) Preprototype NSS Design. These sections are followed by Conclusions and Recommendations based on the work performed.

NITROGEN GENERATION MODULE DEVELOPMENT AND TESTING

The function of the NGM is to generate N_2 and byproduct H_2 from liquid N_2H_4. The NGM consists of alternate catalytic dissociation and H_2 separation stages configured to give high purity N_2 and H_2. The dissociator and separator stages are packaged as a single unit to minimize heat rejection to ambient since both operate at elevated temperatures. The single package concept also allows the heat generated during the dissociation of N_2H_4 to reduce the heater power required to maintain the NGM at operating temperature.

The objective of prior development activities was to develop the initial NGM hardware required to (a) demonstrate and verify the staging concept and the single unit NGM design, and (b) experimentally generate a technology base for use in optimizing subsequent advanced NGM designs. Emphasis in these development activities, therefore, was placed on developing an NGM that could be used as a test bed to generate necessary design data. Secondary emphasis was placed on optimizing NGM hardware design, such as weight and volume.

The following sections review the NGM design concept, hardware description and operation; the NGM test facility and test results obtained under the current program.

Concept, Hardware and Operation Description

The key characteristic of the NGM concept is the alternating stages for dissociation and separation. Packaging these stages into compact, efficient (chemical and thermal) mechanical hardware presents the engineering challenge. Testing the resulting hardware provides the confidence in the design.

Concept Description

A block diagram showing the staging concept is presented in Figure 2. The NGM consists of one N_2H_4 dissociation stage, three NH_3 dissociation stages and four H_2 separation stages. The N_2H_4 feed/N_2 product stream flows in series from stage to stage. The calculated gas concentrations following each dissociation and H_2 separation stage illustrate how the staging concept yields the low NH_3 and H_2 concentrations in the final product N_2.

Hydrazine is catalytically dissociated in the first stage via the following reactions:

$$N_2H_4 = 1/3\ N_2 + 4/3\ NH_3 \qquad (1)$$

$$4/3\ NH_3 = 2/3\ N_2 + 2H_2 \qquad (2)$$

$$N_2H_4 = N_2 + 2H_2 + 1.57\ \text{MJ/kg}\ (678\ \text{BTU/lb}) \qquad (3)$$

All the N_2H_4 is dissociated in this initial stage. Not all of the NH_3 formed by equation 1, however, is dissociated in this stage.

The N_2, H_2 and unreacted NH_3 gases from the first stage enter the first H_2 separation stage. Most (90%) of the H_2 entering this stage is removed and collected at 103 kPa (15 psia) for use in a CO_2 reduction subsystem. The product gas from the first separation state is then manifolded to the first NH_3 dissociation stage. The high NH_3 and N_2 concentrations entering the

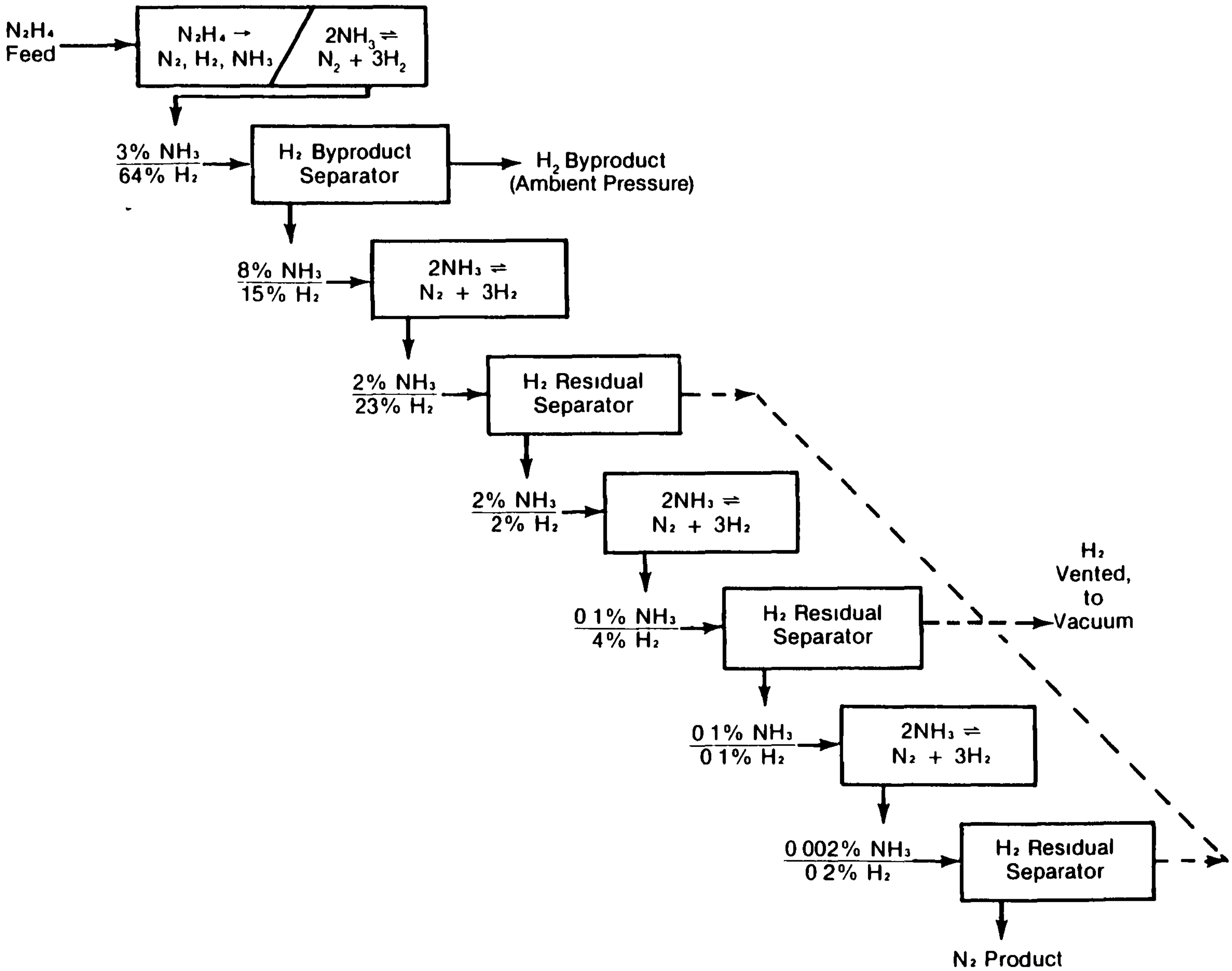

FIGURE 2 NGM GENERATION STAGING CONCEPT BLOCK DIAGRAM

dissociator favor further NH_3 dissociation and the formation of more N_2 and H_2 (equation 2).

Alternate H_2 separation and NH_3 dissociation stages are used to attain the final N_2 product purity. The H_2 removed in the last three H_2 separation stages is vented to space vacuum and is therefore not available for further use. The H_2 separation to vacuum is required to attain the low H_2 concentration needed in the product N_2.

Figure 3 is a functional schematic of the NGM showing a representation of its three functions - N_2H_4 dissociation, NH_3 dissociation and H_2 separation. The addition of an N_2H_4 storage tank, sensors and controls are all that is needed to form a complete NSS.

Hardware Description

Designed to operate at 1,830 kPa (265 psia), the NGM consists of two major subassemblies - dissociator and separator - joined by an end plate. The end plate is manifolded to pass gases back and forth between the various dissociation and separation stages. Gaskets permit disassembly for inspection. Front and rear views of the assembled NGM are presented in Figures 4 and 5, respectively. Figure 6 shows the disassembled NGM hardware.

Physical Characteristics. The temperatures of the dissociation stages and separation stages are maintained using three cartridge heaters located in the dissociator core and five band heaters located around the outside of the separator housing. Thermocouples within the NGM are used to provide closed-loop, feedback temperature control.

The dissociator core is controlled at 1,000 K (1,340 F) and the Pd/Ag separator tubes are controlled at 644 K (700 F). Besides control thermocouples, several others have been added to monitor temperatures during development testing.

Physical characteristics of the NGM are summarized in Table 1. The NGM was designed to give a nominal N_2 generation rate of 3.6 kg/d (8.0 lb/d); however, testing has shown that the output can be controlled over a wide range, i.e., 1.8 to 6.8 kg/d (4 to 15 lb/d). Only five mechanical interfaces are needed: N_2H_4 feed, N_2 product, N_2 purge, H_2 product and H_2 to vacuum. Several other ports have been added for interstage sampling.

Operational Flexibility. Since the NGM was used to generate performance and design data for future NGM designs, maximum flexibility in the design and operation of the NGM was required. The capability to monitor performance of individual stages and temperature profiles, and to individually control separator and dissociator stage temperatures was incorporated into the design. Gas sample taps between each stage were incorporated to allow quantifying individual stage performance during parametric testing. The NGM temperature distribution/profile monitoring capability was provided by 16 thermocouples. Both radial and axial temperature profile determinations were possible. Separate temperature control of the dissociation stages and separator stages was provided through the heaters connected to feedback temperature controllers.

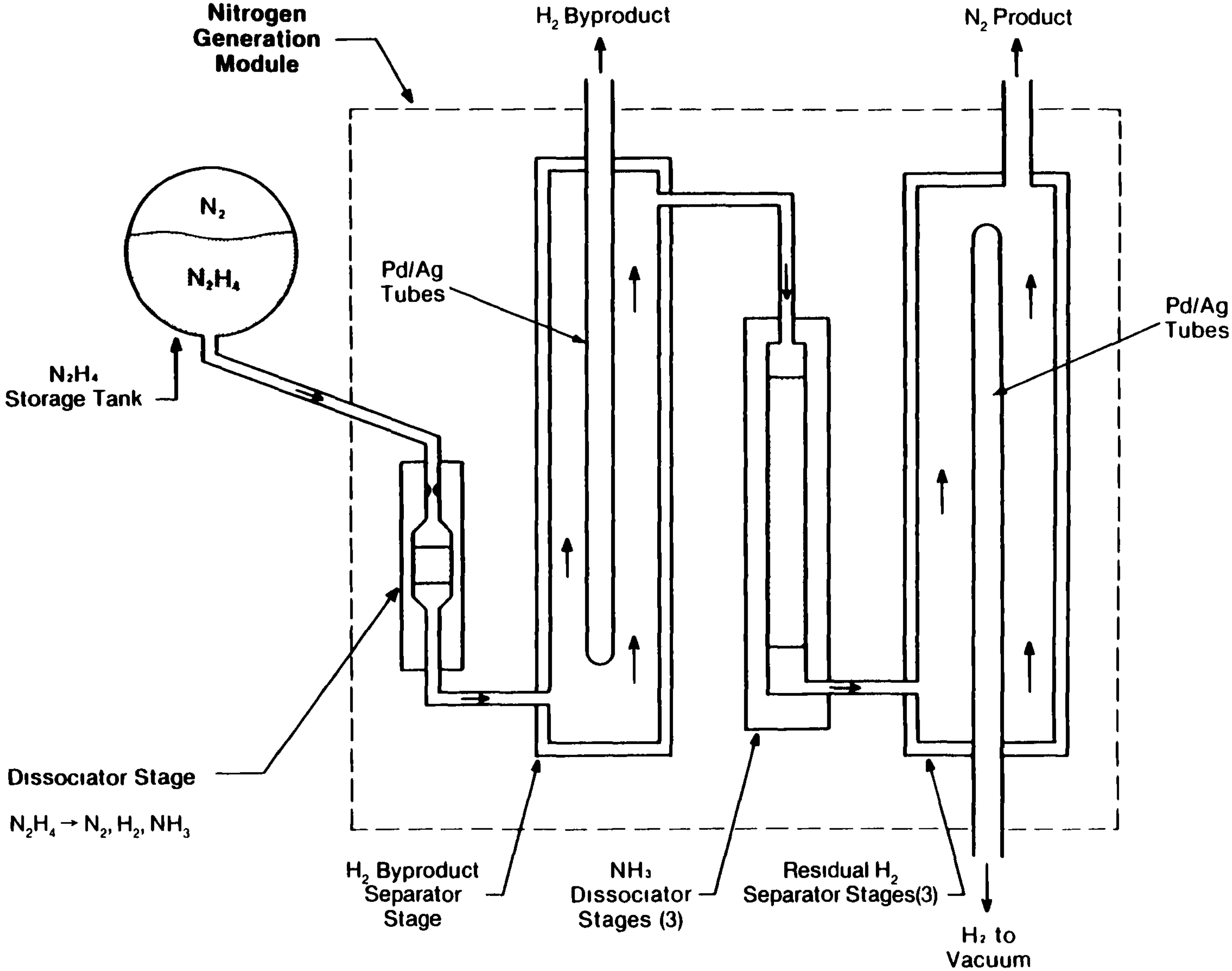

FIGURE 3 NGM FUNCTIONAL SCHEMATIC

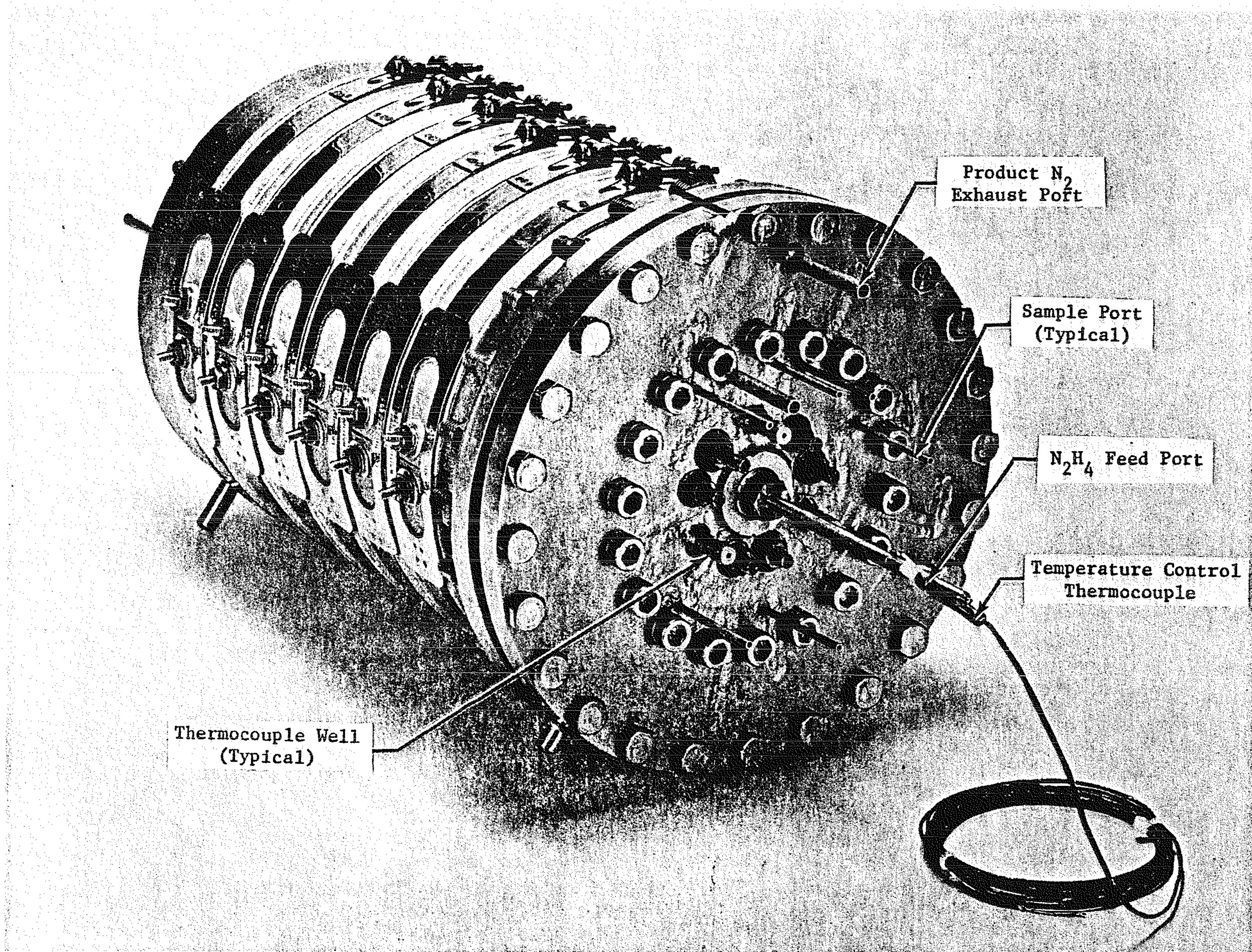

FIGURE 4 ASSEMBLED NGM (FRONT VIEW)

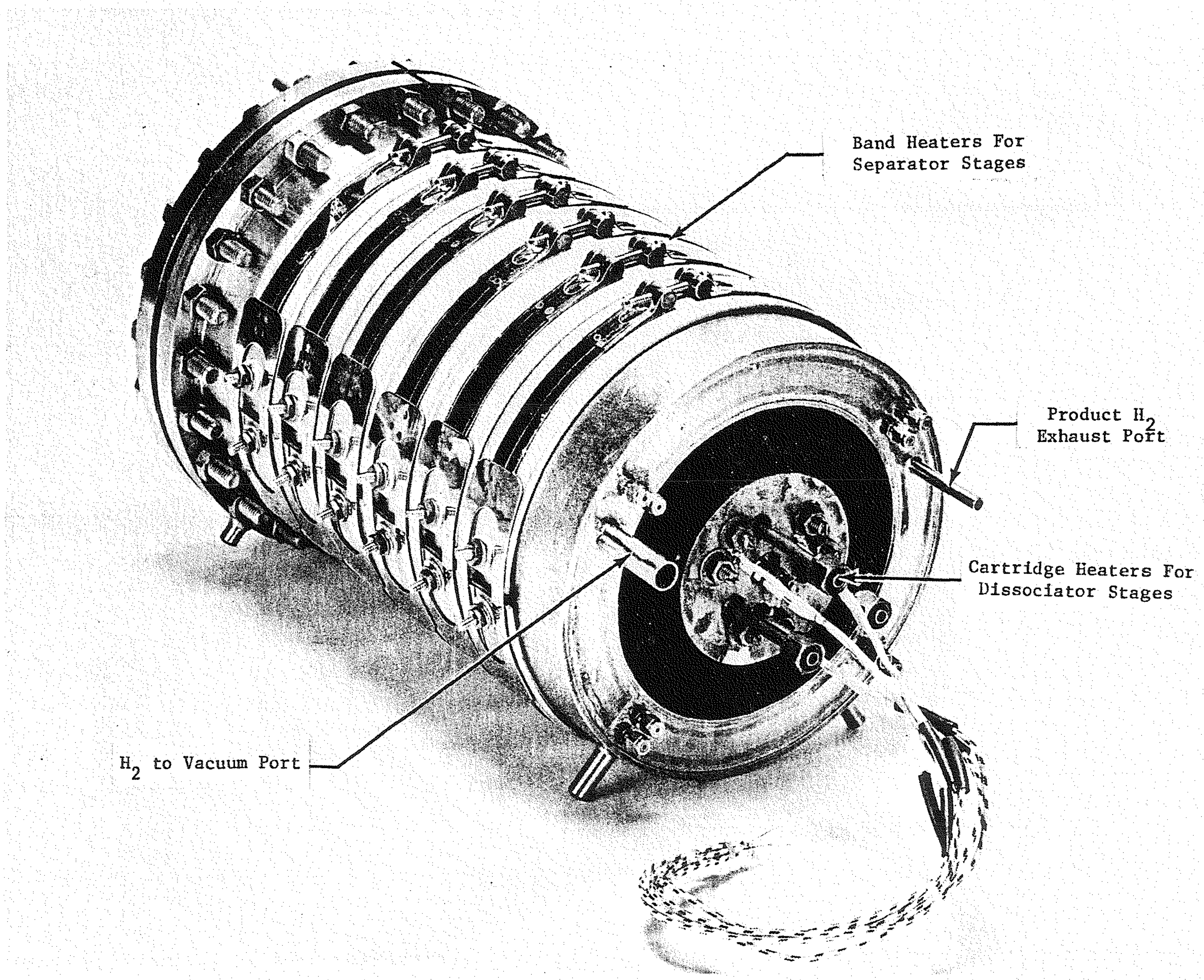

FIGURE 5 ASSEMBLED NGM (REAR VIEW)

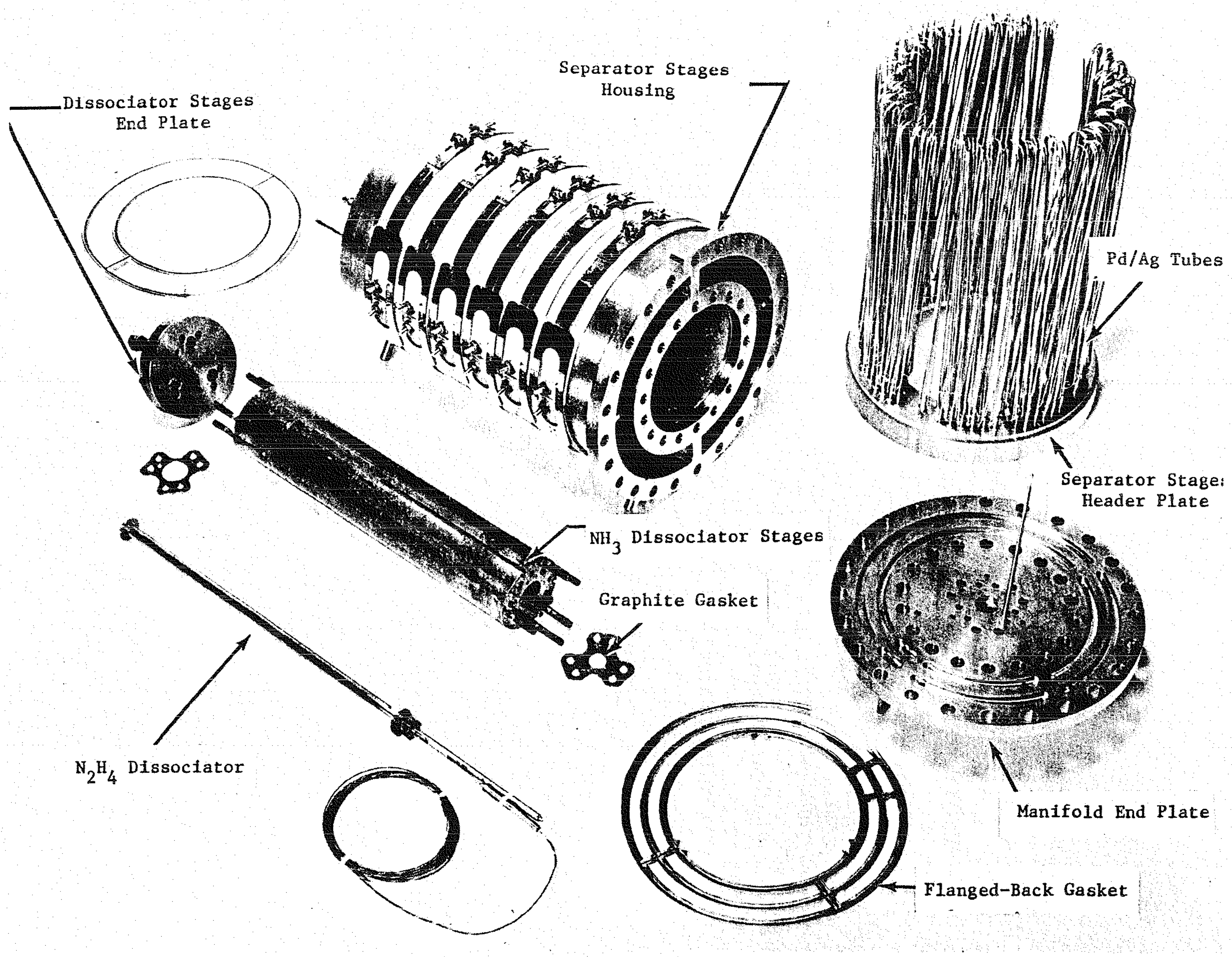

FIGURE 6 DISASSEMBLED NGM

TABLE 1 NGM CHARACTERISTICS

Nominal N_2 Generation Rate, kg/d (lb/d)	3.6 (8.0)
Weight, kg (lb)	33 (73)
Volume, dm^3 (ft^3)	11.6 (0.41)
Power, W	
Startup	8,200
Operational	300
Time for Heatup, h	0.4
Mechanical Interfaces	5

Maintainability. Maintainability is not a design requirement of a flight version NGM. Maintainability, however, for the NGM fabricated for development testing under the present effort was required to add testing flexibility. Operation at elevated temperatures and pressures, and the dimensional tolerances required for adequate sealing make disassembly and maintainability difficult. Operation at elevated temperatures causes the metal surfaces to adhere to each other through oxidation and scaling. In addition, operation at elevated pressures and the large surface area required for sealing result in high sealing forces.

As was shown in Figure 6 the NGM was divided into several subassemblies and components for ease in disassembly during maintenance. Sealing between the subassemblies is provided by graphite or flanged-backed gaskets. Bolts are used to hold these subassemblies together and provide the sealing forces required. However, this design approach was shown to be inadequate. Following prior testing, an inspection revealed a weakness in the separator housing design.[6] The bolt flanges of the housing (both inner and outer) showed signs of high temperature yield and structural deformation which led to a loss in sealing. New inner and outer flange spacers were designed, fabricated and installed for the present testing. This approach solved the flange leakage problems. Elimination of all seals, however, became a primary requirement for the advanced NGM design.

Operation

The NGM operation has been described in detail previously.[6-8] The following is a summary of its operation. The NGM performs three functions: N_2H_4 dissociation, NH_3 dissociation and H_2 separation. The temperatures of the dissociation stages and separation stages are controlled separately using two sets of heaters. Heat is (a) generated in the N_2H_4 dissociation process, (b) required for the NH_3 dissociation process and (c) lost to ambient since the surface of the NGM (the H_2 separator stages) is at 644 K (700 F). The NGM has two distinct temperature zones. The H_2 separator stages must operate at 644 ±28 K (700 ±50 F). The separation process is favored by higher temperatures but temperatures above 700 K (800 F) decrease the structural integrity and life of the Pd/Ag tubes. The NH_3 dissociation stages require temperatures, greater than or equal to 811 K (1,000 F). The center of the dissociator housing (i.e., the N_2H_4 dissociation stage) operates at approximately 1000 K (1,340 F). The temperature decreases to about 811 K (1,000 F) at the surface of the dissociator core.

Hydrazine Dissociation. Hydrazine dissociation takes place in the center cavity of the NGM. Liquid N_2H_4 at a pressure of approximately 1830 kPa (265 psia) is injected into the dissociator through a capillary orifice in the header assembly (refer to Figure 7). The diameter of the capillary opening is smaller than the quenching diameter for N_2H_4 to prevent propagation of the dissociation reaction back to the supply. In the feed orifice, N_2H_4 is converted from a liquid at ambient temperature to a vapor slightly above the boiling point of N_2H_4 at the operating pressure. Hydrazine vapor enters the central dissociator tube at an elevated temperature and dissociates autocatalytically.

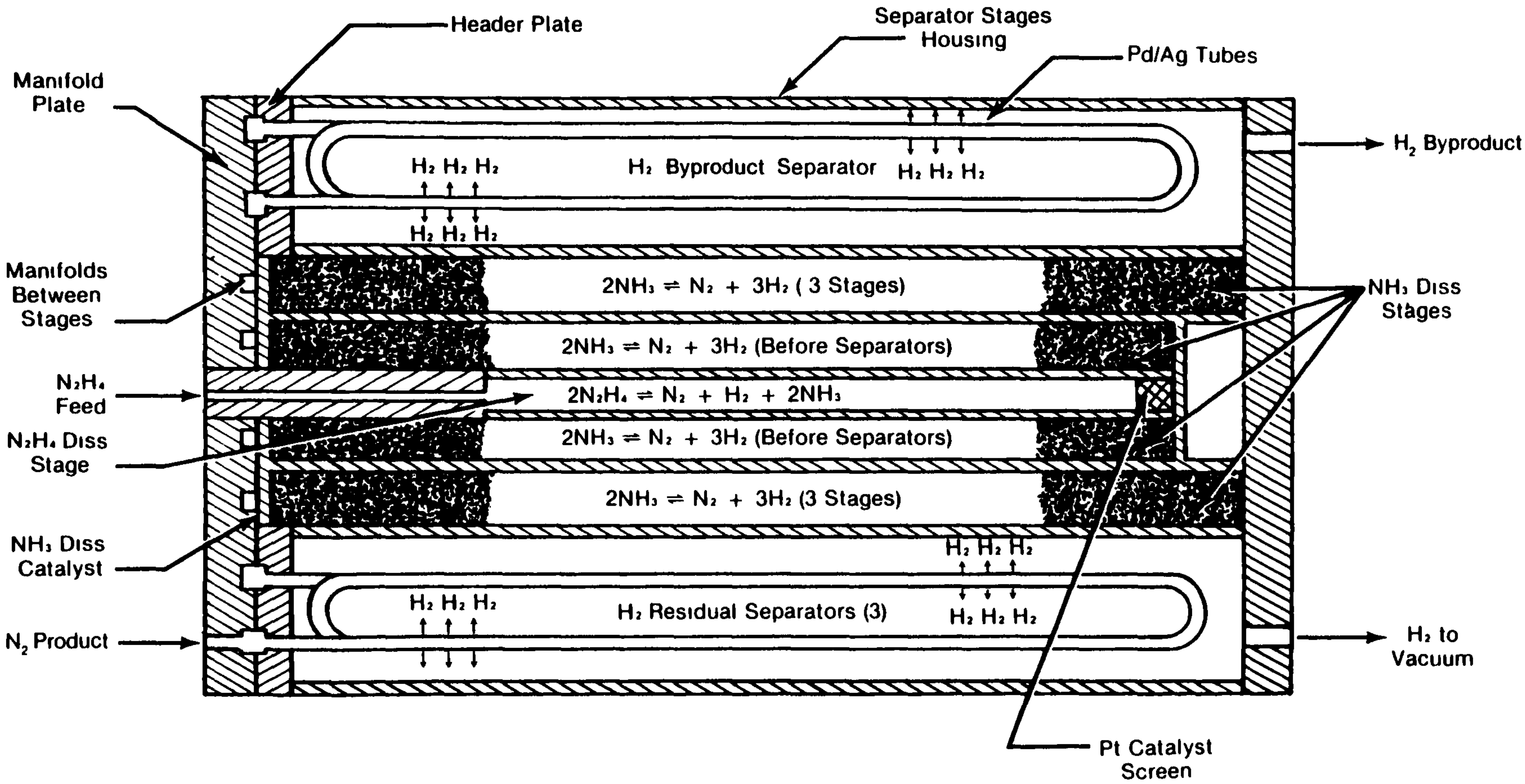

FIGURE 7 NGM FUNCTIONAL DIAGRAM

At the end of the central tube the direction of the product gases is reversed. The product gases then flow in the annular housing concentric with the central tube and exit at the hottest zone of the reactor. The decomposition of NH_3 into N_2 and H_2 (equation 2) is favored kinetically and thermodynamically at higher temperatures.(7) The product gas from the N_2H_4 dissociation stage is manifolded to the first H_2 separation stage.

Hydrogen Separation. The four H_2 separation stages are located around the periphery of the NGM. The Pd/Ag tubes are connected to a donut-shaped header plate and are thermally isolated from the central NGM core where N_2H_4 and NH_3 dissociation takes place. The H_2 separation stages operate at 644 K (700 F) while the dissociator core is maintained at 1000 K (1340 F). The N_2/H_2 mixture from a dissociation stage enters the inside ends (i.e., closest to the center of the NGM) of the Pd/Ag tubes in the stage. The process gas passes through all of the Pd/Ag tubes in each individual stage in parallel. The H_2-depleted gas stream from a H_2 separation stage is then manifolded from the outlet of the tubes to the next NH_3 dissociation stage.

In the first H_2 separation stage H_2 is collected at less than or equal to 172 kPa (25 psia). The H_2 removed in the second, third and fourth H_2 separation stages exhausts the NGM through a common manifold and is vented to vacuum.

Ammonia Dissociation. The three NH_3 dissociation stages are located in the central NGM core around the outside of the N_2H_4 dissociation stage. The product N_2 gas stream, enriched in N_2 and NH_3 after passing through a H_2 separation stage, is fed into a NH_3 dissociation stage at the same end of the NGM as the N_2H_4 feed. The product gas passes through the packed catalyst bed traveling the length of the dissociation core. At the end of the first catalyst bed the gases are manifolded to the second portion of the catalyst bed in the dissociation stage. The product gas then travels back the length of the reactor core and exits at the same end of the reactor as the feed stream. Each NH_3 dissociation stage, therefore, consists of two side-by-side passages packed with catalyst.

Operating Conditions. Table 2 gives the nominal operating conditions for the NGM. These values are for a 3.6 kg/d (8.0 lb/d) N_2 generation rate. The values shown in Table 2 for H_2 and NH_3 concentration in the N_2 product stream have been met or exceeded in the testing program.

NGM Test Facility

An NGM Test Facility was designed and assembled to support the data base generation testing of the NGM. This facility consists of an NGM test stand and support facilities including N_2H_4 supply, instrumentation, recorders and chemical analysis equipment. These are described in the following sections.

NGM Test Stand

A test stand dedicated to NGM characterization and endurance testing was designed, fabricated and checked out (see Figure 8). This test stand, built according to Life Systems test stand development philosophy, permits continuous, automated operation with a minimum of operator or test engineer interface. It has self-protection features for unattended operation.

TABLE 2 NGM NOMINAL OPERATING CONDITIONS

Catalytic Dissociator Temperature, K (F)	1,000 (1,340)
Pd/Ag Separator Temperature, K (F)	644 (700)
Hydrazine Feed	
Source	Liquid Hydrazine
Hydrazine Flow Rate, kg/d (lb/d)	4.15 (9.14)
cm^3/min	2.9
Composition, Weight %	
Hydrazine	99.5 to 100
Water	0 to 0.5
Temperature, K (F)	291 to 297 (65 to 75)
Pressure, kPa (psia)	1,794 (260)
Nitrogen Product	
Flow Rate, kg/d (lb/d)	3.64 (8.00)
dm^3/min (ft^3/min)	2.2 (0.078)
Composition, Volume %	
Hydrogen	<0.5
Ammonia	$<1.9 \times 10^{-3}$
Water	<0.1
Temperature, K (F)	644 (700)
Pressure, kPa (psia)	1,725 (250)
Hydrogen Byproduct	
Flow Rate, kg/d (lb/d)	0.44 (0.96)
dm^3/min (ft^3/min)	3.6 (0.13)
Purity, Volume %	99.9999 to 100
Temperature, K (F)	644 (700)
Pressure, kPa (psia)	172 (25)
Hydrogen Vented	
Flow Rate, kg/d (lb/d)	0.08 (0.18)
dm^3/min (ft^3/min)	0.68 (0.024)
Temperature, K (F)	644 (700)
Pressure, Pa (mm Hg)	0 to 1,330 (0 to 10)

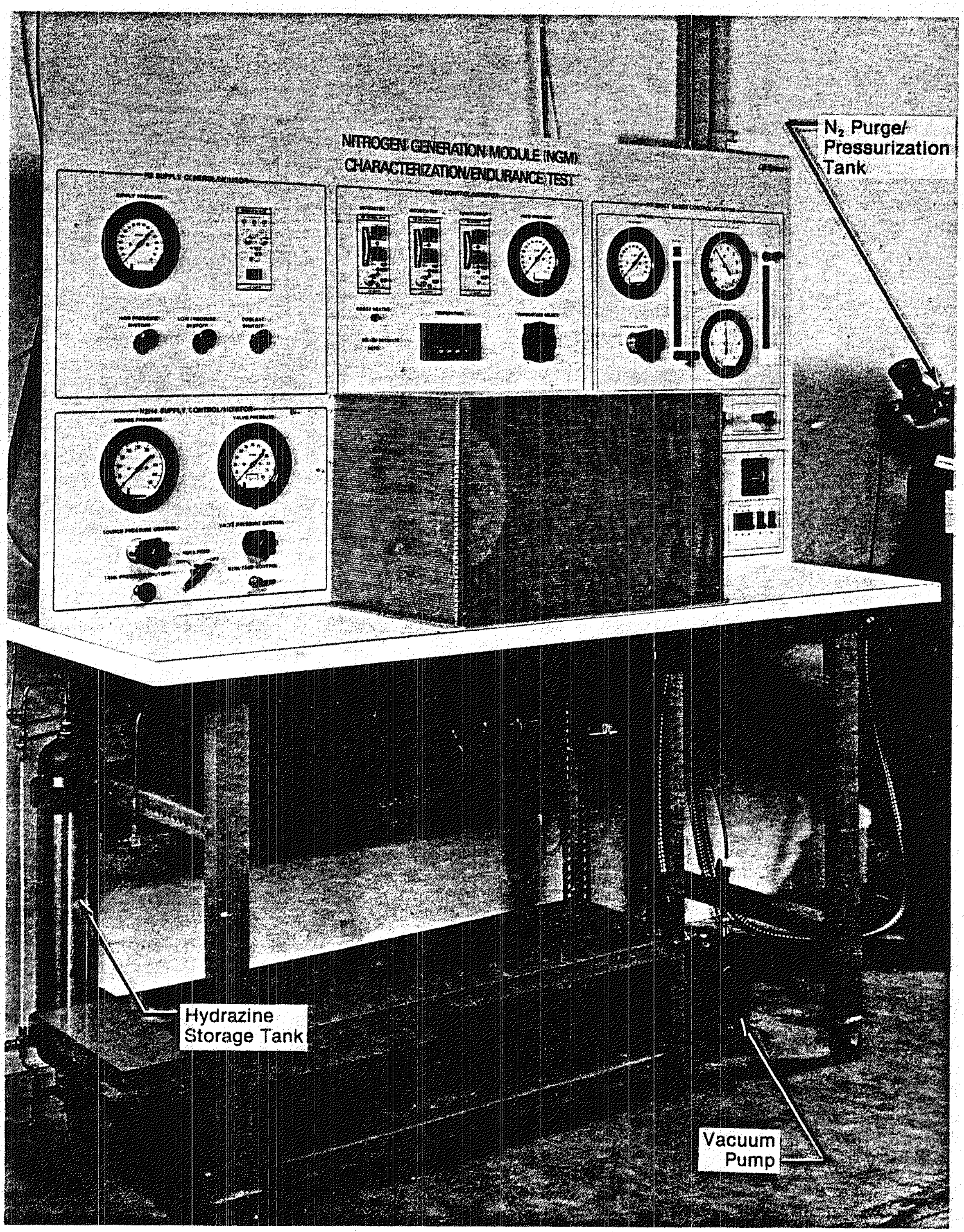

FIGURE 8 NGM TEST STAND

Description. Figure 9 shows the mechanical schematic for the test stand. In many respects the test stand contains all components needed for a complete NSS without automated control for some of them. The automated features that do exist permit safe shutdowns and some control and monitor functions. Others are performed manually.

Considering the NGM (NM1) as the end item under test, the schematic consists of those components which supply inputs and those which measure or control outputs. Hydrazine is stored in a supply tank (HT1) and fed to the NGM under pressure through a manual shutoff valve (MV7), pneumatic shutoff valves (V1 and V27), manual flow control valve (MV8) and a flow control orifice (RX5). The pressure of the liquid N_2H_4 is controlled by a manual regulator (PR2) and sensed by a pressure gauge (P23). The source pressure is an external, high pressure N_2 tank. The pneumatic valves V1 and V27 are controlled by the electrical three-way valve V2 which supplies a 520 kPa (75 psia) pressure through regulator PR3. The flow control office RX5 develops a pressure drop measured by pressure sensor P2. In this fashion a flow monitor (designated Q8) records the flow as a function of the upstream pressure (monitored by P18) and the downstream pressure developed in the module.

The high pressure source is also used for purging the system through valve V31 and flow control office RX3. This is used to purge the N_2 gas chambers of the NGM. A laboratory source of low pressure N_2 provides purge of the H_2 chambers through V28 and RX1 and also coolant through MV24 when required.

At the outlet of the NGM, three flow streams are considered. Nitrogen exits the module and passes through a moisture trap (TR1), a back pressure regulator (PR1) and flowmeter (F1). A portion of the stream can be diverted through MV16 and MV10 to the gas chromatograph (GC) for analysis. As indicated, other sample streams can be diverted to the GC using valves MV13 through MV15. The H_2 product gas stream passes through V24 and flowmeter F2.

The H_2-to-vacuum stream passes through a shutoff valve (V26) and vacuum pump (M1). Pressure sensor P17 monitors the vacuum level on the test stand. Valve V37 is used to evacuate both H_2 outlet chambers prior to startup. Pressure gauge P15 monitors the operating pressure of the system. Designed into the test stand is a method to induce a controlled leak of the system using MV11 and F3. The capability is for checkout purposes only and is seldom used.

Control and Monitor Instrumentation. The NGM test stand control and monitor instrumentation is a combination of automated controllers and mechanical gauges. It is grouped into six logical functions as shown in the front panel layout of Figure 10. In the upper left hand corner is the N_2 supply control and monitoring function. It contains the supply pressure gauge (P19) and the high pressure (MV1), low pressure (MV22) and coolant (MV24) shutoff valves. The N_2 purge controller (NPC) permits automated purging of the system (energizes V31) upon startup and shutdown. The purge time is selectable on the front panel of the NPC.

The lower left hand corner contains those components which establish hydrazine pressure and flow control. They include the source pressure regulator (PR2),

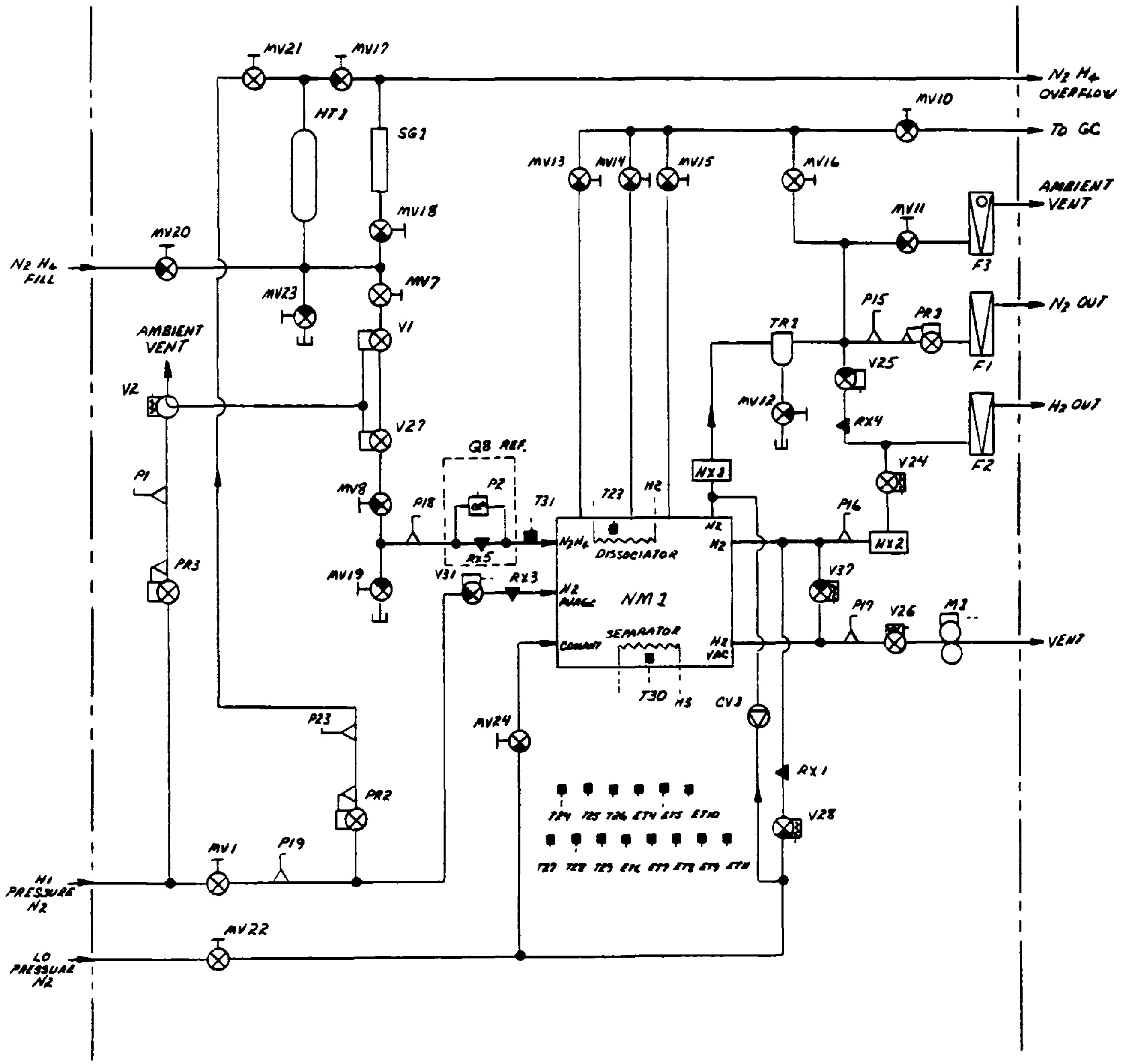

FIGURE 9 NGM TEST STAND MECHANICAL SCHEMATIC

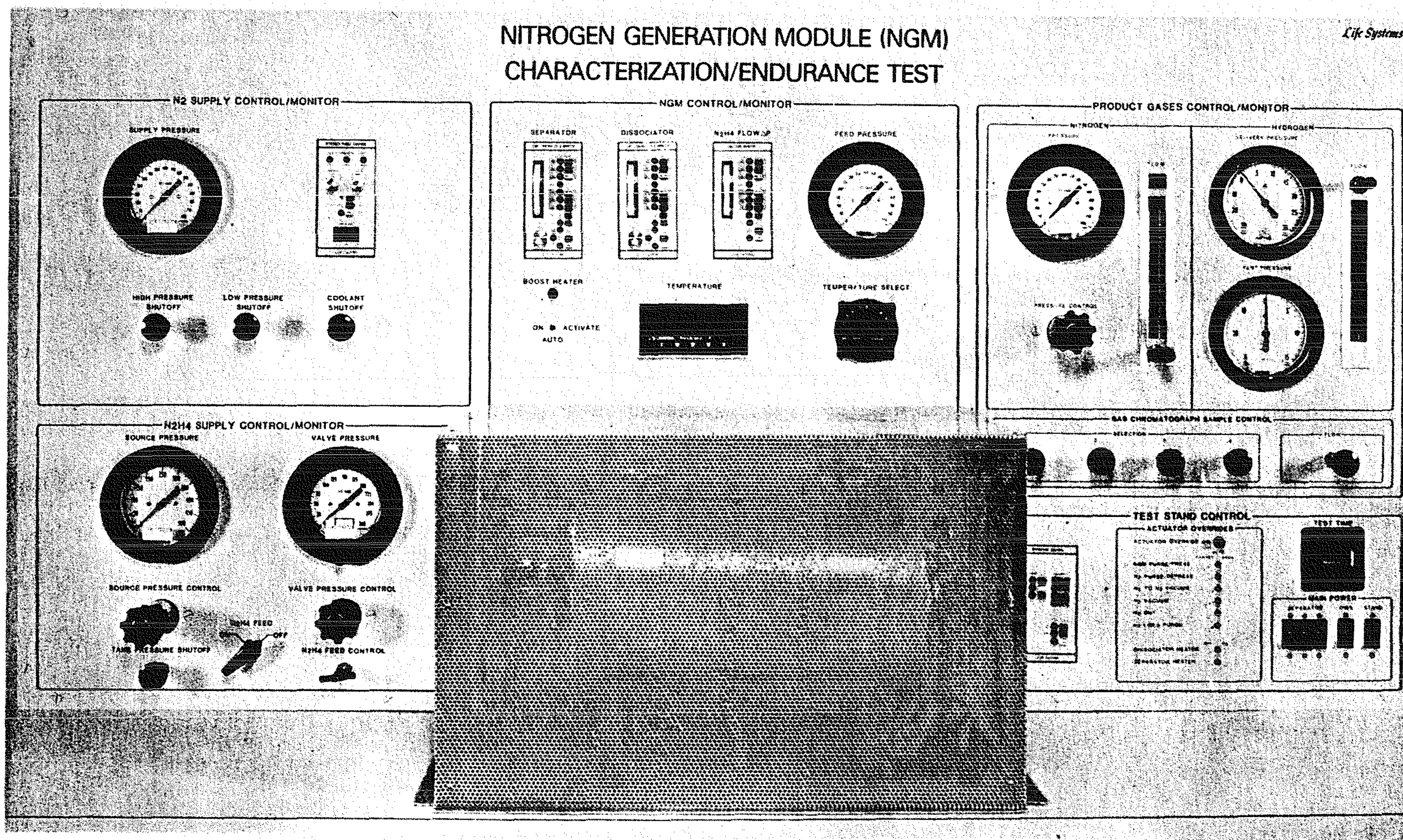

FIGURE 10 NGM TEST STAND FRONT PANEL

source pressure gauge (P23) and the tank shutoff valve MV21. Also the pneumatic valve pressure control (PR3) and the pneumatic pressure gauge (P1) are shown. The N_2H_4 feed shutoff (MV7) and flow control (MV8) are located here.

The top central portion of the test stand panel is dedicated to control and monitor the NGM itself. Two electronic controllers maintain the temperatures of the dissociator and separator. These are further defined in Table 3. A pressure monitor senses and displays the ΔP across RX5 which establishes the N_2H_4 flow. The feed pressure is monitored with a pressure gauge (P18). Below is a temperature sensor selector switch and display from which any of the NGM thermocouples can be monitored.

The upper right section of the front panel is dedicated to N_2 and H_2 product gas monitoring. The N_2 control/monitoring consists of the back pressure regulator PR1, pressure gauge P15 and flow meter F1. Hydrogen product gas is monitored by pressure gauge P16 and flow meter F2. The vacuum is monitored with pressure gauge P17. Below the product gas monitoring section of the panel are five manual valves (MV10, 13 to 16) for controlling interstage sample streams to the GC.

Located in the lower right hand corner of the test stand are functions for controlling the test stand itself. An electronic operations controller (OpC) permits the operator to select the shutdown, standby and normal operating modes. Each actuator (valves and heaters) can be overridden or placed under automatic control. A timer is provided for accumulating the time that the test stand is in an operating mode and not just when power is applied. Finally, circuit breakers are provided for input power to the test stand and to the NGM heaters.

Operation. The operation of the NGM and its test stand is straightforward. After the NGM is installed as shown in Figure 11, all cavities are pressurized with N_2. Then the module is purged to eliminate all air from the module and lines. This can be done either manually or automatically using the NPC. The NGM is then pressurized by opening valve V31 and manually closing regulator PR3 until the desired operating pressure is obtained. Regulator PR2 is adjusted until a fixed delta above the P15 reading is obtained, usually 70 kPa (10 psid). Then MV21 is opened and the N_2H_4 tank pressurized. After the NGM has achieved operating temperature, N_2H_4 flow to it is controlled manually and then automatically by valves MV8 and V21/27. At the same time the OpC is placed in the "normal" operating mode which controls the position of the remaining solenoid valves. Once operational, removal of all override switches from the controllers and the actuators will permit the test stand to operate fully automatically. If any of the key sensors (Q8, T23 or T30) as identified in Table 3 exceed tolerance the test stand goes to shutdown. Also, if it is desired during normal operation to enter a standby mode, actuating the standby button on the OpC will automatically close the N_2H_4 valves (V1/V27).

Support Facilities

Besides the NGM test stand, the NGM test facility consists of a source of N_2H_4, recorders, GC and chemical analysis equipment. Figure 12 shows these support facilities located in the vicinity of the test stand.

TABLE 3 NGM TEST STAND CONTROLLERS

Name	Description	Actuator	Sensor	Control Range	Setpoint Range		
					Caution	Warning	Alarm
TeCM1	Dissociator Temperature Control/Monitor, K (F)	H2	T23	983-1019 (1,300-1,375)	922-1,033 (1,200-1,400)	894-1,047 (1,150-1,425)	866-1,061 (1,000-1,450)
TeCM2	Separator Temperature Control/Monitor, K (F)	H3	T30	630-644 (765-700)	602-650 (625-710)	575-658 (575-725)	533-672 (500-750)
PM	N_2H_4 Feed Flow ΔP Monitor, kPa (psid)	--	Q8	--	27-130 (4-19)	14-140 (2-20)	7-150 (1-22)
NPC	N_2 Purge Controller	V31	--	--	--	--	--
OpC	Test Stand Operations Controller	Other Controllers, Valves	--	--	--	--	--

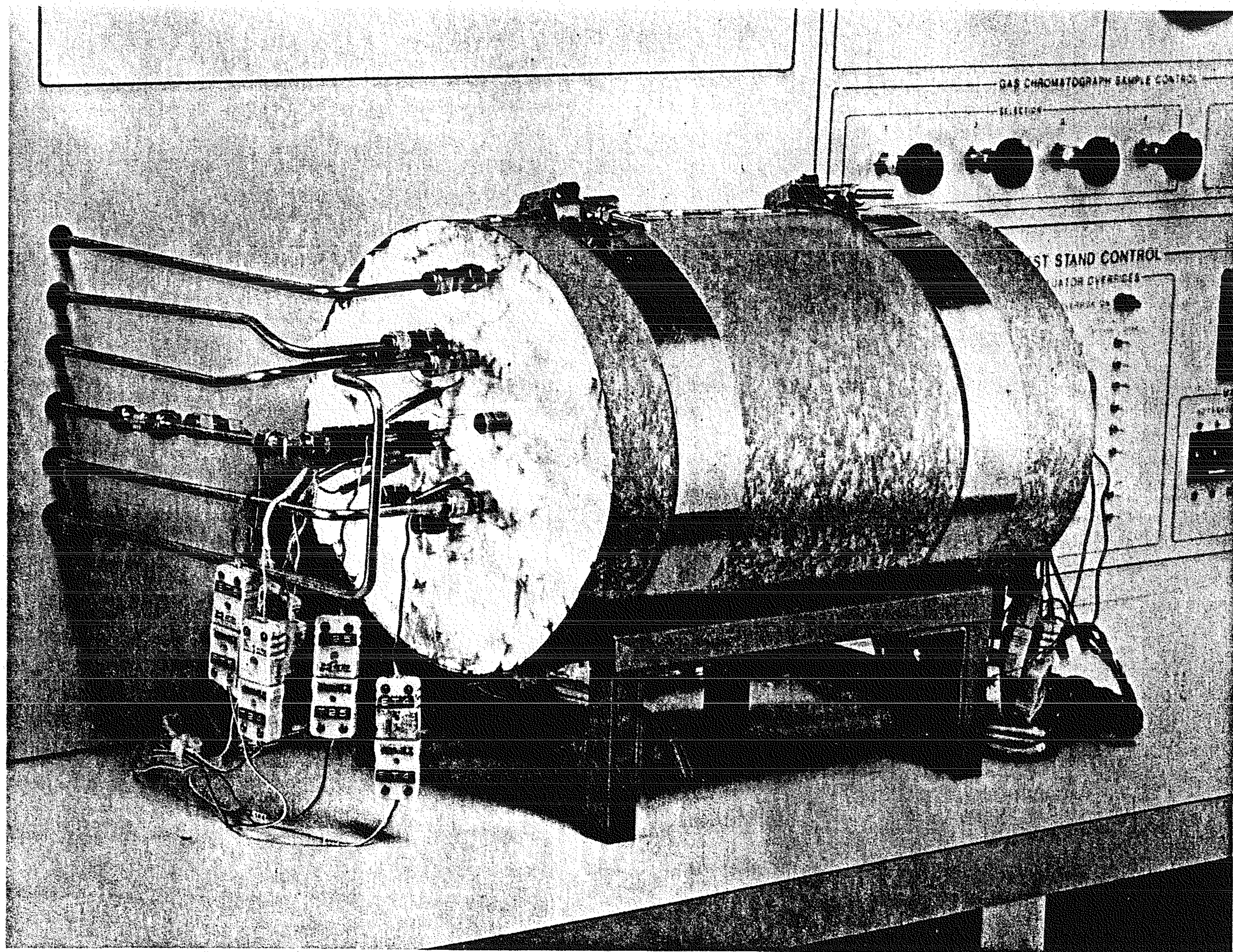

FIGURE 11 NGM MOUNTED ON TEST STAND

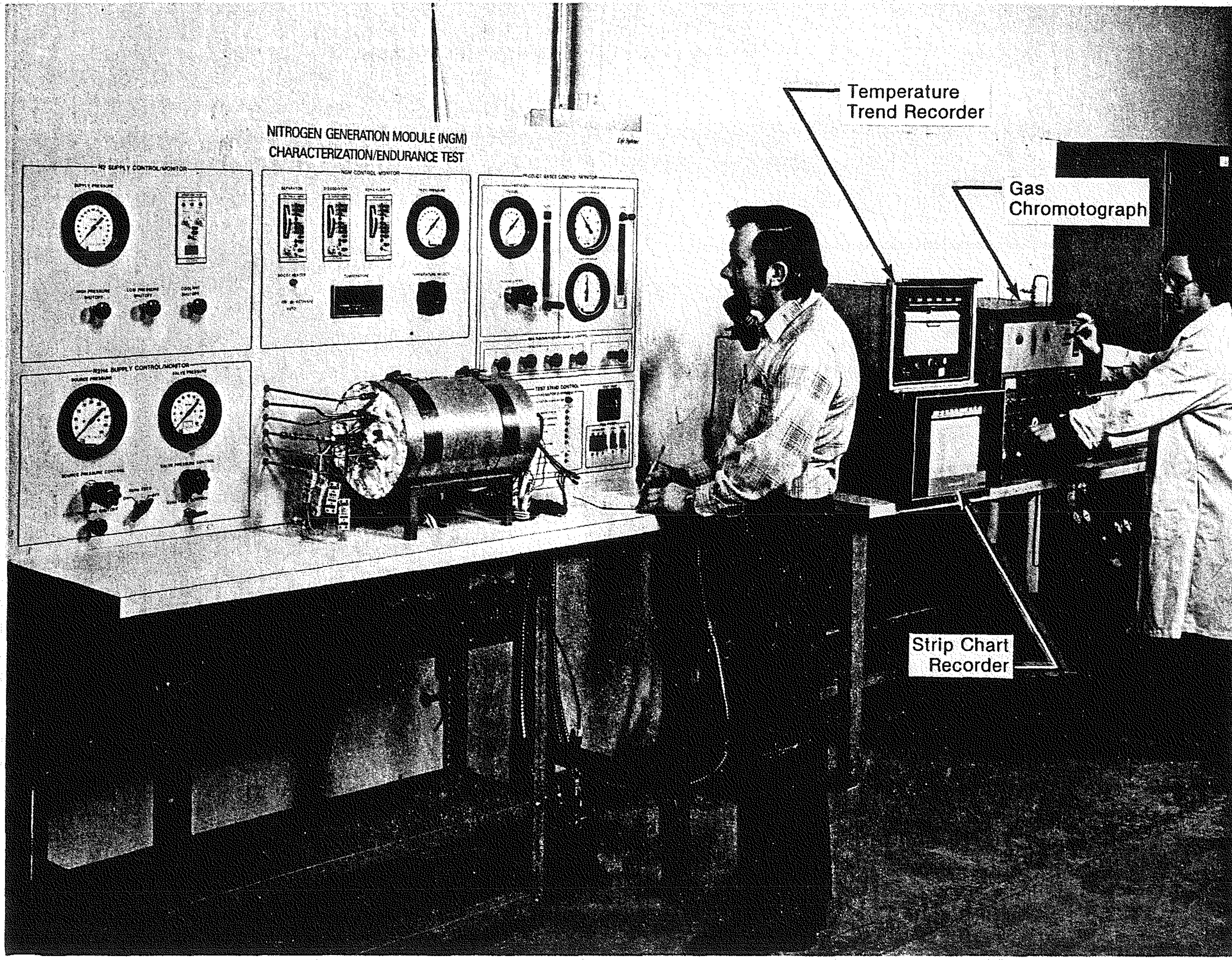

FIGURE 12 NGM TEST FACILITIES

Hydrazine Supply. Figure 13 shows the schematic of the N_2H_4 supply from the storage area to the NGM test stand. Hydrazine is stored in a 0.21 m^3 (55 gallon) drum which can be pressurized up to 138 kPa (20 psia). In order to transfer the N_2H_4 from the drum located in the storage area to the tank located on the test stand, pressures greater than 138 kPa (20 psia) are required. An intermediate, higher pressure transfer tank is used for this purpose.

Recorders. Two recorders were used in the NGM test facility. The temperature trend recorder monitored eight experimental thermocouples located on the NGM. This information gave temperature distribution data in various portions of the dissociator and the separator. A strip chart recorder monitored two key temperatures and the N_2H_4 flow. These recorders were used primarily for observing long term data taken during periods of unattended operation (e.g., overnight).

Gas Chromatograph. A GC was used to periodically sample the product N_2 stream from the NGM and measure the N_2, H_2 and NH_3 concentrations. After testing was initiated a problem occurred whereby the NH_3 concentration peak was obscured by a low moisture level in the N_2 product stream. This produced unreliable NH_3 concentration data. A chemical analysis technique was substituted and performed satisfactorily.

Ammonia Concentration Analysis. Ammonia concentration in the N_2 product stream is a major measure of performance of the NGM. A wet chemistry technique was adopted for analysis as opposed to the GC as discussed above. In this technique, the sample was bubbled through a gas washing bottle containing a hydrochloric acid (HCl) solution and a colorimetric indicator. The NH_3 concentration is given by the equation:

$$\text{Conc. } NH_3, \% = \frac{2205\ (C)(V)}{(T)(F)} \tag{4}$$

Where
C = Concentration HCl, M
V = Volume HCl solution, liter
T = Time to color change, min
F = Flow rate, liter/min

This technique, independently verified with known samples, gave very reliable data.

NGM Testing

The test program was designed to measure the response in performance of the NGM as a function of changes in five operating parameters: operating pressure, N_2H_4 feed rate, dissociator temperature, separator temperature and catalyst weight. Performance was defined as concentration of H_2 and NH_3 in the product N_2 outlet and % H_2 recovered in the product H_2 stream (versus total H_2 produced). A total of 900 hours of operating time and almost 100 data points were obtained during all phases of testing. The test durations and the number of data points taken met or exceeded test program goals.

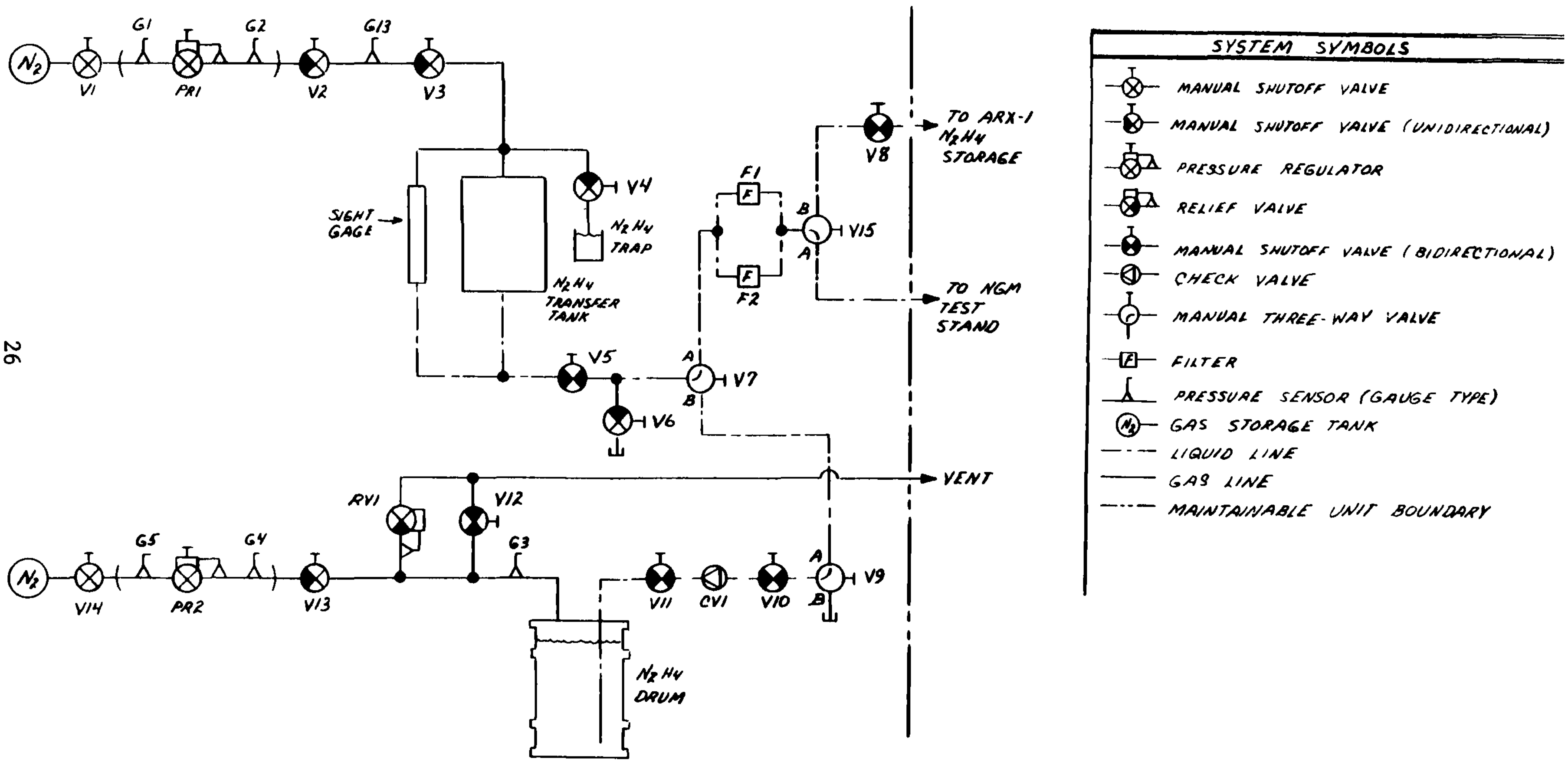

FIGURE 13 N_2H_4 SUPPLY SCHEMATIC

Test Procedures

The overall approach of the test program was to vary one parameter at a time while maintaining the other parameters at nominal values. The nominal values were based on (a) prior operating experience, (b) design analysis or (c) physical constraints. An example of the latter is the maximum amount of NH_3 catalyst as determined by the NH_3 dissociator stage size. Table 4 shows the nominal values and ranges of the operating parameters for which data was recorded.

In a fairly complex chemical reaction, as occurs in the NGM, changing several parameters at one time can influence the optimization of other parameters in terms of overall NGM performance. Ideally, a rigorous testing program would evaluate the effect of all possible combinations of the selected parameters, with several replications to rule out measurement error. The approach taken instead was to vary one parameter while holding the others constant. Also, it was recognized early that operating pressure influences H_2 outlet concentration the most, while dissociator temperature impacted NH_3 concentration and N_2H_4 feed rate impacted both. Therefore, these three parameters were investigated the most extensively.

The general procedure for data taking was as follows. After establishing steady-state, a data point was taken. This consisted of manual recording of all measurements (pressures, flows, temperatures, etc.), a wet chemical sample for NH_3 and a GC sample. The GC was used primarily to measure H_2 concentration in the N_2 product stream. For several of the test points, additional measurements (wet chemistry and GC) were made at intermediate stages within the NGM. In this manner, the effect of NH_3 catalyst was determined.

The testing protocol maintained during one period illustrated the potential versatility of the NGM as part of an operational NSS. During this period of testing, a total of 439 hours of continuous operation were accumulated. Generally, the N_2H_4 flow was adjusted to the level required during the working day but kept at a low value during the night to conserve N_2H_4. Changes in flow, while manual, could be automated to provide an "on-demand" N_2 subsystem. This mode of operation worked extremely well.

Parametric Tests

The test results of the effects of the five operating parameters on NGM performance are presented below. The order of presentation was selected in terms of decreasing order of parameter importance on overall NGM operation.

Operating Pressure. Five levels of operating pressure were investigated: 450, 790, 1,140, 1,480 and 1,830 kPa (65, 115, 165, 215 and 265 psia). Figure 14 shows the NGM performance as a function of pressure at nominal N_2H_4 feed rate and dissociator temperature. Unless otherwise stated, all performance curves will note the test conditions for the results shown. Parameters not stated explicitly were at nominal values (see Table 4). For example, separator temperature would be 644 K (700 F) and catalyst amount would be 160 g (0.352 lb).

TABLE 4 OPERATING PARAMETER RANGES

Parameter	Nominal Value	Range
Operating Pressure, kPa (psia)	1,270 (265)	430-1,270 (65-265)
Dissociator Temperature, K (F)	1,000 (1,340)	866-1,061 (1,100-1,450)
N_2H_4 Feed Rate, kg/d (lb/d)	4.15 (9.14)	1.4-9.1 (3-20)
Separator Temperature, K (F)	644 (700)	589-672 (600-750)
Catalyst Weight, g (lb)	160 (0.352)	54-160 (0.119-0.352)

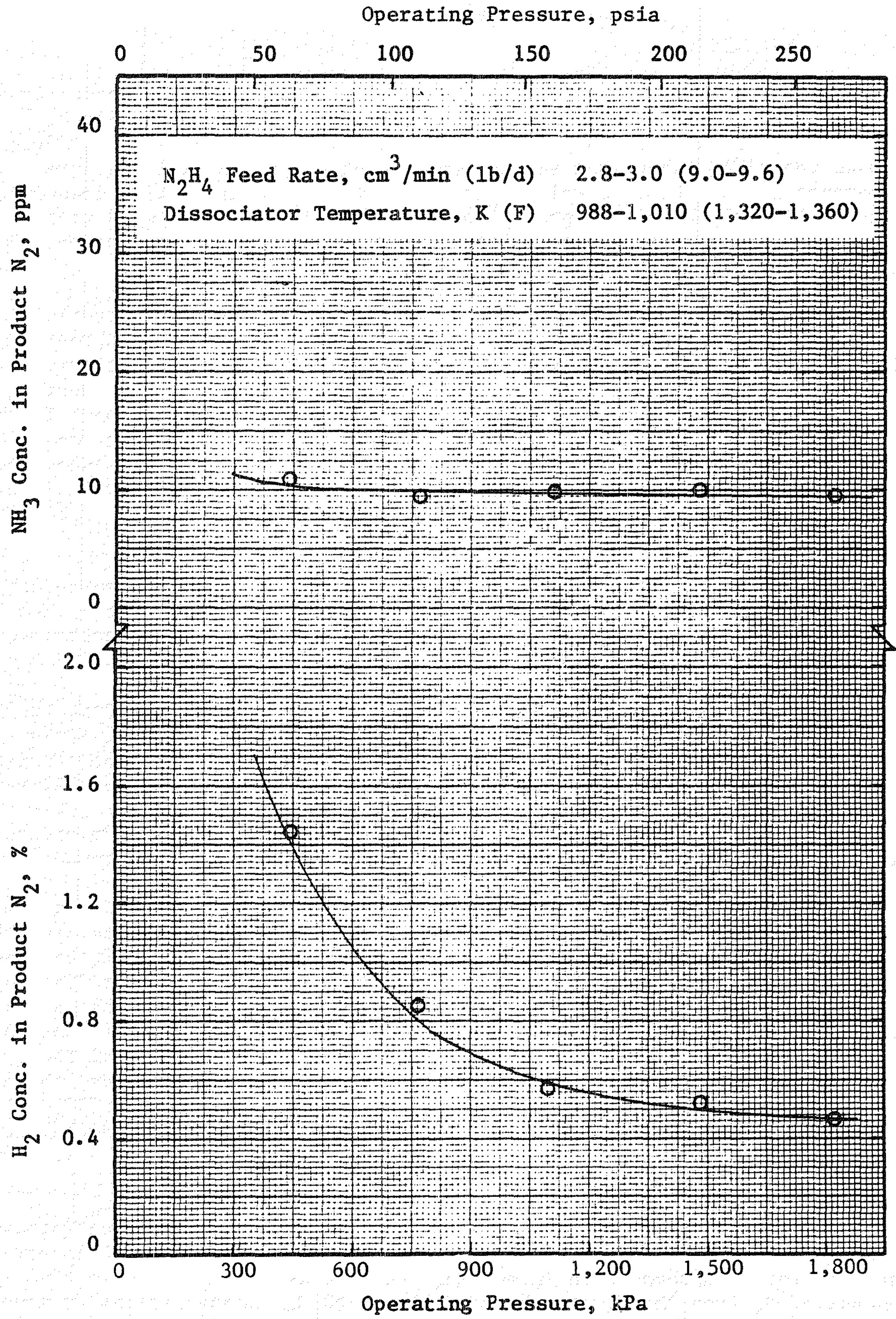

FIGURE 14 NGM PERFORMANCE AS A FUNCTION OF OPERATING PRESSURE

Figure 14 shows the general trend seen in all pressure-related tests. Ammonia concentration in the product N_2 is a weak function of pressure while H_2 concentration is strongly dependent on pressure. This is because H_2 diffusion through the Pd/Ag tubes is a strong function of the H_2 partial pressure difference across the tube wall. The reason the H_2 concentration does not decrease linearly at higher pressures is probably caused by a mass transfer effect since tube surface area is fixed. At lower N_2H_4 feed rates (not shown) a sharp falloff with increasing pressure was noted.

Another important NGM performance parameter is the amount of H_2 actually recovered in the product H_2 stream compared to the available H_2 in the N_2H_4 feed. Figure 15 shows the results of a typical test. Two sets of curves are shown for both percent H_2 recovered and H_2 concentration in the product N_2 stream. In one case, the vacuum pump was on as in normal operation. In the other, the vacuum pump was turned off and the last three separator stages were exhausting to ambient pressure. It is seen that while more H_2 is recovered for use, the H_2 concentration in the N_2 stream is quite high, almost 9%. As expected, the vacuum stages, although causing some loss of available H_2 (about 10%), are needed to provide low concentrations of H_2 in the product N_2.

<u>Dissociator Temperature</u>. Figure 16 shows NH_3 concentration in the product N_2 stream and a sample stream as a function of dissociator temperature. The sample stream is at the outlet of the second separator stage, downstream of the first NH_3 dissociator stage.

The endothermic reaction of NH_3 dissociation (equation 2) is a strong function of temperature and a catalyst temperature of around 1,000 K (1,340 F) is desired. The NH_3 concentration measurements, determined by the wet chemistry technique, actually indicated values less than 10 ppm, but, due to measurement uncertainty, were recorded as 10 ppm. At temperatures below about 940 K (1,230 F) NH_3 concentration rises considerably and can increase two orders of magnitude for a lowering of only 28 K (50 F) in dissociator temperature.

Initially, it was planned to explore the effect of dissociator temperature up to 1,088 K (1,500 F). However, there was some difficulty in maintaining the separator temperature at or below 644 K (700 F) without cooling if the dissociator temperature rose above 950 K (1,250 F). This is due to radiative heat transfer from the high temperature zone to the separator. This problem only occurred with low (or no) N_2H_4 flow since during normal operation heat required for NH_3 dissociation tends to keep the external surface of the dissociator core 56 to 83 K (100 to 150 F) cooler. Therefore, under these conditions, separator temperatures can go higher than the desired 644 K (700 F). Because of this, an insulating sheath was wrapped around the dissociator to reduce the radiative heat transfer. The advanced NGM will have provisions to account for this effect.

<u>N_2H_4 Feed Rate</u>. Figure 17 shows the percent of H_2 in the N_2 product stream as a function of N_2H_4 feed rate and operating pressure. Obviously, this performance parameter improves with increasing pressure as this assists in the removal of H_2 from the N_2 stream. The increased H_2 concentrations at lower feed rates (reversal of slope) were consistently observed and are probably due

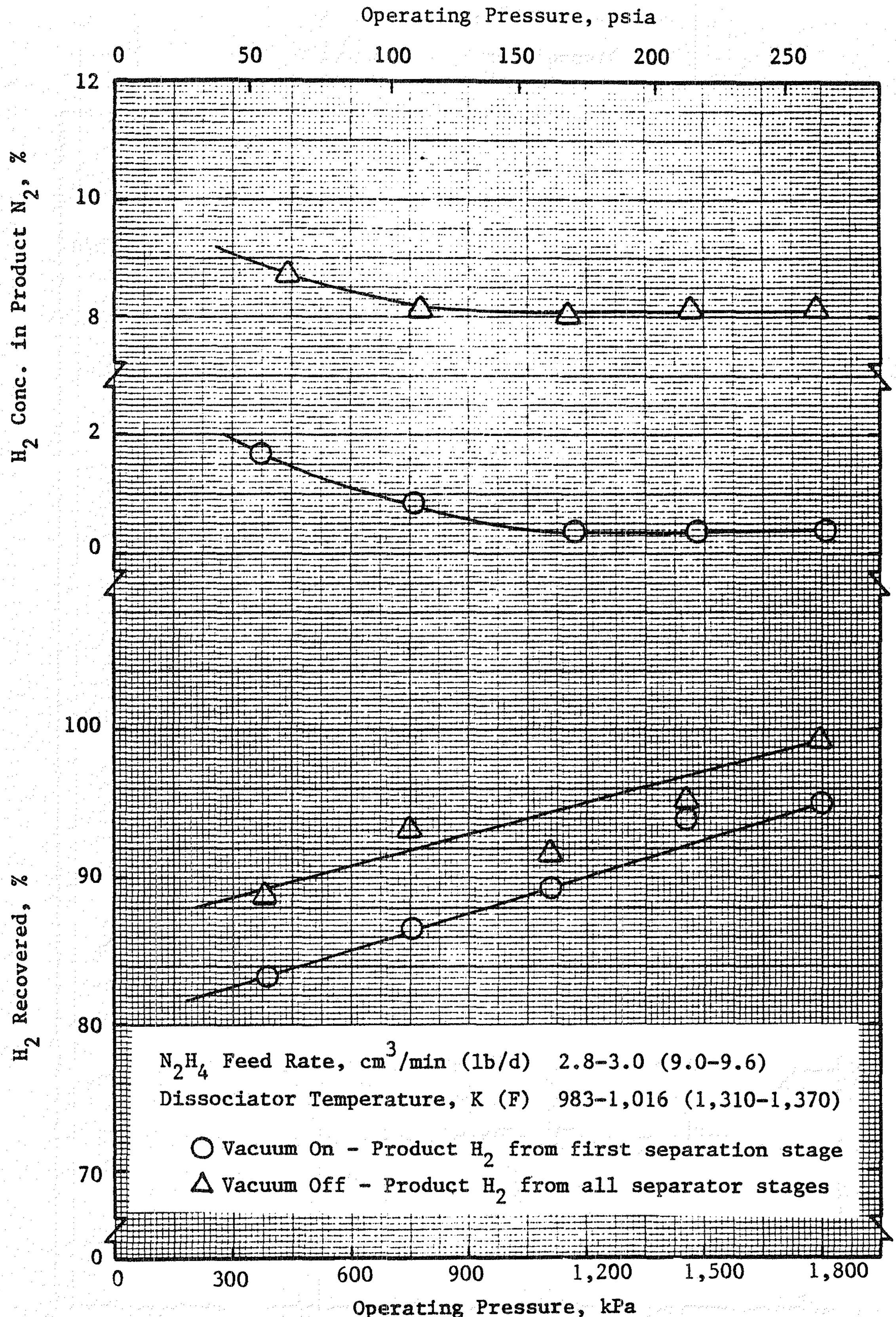

FIGURE 15 H_2 RECOVERY AS A FUNCTION OF OPERATING PRESSURE

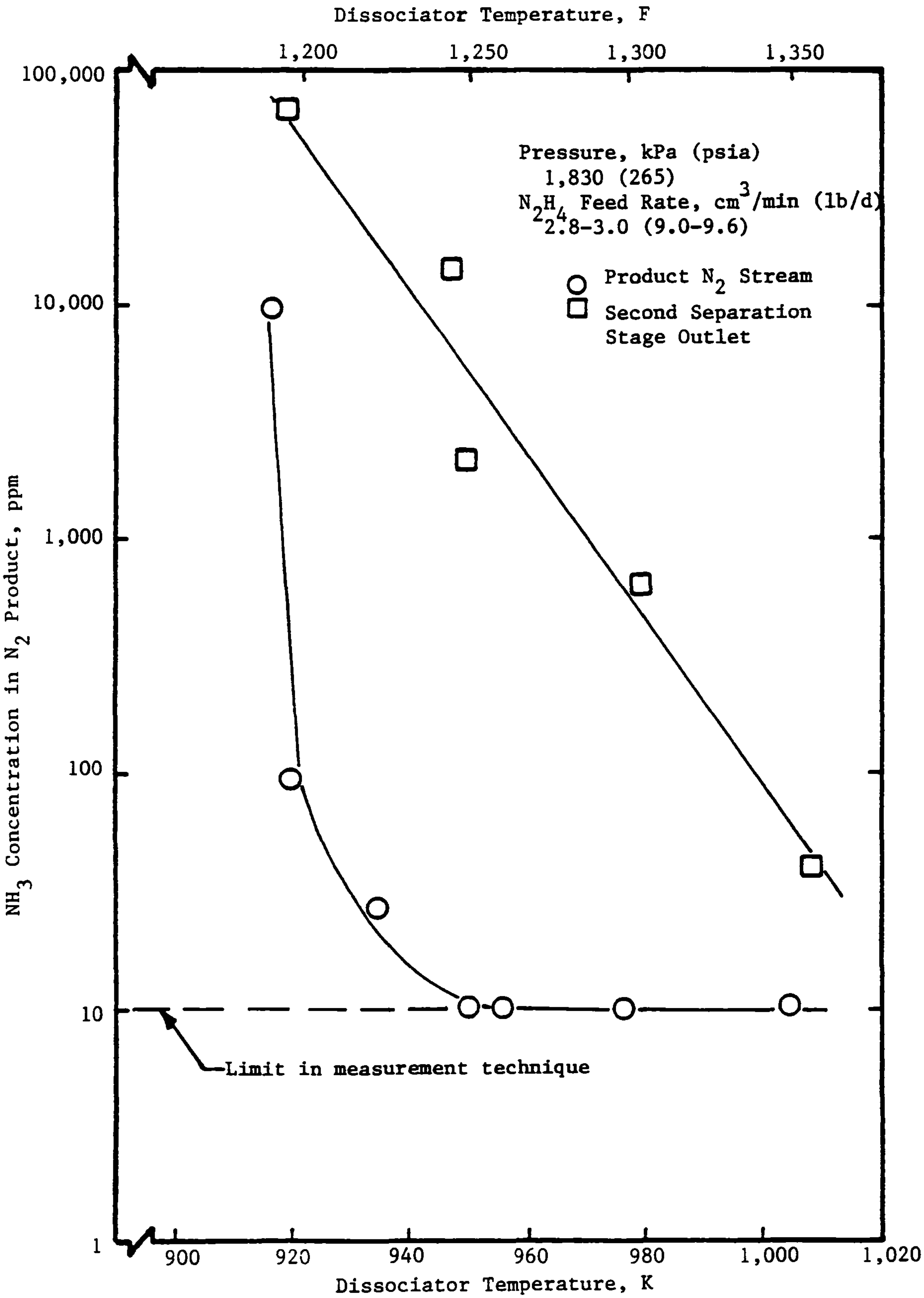

FIGURE 16 NGM PERFORMANCE (NH_3 CONCENTRATION IN PRODUCT N_2)

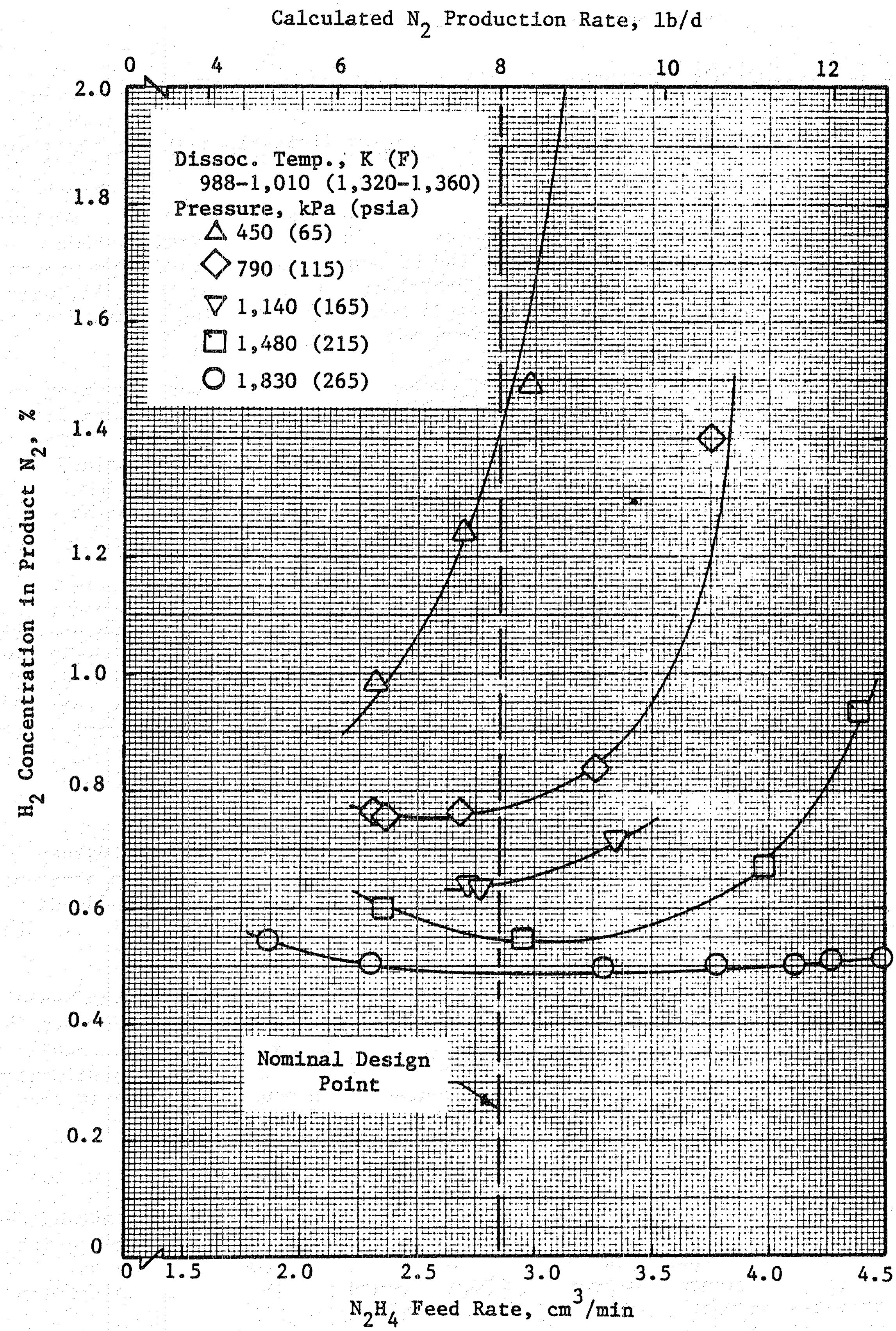

FIGURE 17 NGM PERFORMANCE (H_2 CONCENTRATION IN PRODUCT N_2)

to a lower partial pressure of H_2 in the N_2 stream. The NH_3 concentration shows a much larger dependence on N_2H_4 feed rate (see Figure 18). This is probably due to reaction rate and residence time limitations of the fixed-sized NH_3 dissociation stages.

Generally, these results supported the conclusion that the NGM, as presently configured, will provide N_2 generation rates at up to twice design value without much impact on H_2 impurity in the N_2 product stream at design pressure but NH_3 concentration will increase. Therefore, the advanced NGM will incorporate additional NH_3 catalyst and will do so without changing the size of the dissociator housing due to more efficient packaging.

Separator Temperature. No appreciable changes in H_2 or NH_3 concentration in the product N_2 stream were detected as a function of separator temperature variations. Due to the difficulty in achieving low separator temperatures because of dissociator radiative heating, only limited data was obtained in the range 589 to 672 K (600 to 750 F). No change in NH_3 concentration was observed with increasing temperature. Maintaining the NGM separator at 644 ±28 K (700 ±50 F) is the desired operating level.

Catalyst Weight. The effect of catalyst weight was achieved indirectly by analyzing samples at various NH_3 dissociation stages. Figure 16 showed the results of one such test. These data indicated that NH_3 dissociation performance is a function of residence time of the gas in the dissociation catalyst bed and not amount of catalyst directly. Bed length is more important than cross-sectional area although larger area will reduce space velocity for a given flow. For the current and projected advanced NGM, pressure drops in the catalyst beds are negligible.

PREPROTOTYPE NSS DESIGN

The primary function of the NSS is to generate N_2 for cabin leakage makeup thereby controlling total cabin pressure. Development of an NSS has progressed to a point where a preprototype, self-contained NSS should be designed and built to demonstrate its readiness for manned habitability applications. The program just completed provided the design for such a subsystem.

A 4.4 kg/d (9.6 lb/d) N_2 generation capacity NSS was designed. It was based on further anticipated improvements in NGM performance. The 4.4 kg/d (9.6 lb/d) capacity level allowed using the guidelines, philosophy and the specifications established for the SOC currently being considered by NASA.[9] This selection simplifies direct comparison of the NSS concept with onboard storage in the form of cryogenic or gaseous N_2 as indicated previously in Figure 1.

Design Specifications

Overall design specifications and requirements for the SOC NSS were established and are presented in Tables 5 and 6. The requirements for the N_2 generation rate and product composition were based on anticipated SOC requirements. Recent test experience and projected improvements in NGM performance confirm that they can be met.

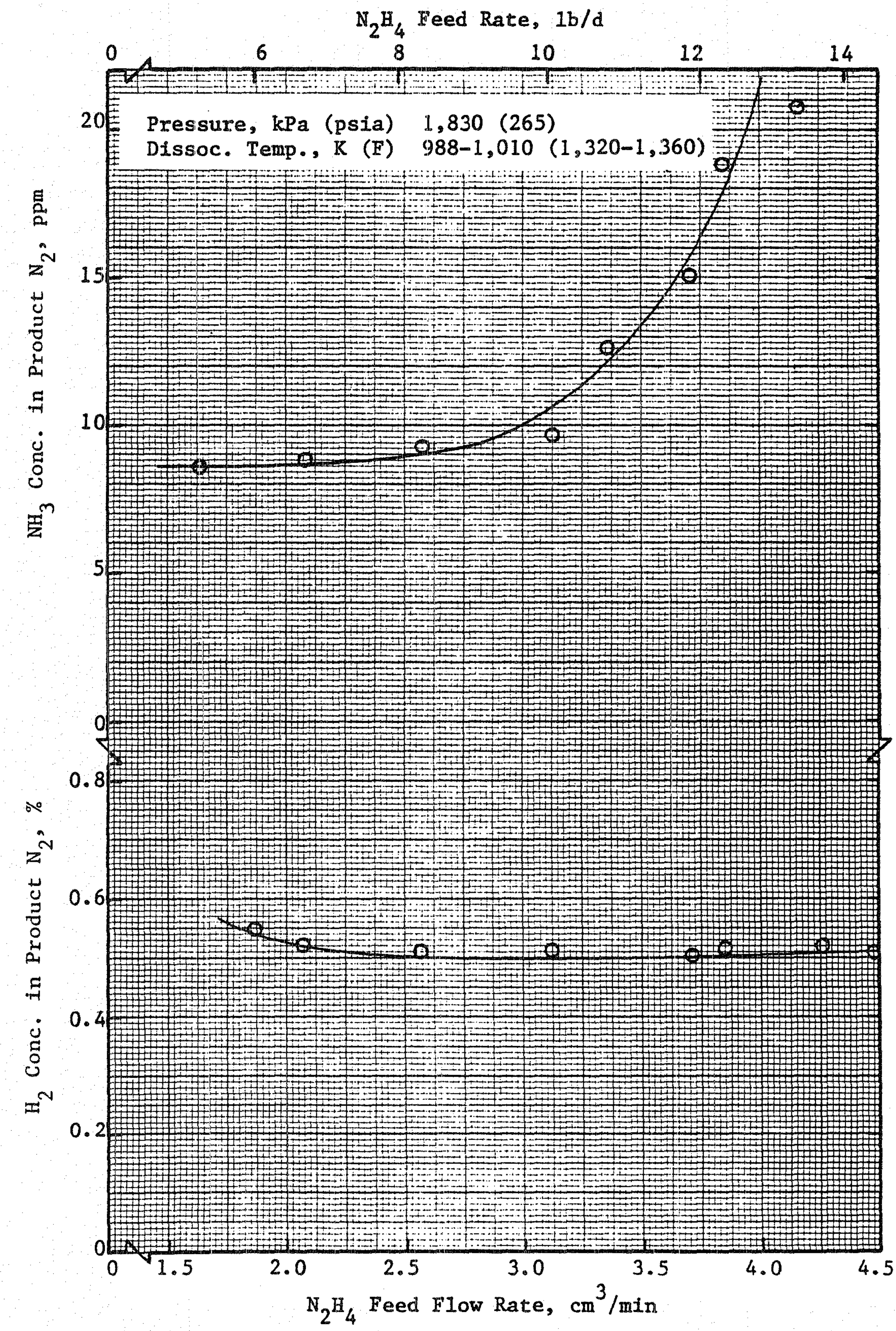

FIGURE 18 NGM PERFORMANCE AS A FUNCTION OF N_2H_4 FEED RATE

TABLE 5 NSS DESIGN SPECIFICATIONS

Hydrazine Feed Rate, kg/d (lb/d)	5.0 (11.0)
Nitrogen Generation Rate, kg/d (lb/d)	4.4 (9.6)
Byproduct Hydrogen Generation Rate, kg/d (lb/d)	0.56 (1.23)
Pressure, kPa (psia)	1,830 (265)
Nitrogen Product Composition, Volume %	
Hydrogen	<0.2
Ammonia	$<1 \times 10^{-3}$
Water[a]	<0.1
Hydrogen Byproduct Purity, Volume %	>99.9
Byproduct Hydrogen Recovery Efficiency, %	>90
Total Hydrogen Removal Efficiency, %	>99.8
Surface Temperature Guidelines, K (F)	322 (120)

(a) Water is in feed "anhydrous" hydrazine

TABLE 6 OTHER NSS DESIGN REQUIREMENTS

- Independent operation as a subsystem, requiring only electrical energy, the liquid (N_2H_4) to be dissociated, a vacuum source, a pressurant source and sources to receive generated gases
- Safety first, second reliability and power optimization -- the sequence of major design drivers
- Compatible with zero-and one-g testing
- Compatible with an unpressurized environment
- Capable of unattended operation for extended periods (>90 days)
- Separate Control/Monitor Instrumentation
- Computer-based instrumentation
- Control/Monitor Instrumentation remotely locatable
- Shelf life greater than ten years
- Operational life five years
- Optimized design for major mechanical components
- Compatible with JSC test facility/chamber
- All materials flight compatible (or flagged if not)

The overall goal of the design effort was to design an NSS as a spacecraft utility. The design features were selected based on both subsystem and design requirements. The following is a list of the major design features incorporated.

1. The subsystem is designed for location in an unpressurized area external to habitable confines.

2. A separate spacecraft N_2H_4 storage facility is assumed which will supply N_2H_4 to the NGM and other subsystems using N_2H_4 (e.g., reaction control units).

3. The byproduct H_2 generated can be used by a Sabatier reactor for CO_2 reduction.

4. Control and monitoring functions are provided by computer-based instrumentation utilizing software programming techniques.

5. Four steady-state operating modes are incorporated: Shutdown, Normal, Standby and Purge.

6. Manual overrides and controls have been included for off-design testing.

7. All materials of construction used are compatible with their environment.

Safety Considerations

Demonstration of highly safe operation of the preprototype hardware is a key aspect of this development program. Qualitatively the goal is to achieve the same degree of safety and confidence in operating the preprototype hardware as to what currently exists on the Shuttle auxiliary power units (APUs) which operate with N_2H_4. Hydrazine has been used in many manned and unmanned spacecraft programs over the past 20 years and is considered a routine element of these programs. Life Systems' operating experience has demonstrated the safe use and handling of N_2H_4 with appropriate precautions. It is imperative in the present subsystem design to maintain these safety considerations. This aspect is essential to ensure that the NSS concept will be used aboard future space vehicles.

Reliability Considerations

Demonstration of high reliability with the preprototype hardware is another key aspect of this development program. Steps have been taken to improve the projected reliability of the "heart" of the subsystem, namely the NGM. Quantitatively, the operational lifetime for individual components and for the overall subsystem shall be five years while operating under design conditions. This operating life shall be achievable any time within ten years of hardware delivery to NASA. Life Systems accepts this requirement as a first step to flight hardware development since it understands the importance of demonstrated reliable operation to achieve the goal of hardware readiness and user acceptability.

Thermal and Power Optimization

The goal of the NSS design and in particular the NGM, is to have the steady-state power input to be as low as possible and only that required to maintain the desired thermal environment. The thermal environment consists of approximately 1,000 K (1,340 F) for the dissociator portion of the NGM and 644 K (700 F) for the separator portion. The dissociation process of N_2H_4 is exothermic and produces heat. The amount of heat production is a direct function of the N_2H_4 feed rate (or N_2 generation rate) and will change as this parameter varies. Therefore, optimization of zero power input can be made at only the nominal design point. At N_2 generation rates less than the nominal, additional heat would be required and at greater than the nominal excess heat would need to be removed. These are some of the considerations of the thermal design.

Packaging Considerations

The primary packaging consideration for the NSS is that the subsystem is intended to be located in an unpressurized area. Furthermore, this unpressurized area may or may not be exposed to deep space. Considerations for thermal insulation of the N_2H_4 storage tank and the pressure controller along with the NGM itself have to be included. The overall dimensions of the NSS will be less than or equal to 56 cm (22 in) wide, 36 cm (14 in) high and 51 cm (28 in) deep. There is no requirement for rack mounting of this hardware. An additional packaging factor is the thermal insulation that may need to be added to meet specific subsystem thermal/warmup requirements.

Subsystem Interfaces

Table 7 lists the projected fluid, power and heat rejection interfaces for the preprototype NSS. The power required by the mechanical hardware of the NSS will be 115/200 VAC, 400 Hz, single phase and 28 VDC which are projected spacecraft resources. The developmental C/M I will use 115 VAC, 60 Hz, single phase power.

Subsystem Schematic and Operation

The schematic of the preprototype NSS is shown in Figure 19 while the components are listed in Table 8. Hydrazine is periodically supplied to the N_2H_4 feed tank (WT1) through valve (V1) from a lower pressure source of N_2H_4. The feed tank is sized to provide operation over approximately 24 hours at nominal N_2 generation rates without refill. The low pressure source of N_2H_4 is assumed to be centrally located for the NSS and other spacecraft equipment.

Under normal operation, N_2H_4 is fed to the NGM (NM1) through valve V2 and flow restrictor RX1 at a controlled pressure P2 above the operating pressure P1. Flow, and therefore N_2 generation rate, is determined by feed tank pressure.

In the NGM, the N_2H_4 is dissociated and H_2 and N_2 is produced. The dissociation of N_2H_4 and NH_3 dissociation is maintained at temperature T1 by heater H1. The H_2 is removed from the N_2 stream in the separator which is maintained

TABLE 7 NSS INTERFACE SPECIFICATION

Hydrazine In	
Usage Rate, kg/d (lb/d)	5.0 (11.0)
Fill Pressure, kPa (psia)	140 (20)
Temperature, K (F)	Ambient
Tank Fill Rate, No. Per day	1
Flow Rate, cm^3/min (ft^3/min)	2,500 (0.09)
Fill Time, min	2
N_2 Purge/Pressurization	
Temperature, K (F)	Ambient
Pressure, kPa (psia)	2,170 (315)
Flow Rate, dm^3/min (ft^3/min)	
Normal Operation	0.053 (0.002)[a]
Duration	Continuous
Purge/Pressurization	1.5 (0.05)[a]
Duration, min	5
N_2 Product	
Flow Rate, dm^3/min (lb/d)	2.6[a] (9.6)
Temperature, K (F)	Ambient
Pressure, kPa (psia)	100 to 140 (15 to 20)
Composition, Volume %	
Nitrogen	>99.7
Hydrogen	<0.2
Ammonia	$<1 \times 10^{-3}$
Water	<0.05
H_2 Product	
Flow Rate, dm^3/min (lb/d)	4.7[a] (1.24)
Pressure, kPa (psia)	100 to 125 (15 to 18)
Temperature, K (F)	Ambient
Purity, Volume %	99.999 to 100
H_2 to Vacuum	
Flow Rate, dm^3/min (lb/d)	0.52[a] (0.14)
Temperature, K (F)	Ambient
Pressure, kPa (psia)	0 to 7 (0 to 1)

continued-

(a) At standard temperature and pressure.

Table 7 - continued

Power, W[b]	
AC (115 V, 400 Hz, 1Ø)	75
DC	63
Heat, W	
Generated	91
Waste (Actuators, Heaters)	138
Other	
Gravity	0 to 1
Surface Touch Temperature, K (F)	<322 (120)

(a) C/M I power is not included.

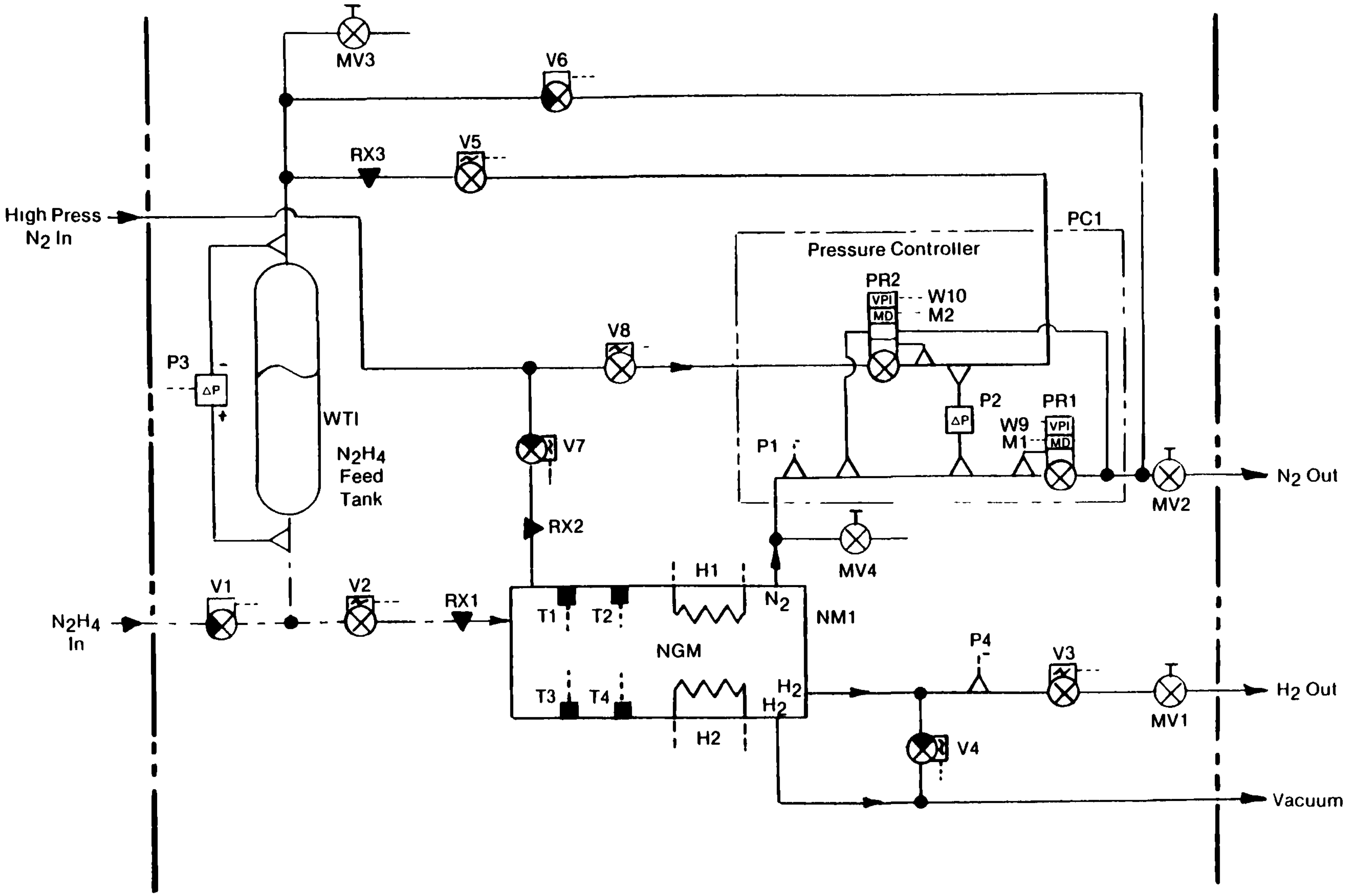

FIGURE 19 NSS MECHANICAL SCHEMATIC

TABLE 8 NSS COMPONENTS LIST

Life Systems, Inc. CLEVELAND, OHIO 44122	PARTS LIST / COMPONENTS	NO. Project 1200 / PAGE 1 OF 1	REVISION LTR. / DATE 6/22/81
TITLE Nitrogen Supply Subsystem		Ref: LSI-B-3003	

ITEM	QTY. REQ.	PART OR IDENT. NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL AND SPECIFICATION	REFERENCE OR NOTE
1	1	NM1	Nitrogen Generation Mod.	Life Systems	D-3094
2	1	PC1	Pressure Controller	Life Systems	J-3191
3	1	WT1	N_2H_4 Storage Tank	Life Systems	D-3213
4	1	P3	Tank Pres. Sen. 5 psid	Viatran 220-15	
5	1	P4	H_2 Pres. Sensor 0-20 psid	Viatran 218-20	
6	3	H1	Dissociator Heater	Watlow ¼ x 12", 600 W	
7	3	H2	Separator Heater	Watlow 7355 EX	
8	1	T1	Dissociator Control T/C	Omega SCAIN-020U-6	
9	1	T3	Separator Control T/C	Omega TJ-CAIN-116U-8	
10	1	T3	Separator Control T/C	Omega TJ-CAIN-116U-8	
11	1	T4	Separator Heater T/C	Omega TJ-CAIN-116U-8	
12	1	RX1	N_2H_4 Fd. Or. (70,000 lohm)	Lee 13VLO CM	
13	1	RX2	Purge Ori. (40,000 lohm)	Lee 13AVL3 CM	
14	1	RX3	Tank. Pr. Or. (8,000 lohm)	Lee 38AVL2 CM	
15	1	V1	N_2H_4 Tank Fill Valve	Marrotta 2060037-0054	
16	1	V2	N_2H_4 Feed Valve	Marrotta 2060037-0054	
17	1	V3	H_2 Out Valve	Skinner B2H-DK1-400	
18	1	V4	H_2 Product Line Purge Val.	Skinner B11-DK1-400	
19	1	V5	Tank Pressurization Valve	Skinner B2H-DK1-400	
20	1	V6	Tank Depressurization Val.	Skinner B2H-DK1-400	
21	1	V7	Purge Valve	Skinner B11-DK1-400	
22	1	V8	Tank Pres. Source Valve	Skinner B2H-DK1-400	
23	1	MV1	H_2 Shutoff Handvalve	Whitey SS43S4	
24	1	MV2	N_2 Shutoff Handvalve	Whitey SS43S4	
25	1	MV3	Tank Depress. Handvalve	Whitey SS43S4	
26	1	MV4	NGM Depress. Handvalve	Whitey SS43S4	

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at temperatures T3 by heater H2. Temperature sensors T2 and T4 monitor the heaters H1 and H2, respectively, to ensure safe heater operation.

Hydrogen can exit the NGM in two streams. Product H_2 exits through valve V3 and manual valve MV1. Its pressure is monitored by pressure sensor P4. The other exit is directly to vacuum. Valve V4 is used to isolate the two streams and provides vacuum purge to the product H_2 stream upon startup and shutdown.

Product N_2 exits the NGM and enters the NSS pressure controller (PC1) which performs two functions. The first is to maintain operating pressure P1. This is performed with a backpressure regulator PR1 which is automatically controlled by motor M1 and position indicator W9. The second function of PC1 is to maintain the feed tank pressure at a fixed differential, P2, above that of the operating pressure P1. The source gas for the feed tank pressurization comes from a high pressure N_2 supply through a shutoff valve V8. Since the amount of N_2 used is only that required to displace the N_2H_4 in the feed tank, the total amount used is minimal. In addition, this N_2 is returned to the outlet stream (to the cabin) when the tank is depressurized for tank refill.

Feed tank refill is accomplished by: (1) isolating the tank - closing valves V2 and V5, (2) depressurizing - opening valve V6, (3) filling - opening valve V1 until full and then closing valve V1, (4) isolation - closing valve V6, (5) repressurization - opening valve V5 and (6) return to operation - opening valve V2. Pressure sensor P3 is used to monitor the filling operation and also to detect a tank empty condition.

Manual valves (MV1 - MV4) are provided to isolate the NSS from downstream subsystems (MV1 and MV2) and/or depressurize the feed tank (MV3) and NGM (MV4) for maintenance.

Operating Modes and Controls

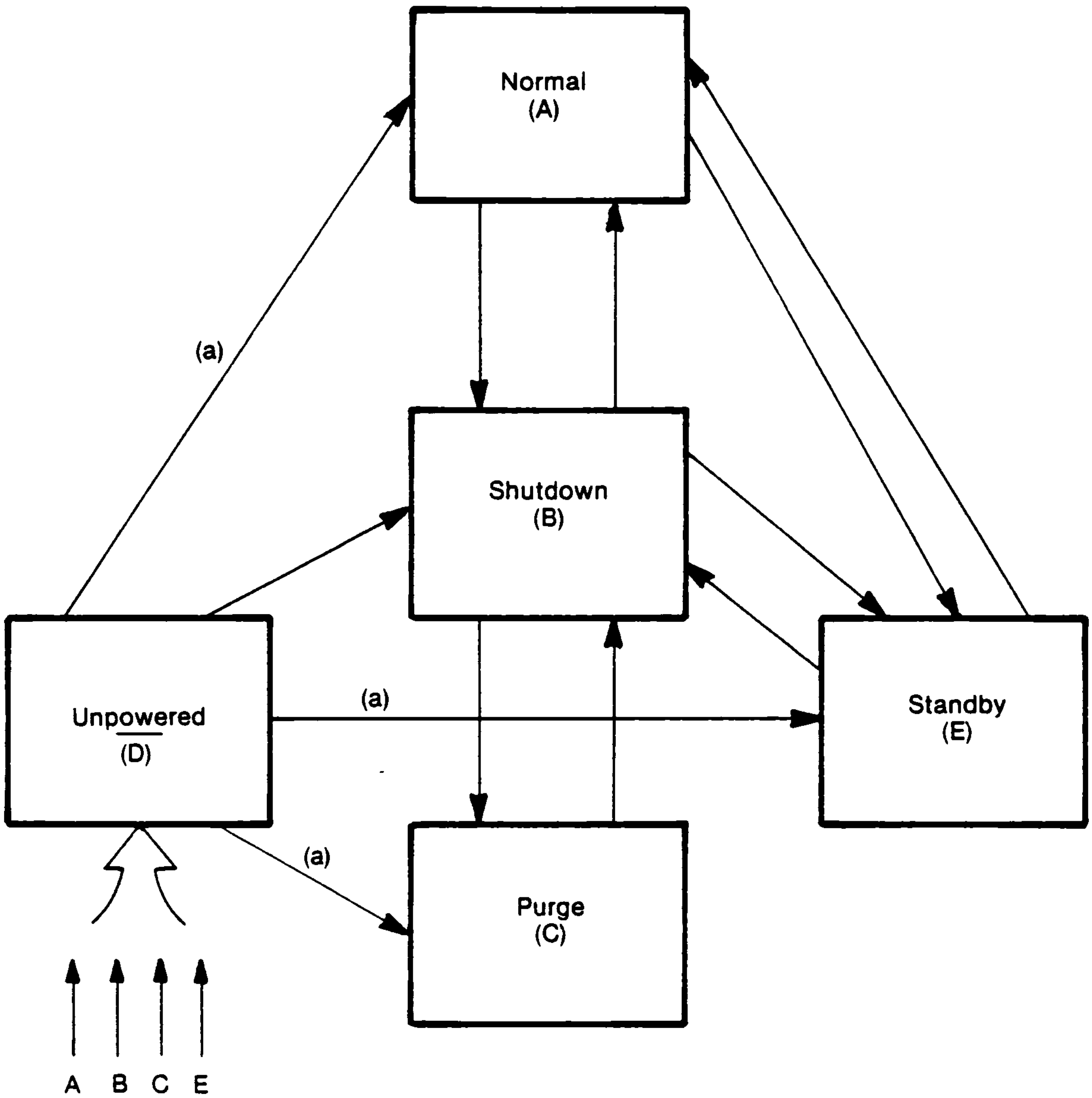
The operating modes and allowable mode transitions are shown in Figure 20 while Table 9 presents the NSS controls definition. The operating modes and unpowered modes are defined in Table 10 while Table 11 defines the steady-state actuator conditions for each mode. Detailed intermode transition sequences are given in Appendix 1.

Subsystem Operating Characteristics and Conditions

The projected operating characteristics and conditions for the preprototype NSS are summarized in Table 12. The nominal N_2 generation rate corresponds to projected SOC leakage rates. Additional requirements to provide leakage for losses due to evacuations and repressurizations following extravehicular activity (EVA's) have not been included since these requirements are undefined at this time.

Mechanical Design

There are three major components to the NSS: the NGM, a pressure controller and a N_2H_4 storage tank. These, along with ancillary components and packaging comprise the subsystem.



- 5 Modes
- 4 Operating Modes
- 16 Mode Transitions
- 9 Programmable, Allowed Mode Transitions

(a) For power interruptions less than 5 0 s

FIGURE 20 NSS MODES AND ALLOWABLE MODE TRANSITIONS

TABLE 9 NSS CONTROLS DEFINITION

No.	Control	Control Parameter	Description	Actuator(s)	Sensor(s)	Setpoint	Setpoint Adjust Range
1	NGM Operating Pressure	P1, P2	Sets the operating pressure and controls the N_2H_4 storage tank and feed pressure to the desired setpoints in all modes and mode transitions	M1(PR1) M2(PR2) V5, V7	P1, P2, Y1	P1-1,830 kPa (265 psia) P2-69 kPa (10 psid)	0 to 1,830 kPa (0 to 265 psia) 0 to 207 kPa (0 to 30 psid)
2	NGM Dissociator Temperature	T1	Controls NGM Dissociator Temp (T1) to desired setpoint by actuating heater H1. Maintains heater temperature T2 at desired (safe) setpoint.	H1	T1, T2	1,000 K (1,375 F)	294 to 1,090 K (70 to 1,500 F)
3	NGM Separator Temperature	T3	Controls NGM Separator Temp T3 to desired setpoint by activating heater H2. Maintains heater temperature T4 at desired (safe) setpoint.	H2	T3, T4	644 K (700 F)	294 to 700 K (70 to 800 F)
4	N_2H_4 Tank (WT1) Fill	WT1	Fills WT1 with N_2H_4 every 24 hours or when empty.	V1, V2 V5, V6	P3	34 kPa (5 psid)	-69 to 69 kPa (-10 to +10 psid)

TABLE 10 NSS MODE DEFINITIONS

MODE (CODE)	DEFINITIONS
Shutdown (B)	The NGM is not generating N_2. Dissociator heater (H1) and Separator heater (H2) are off. V1, 2, 3, 5, 6, 7, and 8 are closed. V4 is open. PR1 is turned to and held at lowest VP1 setting. PR2 is held at a predetermined VP1 setting. The system is powered and all sensors are working. The Shutdown Mode is called for by: • Manual actuation • High Dissociator Temperature (T1) • Low Dissociator Temperature (T1) • High Separator Temperature (T3) • Low Separator Temperature (T3) • High Dissociator Heater Temperature (T2) • Low Dissociator Heater Temperature (T2) • High Separator Heater Temperature (T4) • Low Separator Heater Temperature (T4) • Low Hydrazine Feed Pressure (P2) • High Hydrazine Feed Pressure (P2) • Low NGM Operating Pressure (P1) • High NGM Operating Pressure (P1) • High Feed Tank ΔPressure (P3) • Low Feed Tank ΔPressure (P3) • High H_2 Delivery Pressure (P4) • Low H_2 Delivery Pressure (P4) • Power on reset (POR) from long term (>5 sec) unpowered Mode (D) • Mode transition from Shutdown Mode (B) to Normal (A), Standby (E), or Purge (C) was not successful. All transitions to the Shutdown Mode except from power on include a timed purge sequence as part of the mode transition sequence.
Normal (A)	The NGM is generating N_2 at the nominal rate. V2, 3, 5 and 8 are open. V1, 4, 6, 7 are closed. M1, M2, H1, H2 are controlling. The Normal Mode is called for by: • Manual Actuation

continued-

Table 10 - continued

MODE (CODE)	DEFINITIONS
Standby (E)	The NGM is ready to generate N_2. Dissociator (H1) and Separator (H2) heaters are controlling. Pressure regulators are holding at last VPI setting. Valves V1, 2, 3, 6, 7 and 8 are closed. V4 and V5 are open. • Manual Actuation
Purge (C)	The NGM is being purged with N_2 through the gas lines. Hydrogen product is purged to a vacuum. Valves V1, 2, 3, 5, 6, 8 are closed. V4, 7 are open. Dissociator (H1) and Separator (H2) heaters are off. Regulators remain in same condition as Shutdown. • Manual Actuation
Unpowered (D)	No electrical power is applied to the NSS. All valves are closed except V4 and V7 which are open. The unpowered Mode is called for by: • Manual Actuation (Circuit Breaker in TSA) • Electrical power failure • Built-in-Diagnostic (BID) Circuit removes power

TABLE 11 STEADY-STATE ACTUATOR CONDITIONS FOR NSS OPERATING MODES

Operating Mode	Actuators and Status											
	Solenoid Valves								Regulators		Heaters	
	V1	V2	V3	V4	V5	V6	V7	V8	M1	M2	H1	H2
Shutdown (B)	C	C	C	O	C	C	C	C	(b)	(a)	Off	Off
Normal (A)	C	O	O	C	O	C	C	O	(c)	(d)	On/Off	On/Off[(g)]
Standby (E)	C	C	C	O	O	C	C	C	(e)	(e)	On/Off	On/Off[(g)]
Purge (C)	C	C	C	O	C	C	O	C	(b)	(a)	Off	Off
Unpowered (D)	C	C	C	O	C	C	O	C	(f)	(f)	Off	Off

(a) Hold at predetermined VPI setting.
(b) Turn to and hold at lowest VPI setting.
(c) Controlled by P1.
(d) Controlled by P1 and P2.
(e) Hold at last VPI setting.
(f) Position and status depend on when power was removed.
(g) The heater is used in an On/Off Temperature Control Mode.

TABLE 12 NSS NOMINAL OPERATING CONDITIONS/CHARACTERISTICS

Catalytic Dissociator Temperature, K (F)	1,000 (1,340)
Pd/Ag Separator Temperature, K (F)	644 (700)
Hydrazine Feed	
Source	Liquid Hydrazine
Hydrazine Flow Rate, kg/d (lb/d)	5.0 (11.0)
cm^3/min	3.5
Composition, Weight %	
Hydrazine	99.5 to 100
Water	0 to 0.5
Temperature, K (F)	291 to 297 (65 to 75)
Pressure, kPa (psia)	1,830 (265)
Nitrogen Product	
Flow Rate, kg/d (lb/d)	4.4 (9.6)
dm^3/min (ft^3/min)	2.6 (0.092)
Composition, Volume %	
Hydrogen	<0.2
Ammonia	$<1.0 \times 10^{-3}$
Water	<0.1
Temperature, K (F)	644 (700)
Pressure, kPa (psia)	1,830 (265)
Hydrogen Byproduct	
Flow Rate, kg/d (lb/d)	0.56. (1.24)
dm^3/min (ft^3/min)	4.7 (0.164)
Purity, Volume %	>99.99
Temperature, K (F)	644 (700)
Pressure, kPa (psia)	103 (15)
Hydrogen Vented	
Flow Rate, kg/d (lb/d)	0.064 (0.14)
dm^3/min (ft^3/min)	0.52 (0.18)
Temperature, K (F)	644 (700)
Pressure, Pa (mm Hg)	0 to 1,330 (0 to 10)

Advanced NGM

The preprototype NSS will incorporate the advanced NGM design generated under this program. The two principal design improvements are: (1) elimination of all sealing surfaces, and (2) minimization heater power required to maintain steady-state operating temperatures.

A functional diagram of the NGM was shown in Figure 7 along with the chemical reactions occurring in different sections of the hardware. The principal design feature of the NGM is the ability to transfer gases back and forth from the central dissociation (N_2H_4 and NH_3) zone which is maintained at 1,000 K (1,340 F) and the separation zone near the periphery which is maintained at 644 K (700 F). Gases pass back and forth through a manifold shown at the left end of Figure 7.

Prior hardware was designed to be taken apart for maintenance. This approach utilized seals in the manifolding area. Also seals were used at the ends of the central dissociator core to permit installation, removal and change of catalyst materials. The present design has eliminated these seals by making all of these joints welded or brazed. A sketch of the current configuration indicating the areas where improvements have been made is shown in Figure 21. All mechanical fasteners (bolts, studs, etc.) and gaskets will be eliminated.

The central N_2H_4 dissociator (cracker) is the same design as the previous NGM. The three passages for NH_3 dissociation have been altered to contain slightly more catalyst and also incorporate the welding/brazing mentioned above. Also the Pd/Ag tube header will contain 60 tubes versus 50 that the previous design had. The increased capacity resulting from increased NH_3 dissociation catalyst and additional Pd/Ag H_2 separation tubes will provide performance improvement and yet the NGM overall size of 26.7 cm diam. x 38.6 cm (10.5 in diam. x 15.2 in) will be less than the previous design. Also the weight is projected at 28 kg (62 lb) versus the previous 33 kg (73 lb).

The second design driver was to minimize heater power. It is recognized that input power can never be zero, or there would be no passive zone temperature control. On the other hand, the design must accommodate variations in N_2 generation rate which means that internally generated heat will vary. Additionally, it is necessary to isolate thermally the central core and the separator at the periphery. This is done with radiation shields installed in the dead space between the two zones. A series of three radiation shields is planned to be installed; however, one or more can be easily removed. This, with a combination of additional insulation at the back and provisions for removing or adding insulation, will reduce the overall power requirements. A goal of 75 W of steady-state input power has been established.

Minor design changes include (a) use of welded thermocouple wells instead of compression-fitted thermocouples to eliminate sources of leakage, and (b) elimination of interstage sample ports. Only those mechanical interfaces absolutely needed for the control or connection with other NSS components will be included. Past performance of the NGM has given confidence in the unit to

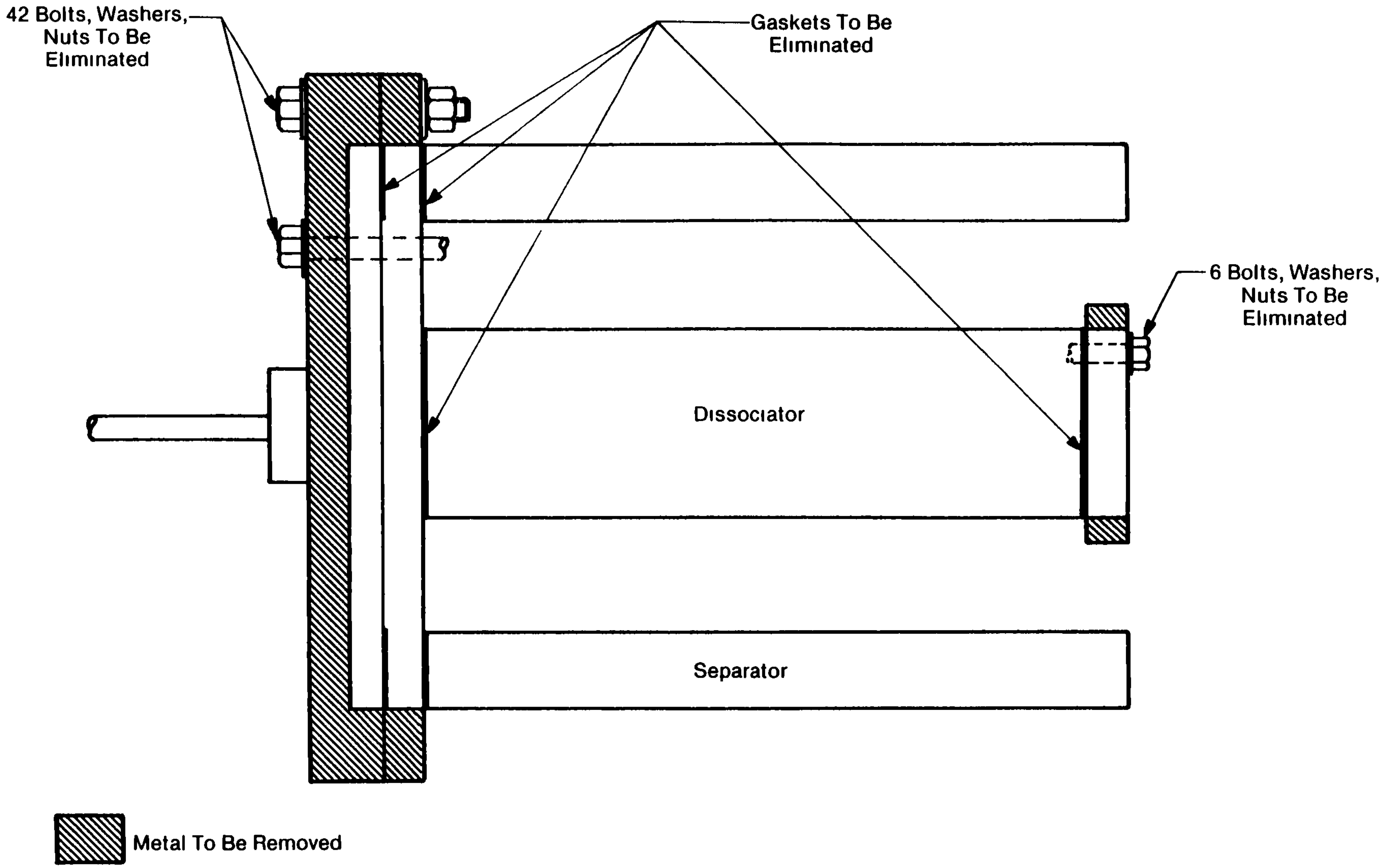


FIGURE 21 NGM DESIGN MODIFICATIONS HIGHLIGHTS

perform its N_2 generation function without additional provisions for monitoring interstage performance. Therefore, those provisions have been eliminated.

Pressure Controller

The N_2 pressure controller permits subsystem startup from ambient pressure by using an external N_2 source. This N_2 source also provides the initial pressurization of the N_2H_4 to produce flow to the NGM. Over a SOC mission, this amount of N_2 is less than 2% of the total N_2 generated at baseline conditions. This gas is returned to the cabin. Use of the high pressure N_2 source (and treated as a consumable) trades off favorably with a low reliability, power consuming N_2H_4 pump to provide N_2H_4 at the needed pressure.

The N_2 pressure controller is similar to others built by Life Systems for controlling absolute pressure and pressure differentials between two or more fluids. Its functional operation is shown in Figure 22. It combines in a single assembly the sensors and actuators necessary to control and monitor fluid pressure levels and differentials during all phases of operation including steady-state, startup, shutdown, etc.

It consists of a backpressure regulator for maintaining NGM operating pressure and a forward pressure regulator for providing the pressure to force the feed N_2H_4 into the NGM at the desired controlled rate. Besides the two regulators it also contains two pressure sensors and two feedback position indicators, which under computer control, will maintain the appropriate pressures. The controller has four fluidic interfaces shown in Figure 22 and a standard connector for the electrical interface with the subsystem instrumentation. A sketch of the controller is shown in Figure 23.

N_2H_4 Storage Tank

Based on the nominal N_2 generation rate of 4.4 kg/d (9.6 lb/d) and corresponding N_2H_4 feed requirements 5.0 kg/d (11 lb/d), a 5 liter (0.18 ft^3) tank has been designed for use in the NSS. This standard tank has a ethylene propylene (EPR) membrane to serve as a bladder. A flight N_2H_4 tank of the same capacity has been identified as potential Government Furnished Equipment from the NASA Goddard Space Flight Center. This tank would be considerably lighter since it is spherical and made of titanium. Another advantage of this tank is that it is flight qualified.

Ancillary Components

The proposed subsystem will have a total of 18 sensors. These are listed in Table 13. Of these sensors, pressure sensors P1 and P2 and position indicators W9 and W10 are considered part of the pressure controller. Temperature sensors T1 through T4 are a part of the NGM. Nonintegrated sensors are the feed tank pressure transducer P3, NGM H_2 delivery pressure sensor P4 and the six valve position indicators associated with solenoid valves V3 through V8.

The actuators required are listed in Table 14. Of these, heaters H1 and H2 are part of the NGM while the regulator motors M1 and M2 are part of the

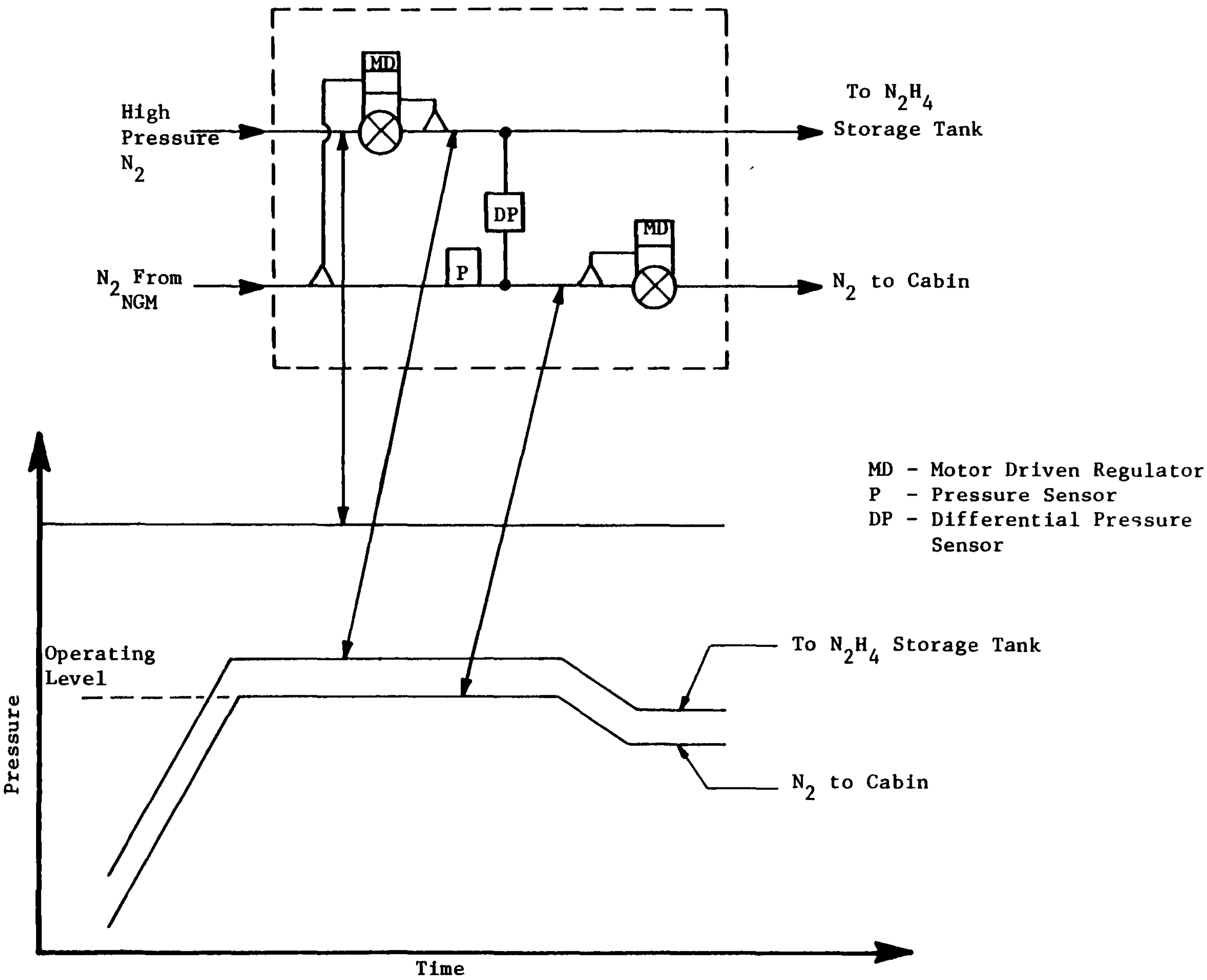


FIGURE 22 NSS PRESSURE CONTROLLER FUNCTIONAL DESCRIPTION

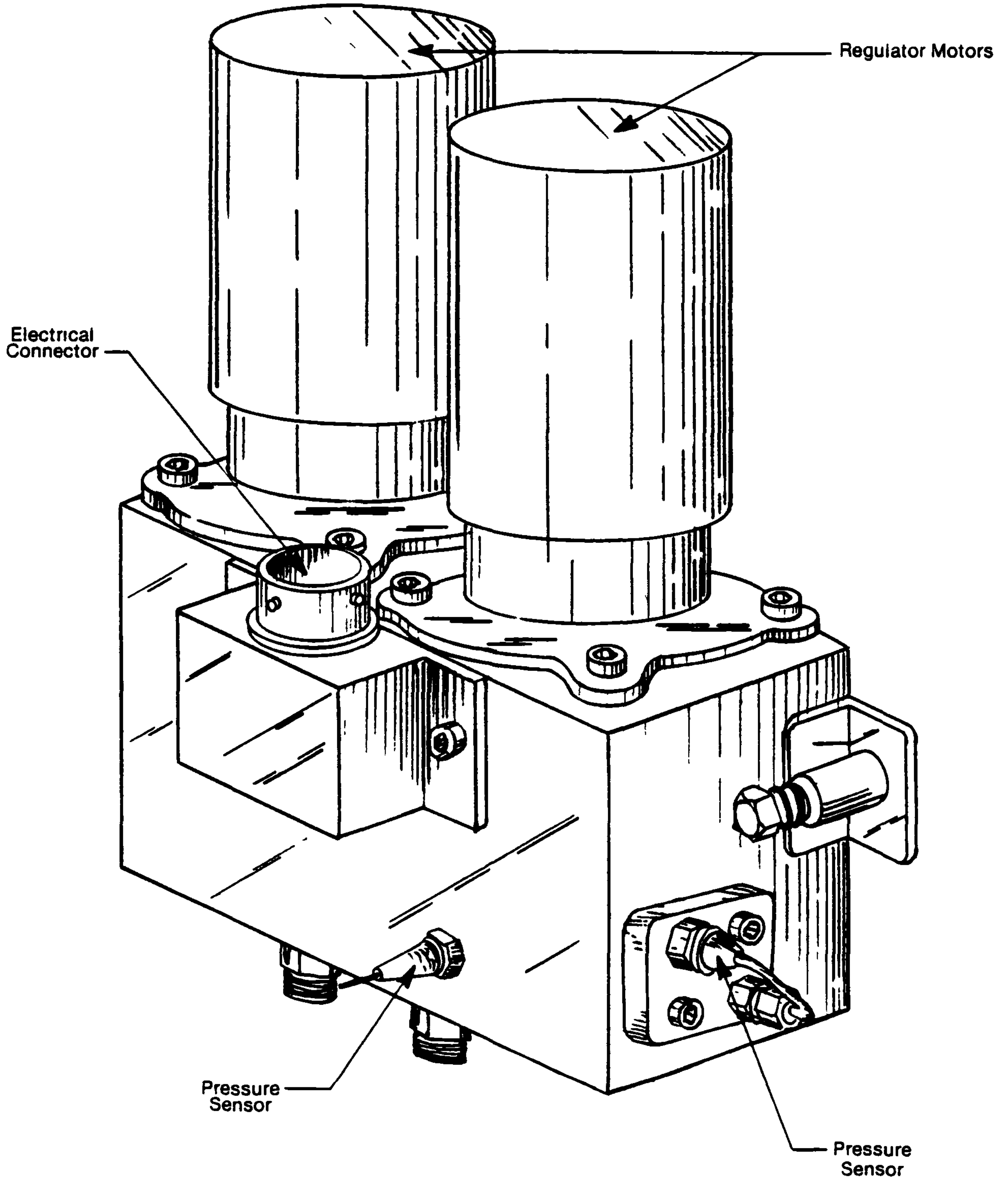


FIGURE 23 NSS PRESSURE CONTROLLER

TABLE 13 NSS SENSOR LIST

Description	Qty.	Symbol	Redundancy Level	Notes
Dissociator Temperature	1	T1	1	Thermocouple
Dissociator Heater Temp	1	T2	1	Thermocouple
Separator Temperature	1	T3	1	Thermocouple
Separator Heater Temperature	1	T4	1	Thermocouple
NGM Operating Pressure	1	P1	1	Strain Gauge
N_2H_4 Feed Δ Pressure	1	P2	1	Strain Gauge
Feed Tank Δ Pressure	1	P3	1	Strain Gauge
H_2 Delivery Pressure	1	P4	1	Strain Gauge
Solenoid Valve Position Indicator	8	W1-W8	1	Relay Contacts
Pressure Controller Position Indicator	2	W9,W10	1	Potentiometer

TABLE 14 NSS ACTUATOR LIST

Description	Qty.	Symbol	Redundancy Level
Dissociator Heater	1	H1	1
Separator Heater	1	H2	1
N_2H_4 Tank Fill Valve	1	V1	1
N_2H_4 Feed Valve	1	V2	1
H_2 Product Valve	1	V3	1
H_2 Product Vacuum Purge Valve	1	V4	1
Tank Pressure Valve	1	V5	1
Tank Vent Valve	1	V6	1
N_2 Product Purge Valve	1	V7	1
Source Pressure Valve	1	V8	1
N_2 Product Regulator	1	M1	1
N_2H_4 Tank Press Regulator	1	M2	1

pressure controller. The NSS will utilize standard off-the-shelf solenoid valves. The valves for the gas lines will consist of laboratory proven standard solenoid valves. The valves for the N_2H_4 will consist of more expensive but higher reliability Marrotta valves. These valves were used in prior NGM testing.

Packaging

Plumbing interconnections in the NSS utilize 304 stainless steel, particularly those lines which contact N_2H_4. Fittings will be 304 stainless steel, welded where possible. A welded framework will be used to support the NGM, the tank and the remaining components. A facing plate will be located on the front on which the pressure controller and valves will be mounted. Electrical and mechanical interfaces will be made at the back. A packaging layout with dimensions is shown in Figure 24.

Table 15 shows the projected weight, volume and power requirements of the NSS mechanical components.

Control and Monitor Instrumentation

- Automatic mode and mode transition control
- Automatic shutdown provisions for self-protection
- Provisions for monitoring typical subsystem parameters
- Provisions for interfacing with ground test instrumentation

The C/M I designed for the preprototype NSS is a Life Systems' Series 100 C/M I, specifically the Model 170A. The Series 100 refers to a mini-computer based C/M I with extensive operator/system interface suitable for laboratory development and testing. The "A" refers to upgrades presently in the Series 100.

Functional Description

Figure 25 shows the first level (Level I) Series 100 C/M I hardware functional block diagram. The hardware consists of the following major sections:

a. System Input/Output (I/O)
b. Computer
c. Operator/System Interface
d. Power Supply
e. Enclosure

The C/M I interfaces with external AC power sources, ambient cooling air, and the subsystem sensor/actuator signals and power. In some applications, special external electronics packages might be required. The C/M I also interfaces with these packages as required. In the NSS, for example, heater electrical power would be switched by relays located in the mechanical assembly.

Figure 26 shows the NSS C/M I hardware functional block diagram in more detail (Level II). This block diagram shows the subassemblies and components in each section:

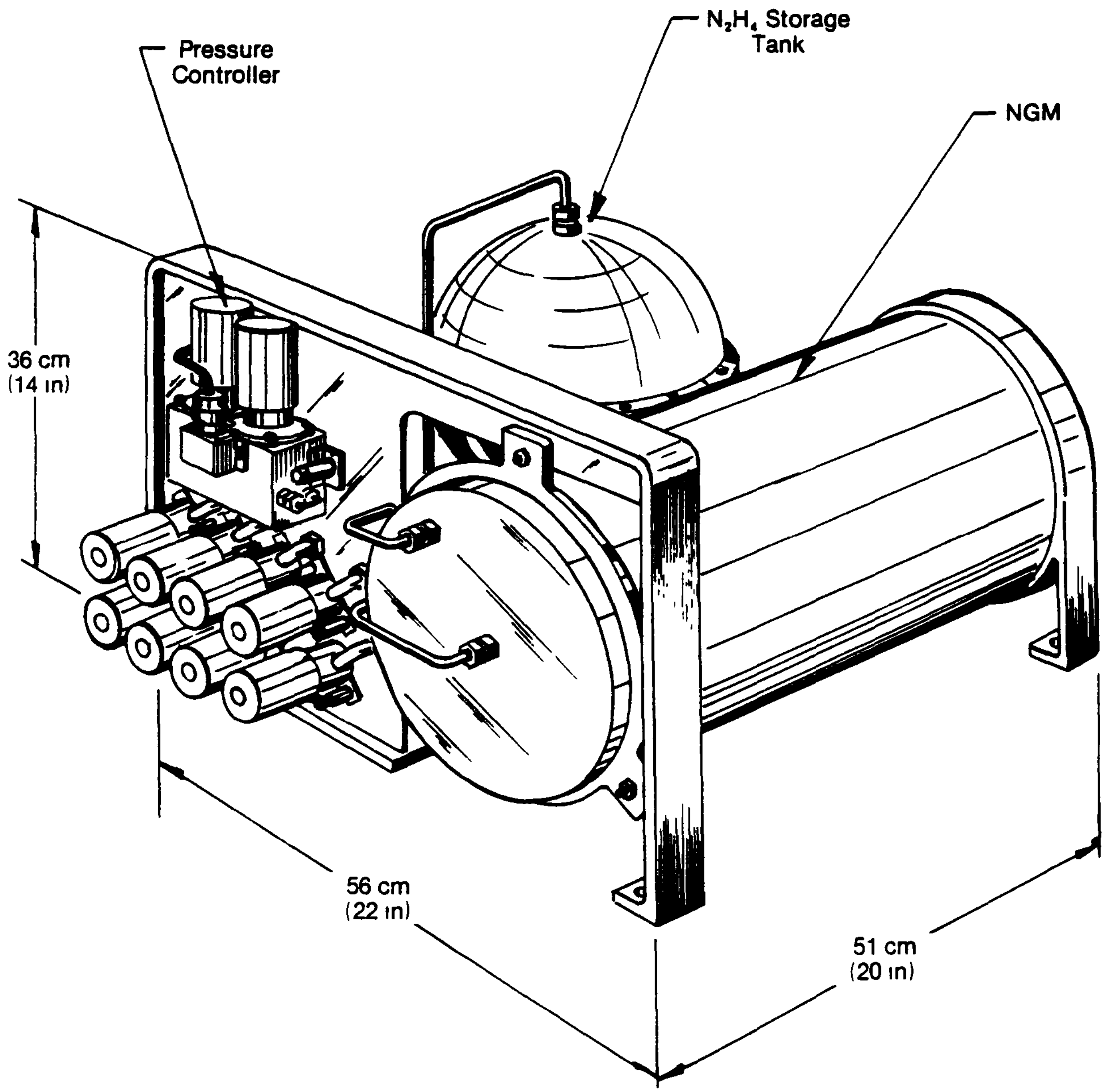


FIGURE 24 NSS PACKAGING

TABLE 15 NSS MECHANICAL COMPONENT WEIGHT, POWER AND HEAT REJECTION SUMMARY

Item	Symbol	Component	No. Req'd	Unit Weight, kg (lb)	Total Weight, kg (lb)	Total AC Power, W	Total DC Power, W	Heat Rejection, W
1	NM1	NGM	1	28 (62)	28 (62)	75[a]	-	166[c]
2	PC1	Assembly Pressure Controller	1	3.2 (7.1)	3.2 (7.1)	-	2[b]	2
3	WT1	Tank, N_2H_4	1	13 (29)	13 (29)	-	-	-
4	V1, V2	Valves, Solenoid (N_2H_4)	2	0.45 (1)	0.91 (2)	-	6	6
5	V3-V8	Valves, Solenoid	6	0.14 (0.31)	0.85 (1.86)	-	30	30
6	P3, P4	Sensor, Pressure	2	0.64 (1.4)	3.1 (2.8)	-	-	-
7	RX1-RX3	Orifice	3	0.11 (0.25)	0.34 (0.75)	-	-	-
8	MV1-MV4	Valves, Manual	4	0.11 (0.25)	0.45 (1.0)	-	-	-
9		Enclosure, Heater Relay	1	2.3 (5.0)	2.3 (5.0)	-	-	8
10		Frame, Plumbing, Wiring	-	2.7 (6.0)	2.7 (6.0)	-	-	-
					53.4 (117.5)	75	38	212

(a) Heater power required for steady-state operation
(b) Steady-state operation; max. power for both motors is 21.6 W
(c) Includes 91 W generated heat

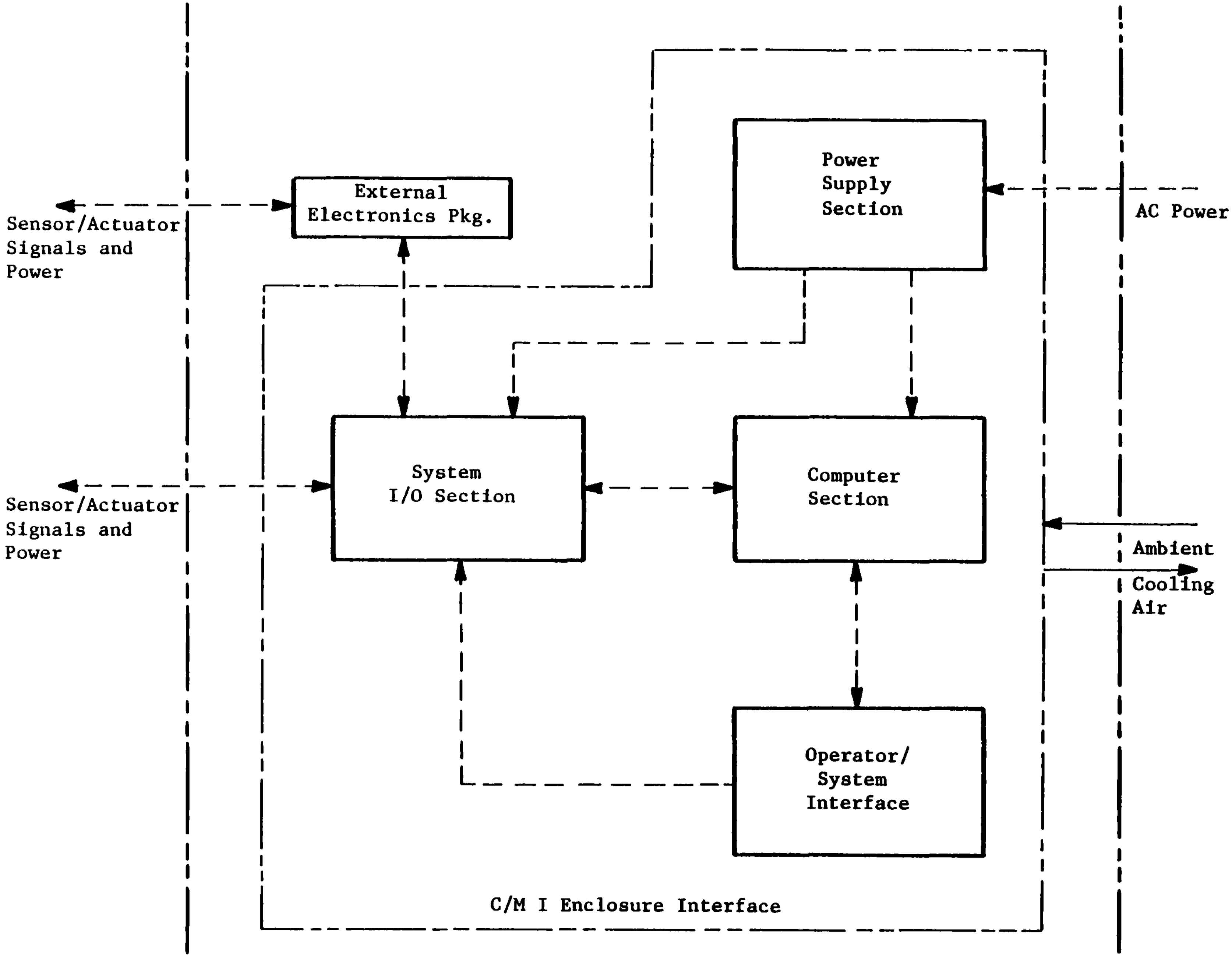


FIGURE 25 NSS C/M I HARDWARE FUNCTIONAL BLOCK DIAGRAM (LEVEL I)

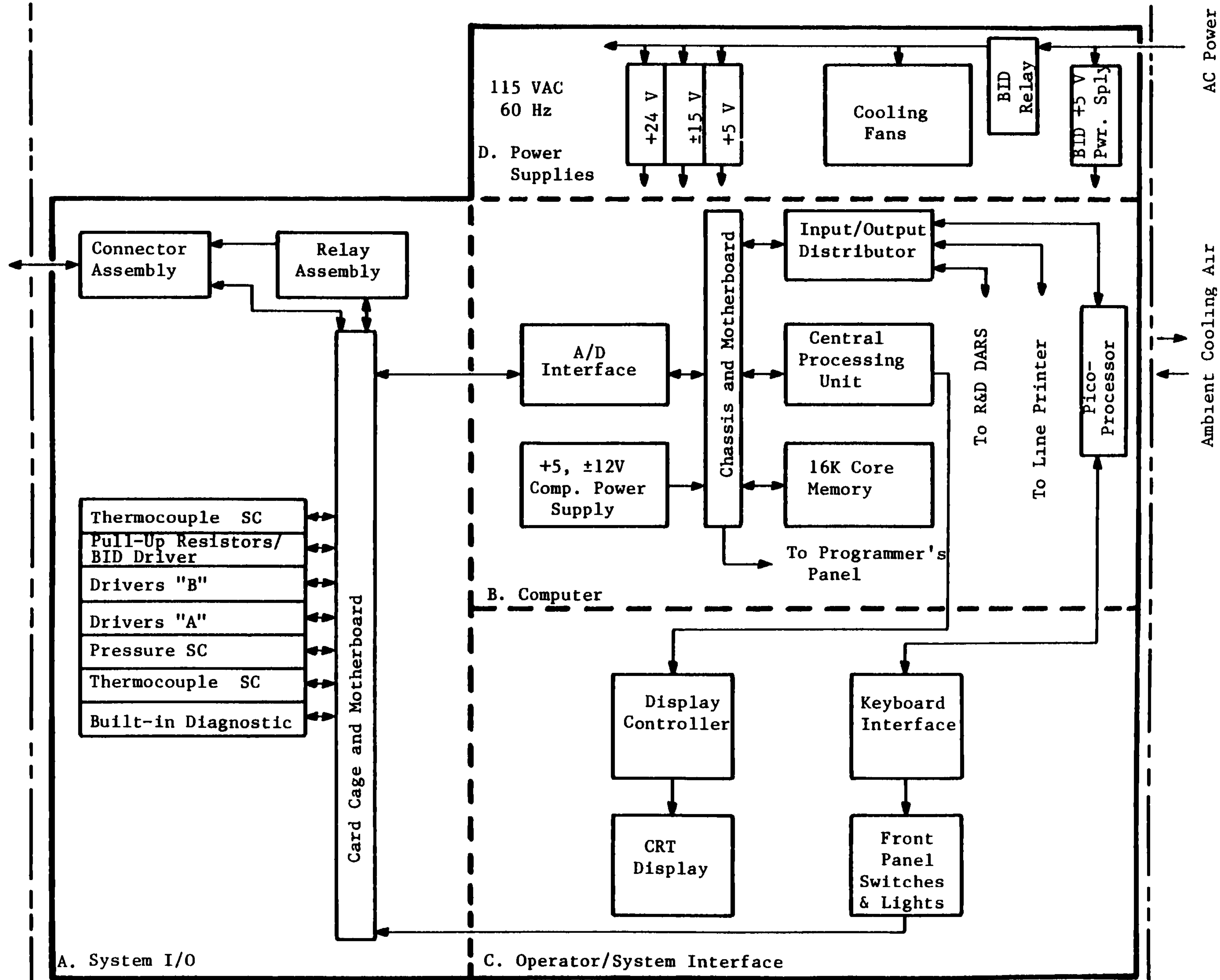


FIGURE 26 NSS C/M I HARDWARE FUNCTIONAL BLOCK DIAGRAM (LEVEL II)

a. System I/O. This section consists of a connector assembly, a relay assembly, a card cage and the motherboard and a series of spaces containing electronic circuit cards such as signal conditioners and actuator drivers. Shown are the seven signal conditioning cards required.

b. Computer. The computer section consists of a computer chassis and motherboard which houses the Central Processing Unit (CPU), 16 K core memory, I/O distributor, analog/digital (A/D) interface and +5, ±12 V computer power supplies. An intelligent cable called "pico-processor" is also functionally a part of this section although physically packaged separately. The picoprocessor is used to interface the computer with the operator/system interface keyboard and lights. The I/O distributor also has provisions to interface with the R&D Data Acquisition and Retrieval Systems (DARS) and the line printer. The motherboard has provision for interfacing with a programmer's panel for maintenance purposes.

c. Operator/System Interface. The operator/system interface consists of four subassemblies. The display controller interfaces with the CPU and the cathode ray tube (CRT) display unit. The keyboard interface controls the signals between the computer (picoprocessor and I/O distributor) and the front panel switches and lights. Some of the front panel switches are wired to the card cage and the motherboard of the system I/O section for manual overrides.

d. Power Supply. The power supply section converts the external AC power into DC power at the various voltage levels required by the C/M I subassemblies and components. These DC voltage levels are +5 V, ±12 V, ±15 V and +24 V. A separate +5 V power supply operates the Built-in Diagnostic (BID) circuit. The BID checks operation of the computer assembly and, in the event of a failure, can power down the entire C/M I through its own relay.

   The AC power source is 115 V at 60 Hz. This AC power is also available to the internal subassemblies and components. Cooling fans are included in this section to maintain the C/M I within allowable temperature ranges.

e. Enclosure. The enclosure is a standard bench style instrument cabinet with panels and/or doors easily removeable from the sides, front, back and top.

Hardware Description

Table 16 shows the design characteristics of a Model 170 A hardware. The hardware excluding interface cabling, is contained in a 53.3 x 53.3 x 71.3 cm (21 x 21 x 28.6 in) enclosure. The weight is 95 kg (208 lb), power input 610 W and power consumption 447 W. The numbers of I/O channels, manual overrides and operating modes are dependent on the system application, too. Those required for the NSS are given in Table 16. The following are the maximum available:

TABLE 16 NSS CONTROL/MONITOR INSTRUMENTATION DESIGN CHARACTERISTICS

Dimensions (D x W x H), cm (in)	53.3 x 53.3 x 71.3 (21 x 21 x 28.6)
Weight, kg (lb)	94.7 (208)
Power Input, W	610
Power Consumption, W	447
Line Voltage, V	115
Line Frequency, Hz	60
Input Sensor Signal Range, VDC	0 to 5
Output Actuator Signal Range, VDC	0 to 5
Processor	
Type of Computer	CAI LSI-2/20 Minicomputer
Word Size, Bits	16
Memory Size, K Words of Core	16
Memory Speed, ns	1,200
Instruction Cycle Time, ns	150
I/O Transfer Rate, Megawords/s	1.67
Other Important Features	• Real Time Clock • Direct Memory Access • Hardware Multiply/Divide • Stack Processing • Automatic and Blocked I/O • Power Fail Restart
Input/Output	
Number of Analog Inputs	11
Number of Analog Outputs	0
Number of Digital Inputs	8
Number of Digital Outputs	14
Front Panel	
Command Inputs	Pushbutton Switches
Message Display	Color-Coded Indicators and CRT Display
Display CRT Capacity, Characters	1,920 (80 x 24)
Number of Manual Overrides	
Actuator	12
Auto Protection	8
Operating Modes	
Number of Operating Modes	4
Number of Allowable Mode Transitions	9

a. Analog Inputs - 64
b. Analog Outputs - 4
c. Digital Inputs - 64
d. Digital Outputs - 32
e. Manual Overrides - 24
f. Operating Modes - 4
g. Allowable Mode Transitions - 13
h. Auxiliary Controls (e.g., Vent Select) - 2

Figure 27 shows the Series 100 C/M I hardware package and Figure 28 shows the design of the Operator/System interface panel for the NSS. The recessed portion of the interface panel for the Model 170A is shown in Figure 29. A detailed description of the front panel is given in Appendix 2.

Table 17 gives a summary of the weight, volume and power of the Model 170A C/M I.

Software Description

Figure 30 shows a simplified Series 100 C/M I software block diagram for the NSS. The software consists of the following major elements:

a. Power-Failure Control (PFC)
b. Real-Time Executive (RTE)
c. Operator/System Interface Command Handler
d. Operating Mode Control
e. Mode Transition Control
f. Process Parameter Control
g. Fault Detection and Trend Analysis
h. Input/Output (I/O)
i. Data Acquisition and Reduction System (DARS) Handler

Power-Failure Control. The PFC resets the system conditions when the power is applied to the C/M I. When a short-term (on order of 5 s) power interruption occurs, the PFC will detect it by reading the hardware status and restore the system to the condition prior to when the power failure was detected. Upon a long-term power outage, the PFC will bring the system to its Shutdown state. This module also restarts the RTE and the I/O devices.

Real-Time Executive. The RTE is the heart and "chief executive" of the software. It is driven by the real-time clock (a hardware function) and is designed to execute different programs in a timely fashion. It allows the programs under the control of the RTE to be assigned a priority level: A or B. The RTE will execute priority A program first; then executes the programs of priority level B as time permits. Using this mechanism, the RTE can recover from a bottleneck situation.

Operator/System Interface Command Handler. The Operator/System Interface command handler services the operator/system interface to allow the operator to communicate with the system through the front panel keyboard. An operator can enter two types of commands:

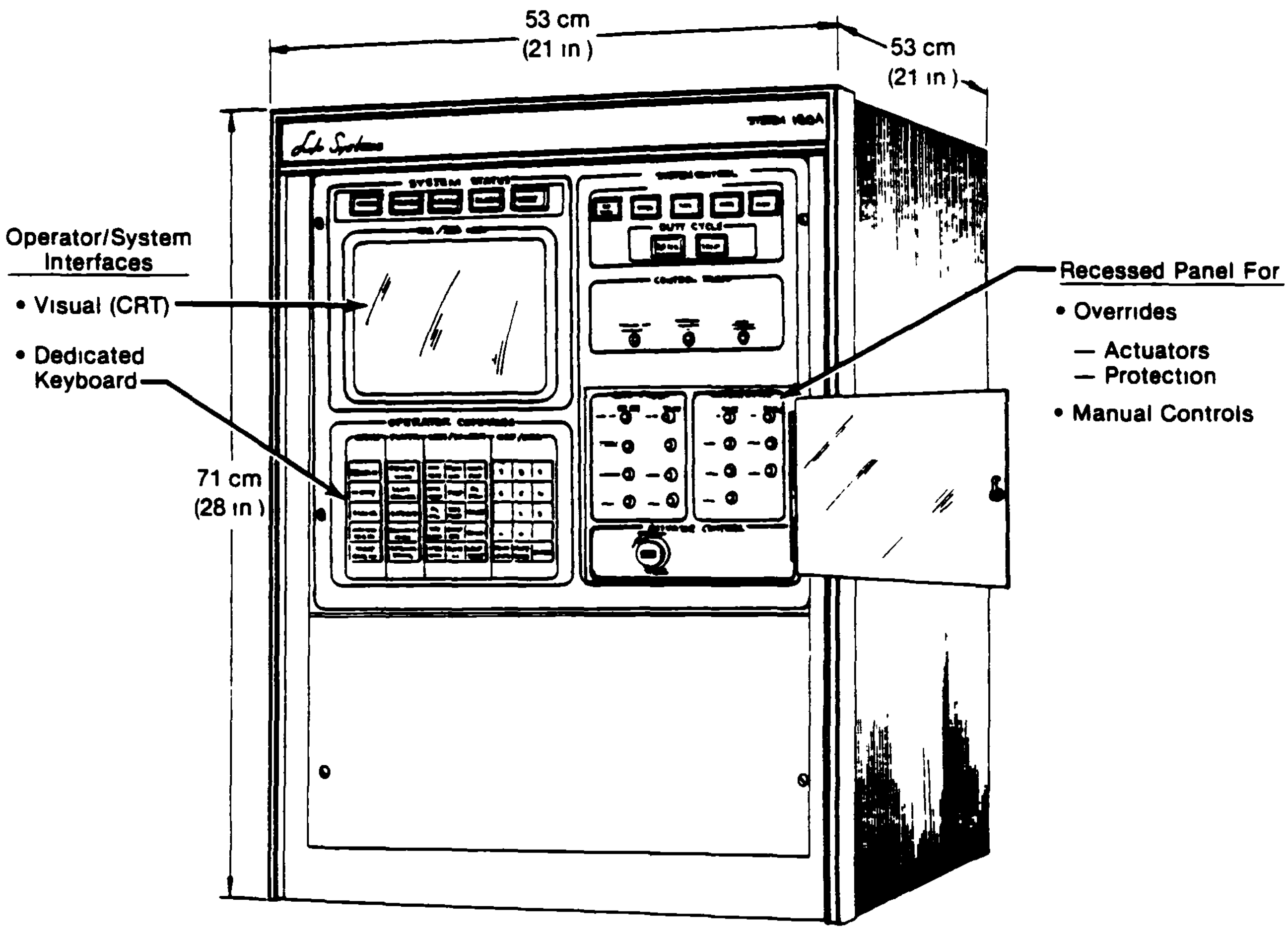


FIGURE 27 C/M I PACKAGE

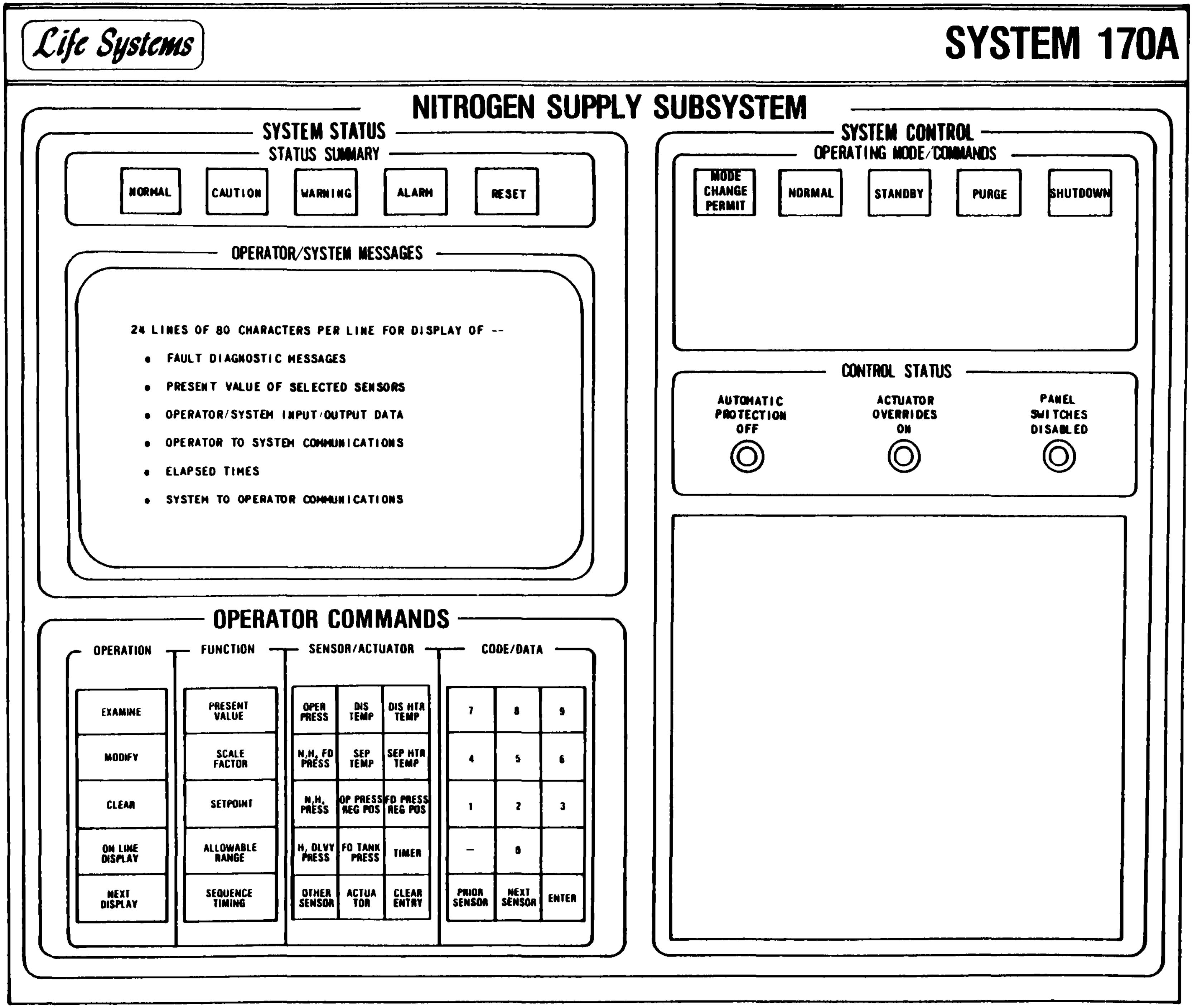


FIGURE 28 NSS C/M I OPERATOR/SYSTEM INTERFACE PANEL

Life Systems, Inc.

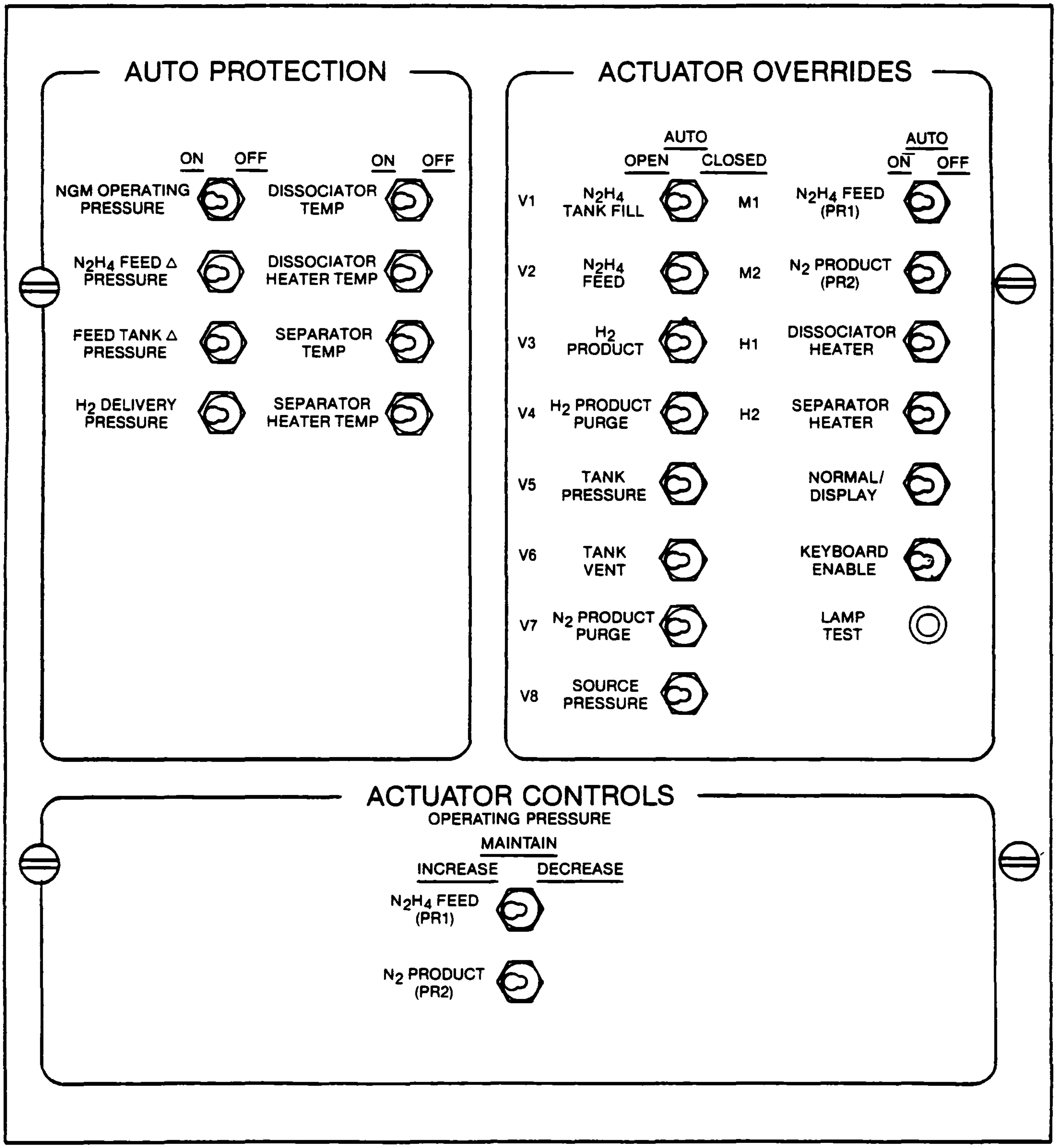


FIGURE 29 NSS C/M I OPERATOR/SYSTEM INTERFACE PANEL (RECESSED PORTION)

TABLE 17 CONTROL/MONITOR INSTRUMENTATION DESIGN COMPONENT SIZE, WEIGHT AND POWER CONSUMPTION SUMMARY

Component	H x W x D, cm (in)	Volume, m^3 (ft^3)	Weight, kg (lb)	AC Power,[a] W	DC Power, W
Instrument Enclosure	72.6 x 53.3 x 53.3 (28.6 x 21.0 x 21.0)	0.21 (7.30)	22.7 (50)	--	--
LSI-2/20 Computer and Accessories	22.1 x 25.4 x 49.8 (8.7 x 10.0 x 19.6)	0.028 (0.99)	9.1 (20)	148	--
CRT Display	17.8 x 22.9 x 25.4 (7.0 x 9.0 x 10.0)	0.01 (0.36)	13.6 (30)	36	--
Keyboard Interface	16.5 x 22.9 x 5.1 (6.5 x 9.0 x 2.0)	0.02 (0.07)	4.1 (9)	15	--
Front Panel Switches, 46	2.0 x 3.0 x 3.3 (0.8 x 1.2 x 1.3)	0.001 (0.04)	2.3 (5)	1	--
Front Panel Lamps	--	-- --	0.5 (1)	15	--
Intelligent Cable	22.9 x 10.2 x 2.5 (9.0 x 4.0 x 1.0)	0.001 (0.02)	0.5 (1)	4	--
Recessed Override Switch Panel (with 25 Switches	19.1 x 22.9 x 10.2 (7.5 x 9.0 x 4.0)	0.004 (0.16)	2.3 (5)	1	--
Power Supplies (5 V, ±12 V, ±15 V, 24 V)	15.2 x 15.2 x 48.3 (6.0 x 6.0 x 19.0)	0.01 (0.40)	18.2 (40)	131	--
Circuit Card Cage and Signal/Power Conditioners	15.2 x 15.2 x 38.1 (6.0 x 6.0 x 15.0)	0.009 (0.31)	13.6 (30)	28	--

continued-

Table 17 - continued

Component	H x W x D, cm (in)	Volume, m^3 (ft^3)	Weight, kg (lb)	AC Power, W	DC Power, W
Relay Assembly and Time Delay Relays	19.1 x 29.2 x 7.6 (7.5 x 11.5 x 3.0)	0.004 (0.15)	1.4 (3)	8	--
Connectors and Cables	---	-- --	4.6 (10)	--	--
Fans, Total 3	12.7 x 12.7 x 5.1 (5.0 x 5.0 x 2.0) ea.	-- --	1.8 (4)	60	--
Total	72.6 x 53.3 x 53.3 (28.6 x 21.0 x 21.0) (Envelope)	0.21 (7.30) (Envelope)	94.7 (208)	447	0

(a) 115 V and 60 Hz, Single Phase.

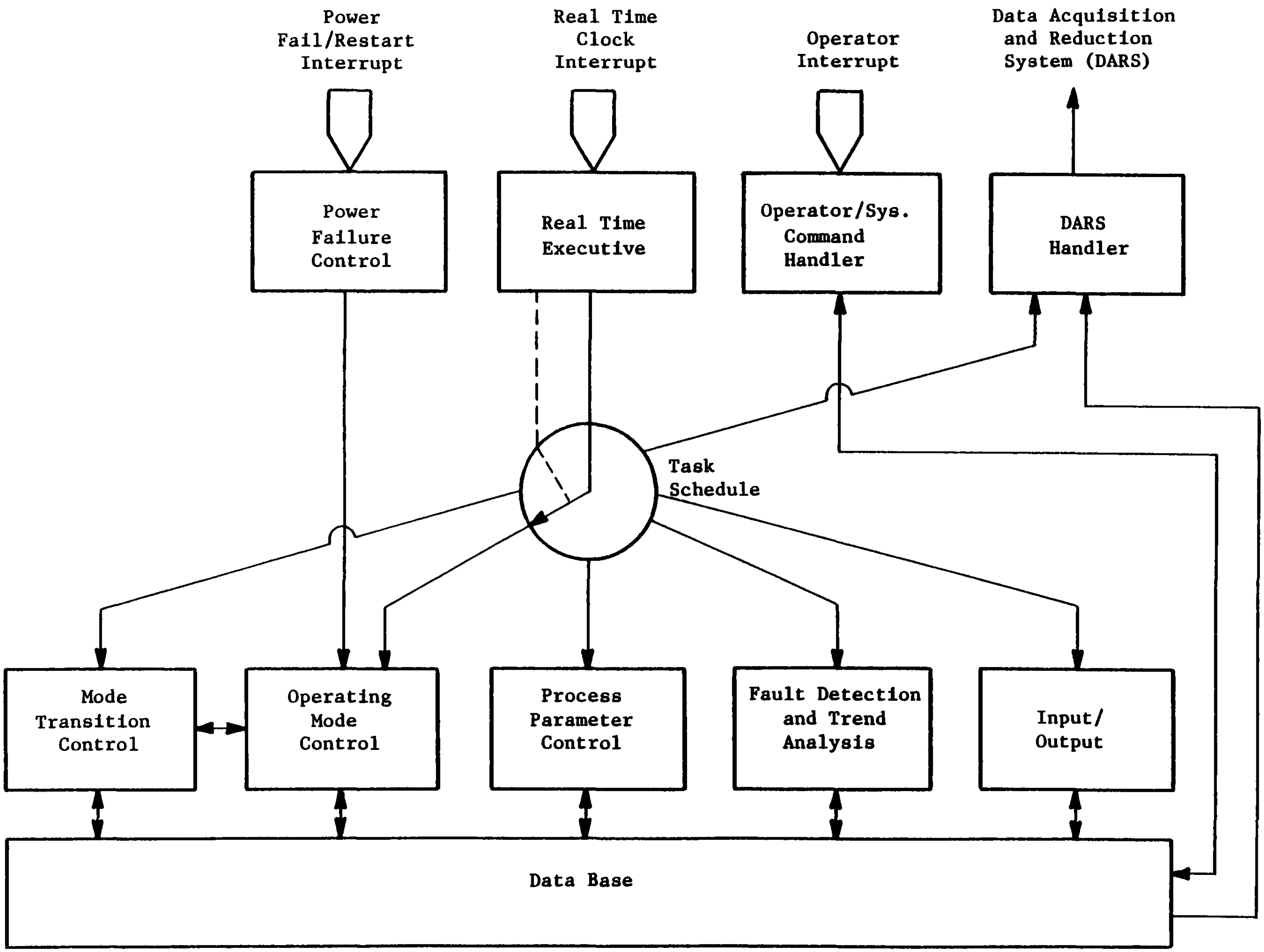


FIGURE 30 NSS SOFTWARE BLOCK DIAGRAM

1. The system command for operating mode change or auxiliary controls such as vent selections.

2. The operator commands for process parameter examination, display and setpoint modifications.

The validity of both types of command is checked automatically as the commands are entered.

For system commands, the pushbutton indicator will be lit and a proper command flag will be set when the command is accepted. The operating mode control module will then implement the requested actions. For operator commands entered through the keyboard switches, the validity of the command is checked after the termination key ENTER is pressed, and the operator command will be echoed on the CRT. The system messages will then appear on the CRT for interchange of information depending on the type of operator commands. If a mistake is detected, an error message will be displayed and the command will be rejected.

Operating Mode Control. Operating mode control is designed to resolve all the mode change requests in this system. Whenever the power is first applied to the C/M I, the computer will go through the startup procedure as programmed in the power-failure control module (PWRUP) such that the C/M I is in Shutdown operating mode when completed. Any mode change request, either manually generated or system generated, will be checked by the operating mode control module. The operating mode control module (OPCON) produces a control word called System Action Word (SYSACT). This control word activates or de-activates all the software modules in this system.

The OPCON is the master controller for the operating modes and mode transitions. It performs the following functions:

1. To reset actuators when the system is in the shutdown mode.
2. To initialize mode transition and acknowledge the completion.
3. To monitor operating modes and provide housekeeping functions.
4. To update the elapsed timers.
5. To service status lamps changes.
6. To service Shutdown request generated by the fault detection module (FTDT).
7. To set or reset RTE modules enable bit.
8. To enable/disable sensor fault detection functions.
9. To implement the auxiliary controls such.

In applications where the system can generate mode change requests automatically based on certain conditions of the system, OPCON will check the conditions for valid requests and resolve the conflicts with the manual request.

Mode Transition Control. Mode transition control modules provide the necessary transition sequences from one operating mode to another. The transition sequences are implemented using macros. A macro is a user-defined statement, according to which the assembler can generate a user-defined group of instructions or calling sequences. There are 17 macros used in the NSS C/M I software for coding mode transitions. A programmer can code the transition sequences easier by letting the macros and the assembler generate the calling sequences for the subroutines. Using these macros, the transition control programs will be similar to the steps defined in Appendix 1; therefore, the programs are easier to understand and debug.

Process Parameter Control. Process parameter control and monitor routines are designed for specific applications and running under RTE to maintain the parameters within the specified ranges.

There are basically three closed loop controls for the NSS. One maintains the subsystem pressure by operating the pressure controller. The other two control the dissociator and heater temperatures. Figure 31 and 32 illustrate how the dissociator temperature control is implemented. Heater H1 is actuated until the dissociator temperature T1 reaches its desired level, typically 1000 K (1340 F). In order to protect the heater itself, an internal heater temperature sensor, T2, is monitored and the heater current is controlled on/off so that T2 does not exceed approximately 1090 K (1500 F). Otherwise, due to thermal lags in the dissociator, the heater could be damaged long before T1 reaches its desired level.

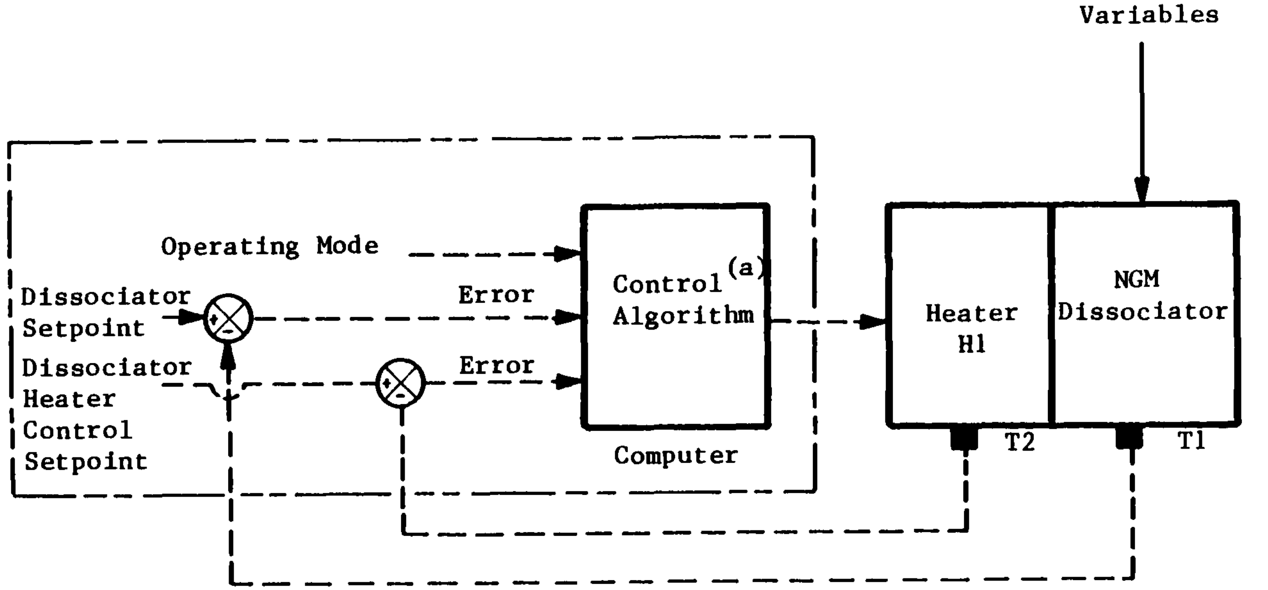
Fault Detection and Trend Analysis. The fault detection module is designed to check the parameter readings with predetermined setpoints and obtain the status of the parameters. When a parameter exceeds the alarm limits, the subsystem will be brought to Shutdown. In the 170A design, the subsystem has four-level status indicators on the front panel. They are Normal, Caution, Warning and Alarm. The fault message will be displayed on the CRT. The performance trend analysis includes the static trend analysis and the dynamic trend analysis. The static trend analysis compares the parameter readings with setpoints indicating Caution, Warning and Alarm thresholds. The dynamic trend analysis module calculates the rate of change of a (e.g., P1) parameter and predicts a fault condition based on the rate of change when and only when the parameter is outside the normal range.

Input/Output. The I/O modules are under RTE control in C/M I 170A. The input routine reads all data from the analog to digital converter channels and puts them into the input buffer. The output routine transfers all the data in the output buffer to the output channels of the Analog/Digital (A/D) interface. Each analog input has a 12-bit resolution and occupies one word in the buffer.

Each analog output has an 8-bit resolution and occupies a byte. The digital input and digital output are grouped into 16-bit words.

Data Acquisition and Reduction System Handler. The DARS Handler consists of two parts: one designed to transmit sensor data to an external DARS for storage and the other designed to print a hard copy of the CRT messages on an external line printer.

The DARS transmitter is an RTE-driven program which is executed at a predetermined interval. The C/M I does not check to see if the data has been received by the DARS.



(a) Direct Digital feedback control; active in Normal and Standby Modes only.

FIGURE 31 NSS DISSOCIATOR TEMPERATURE CONTROL BLOCK DIAGRAM

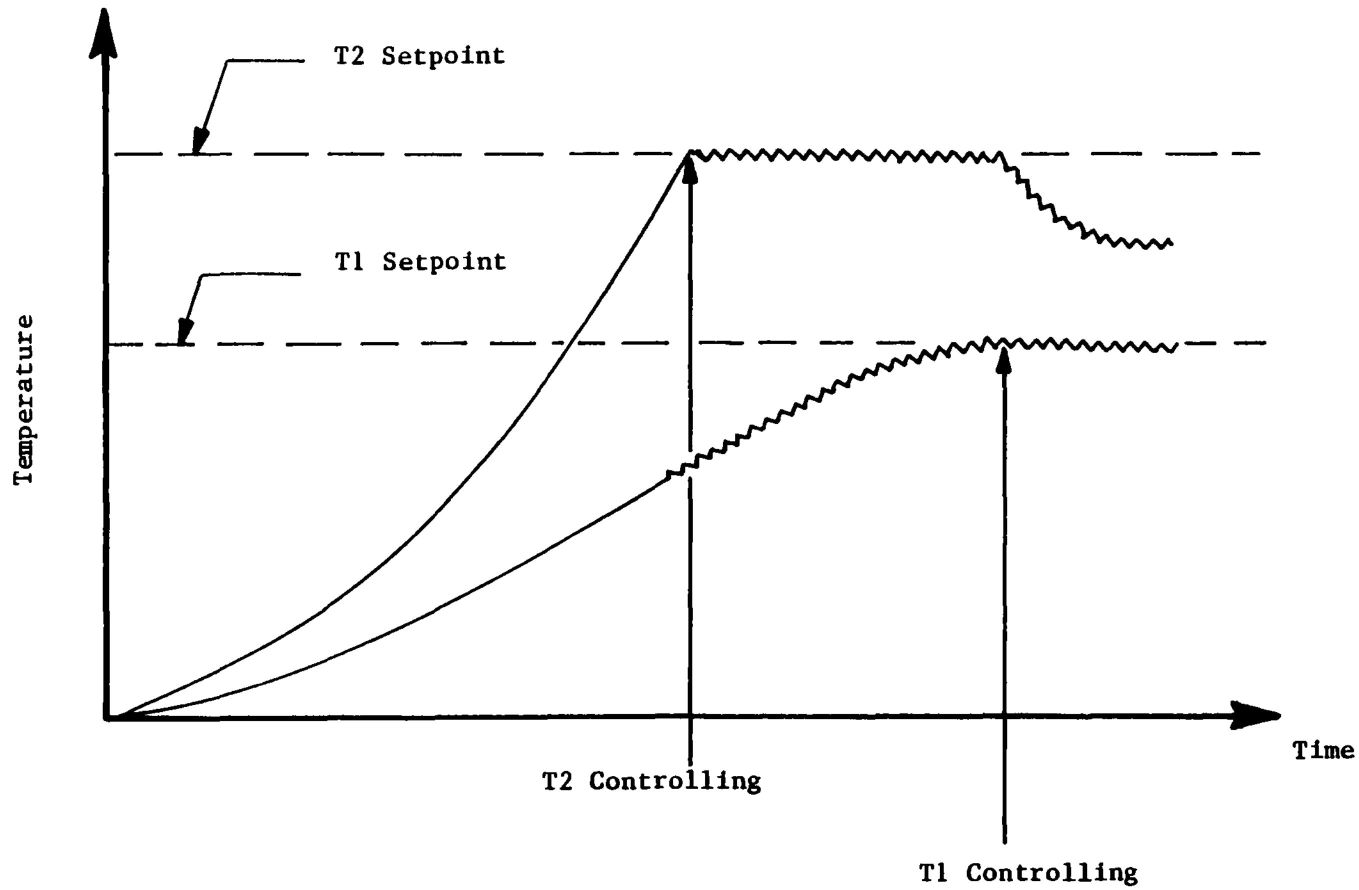


FIGURE 32 NCS DISSOCIATOR TEMPERATURE CONTROL CONCEPT

The line printer/hard copy program is interrupt-driven. It is designed to respond to an operator's request and outputs the CRT messages to the printer.

Software Organization

Table 18 lists all of the software programs of the Model 170A. Each program consists of a set of assembly language code which when linked together forms the entire software package. The programs are categorized according to function as indicated above. The categories as referenced in Table 18 are:

A. System Definition and Data Base
B. Front Panel Service
C. Real Time Executive, I/O and Utilities
D. Control/Monitor
E. Operating Mode Control and Transitions
F. Data Acquisition and Reduction System
G. Others

Test Support Accessories

Certain TSA are required for the preprototype NSS. These are required to: (a) simulate the spacecraft interfaces and (b) provide equipment to monitor performance during testing. Figure 33 shows the projected test setup in the laboratory including the TSA and NSS with C/M I. The fluidic interfaces are identified in Figure 34 and Table 19. The TSA identified as N_2H_4 storage and supply are those that have been constructed and utilized in the past. These have been designed and operated under safety guidelines developed for prior programs.

CONCLUSIONS

The testing conducted with the NGM to date has given the confidence that the N_2H_4-based NSS will be a success. Low amounts of H_2 (less than 0.5%) and NH_3 (less than 10 ppm) were measured in the N_2 product stream. Except for some hardware deficiencies, that will be addressed in the advanced NGM design, there are no major questions regarding the technology readiness of the NSS concept.

Nitrogen storage will be required for future manned space efforts to replace gases which leak from inhabited volumes. A N_2H_4-based NSS has been shown to be the most viable candidate for supplying the N_2. An NSS employing the inherently simple dissociation of N_2H_4 and subsequent separation of N_2 and H_2 is an exceptionally attractive subsystem. The NSS design incorporates all the operational concepts projected for a flight unit. The design of a preprototype NSS completes the next step in developing prototype/flight hardware.

RECOMMENDATIONS

Based on the program results, the following recommendations are made:

TABLE 18 NSS C/M I SOFTWARE PROGRAM INDEX

Mnemonic	Category	Description
AEB	E	Normal to Standby to Shutdown
ALRMOV	D	Alarm Shutdown Override
AMPLIT	B	Analog Sensor Amplitude Limiting
AUDIO	C	Audio Signal Driver
AVGAIN	C	Analog Sensor Data Averaging
BASEPG	A	Base Page Pointers and Data
BC	E	Shutdown to Purge
BEA	E	Shutdown to Standby to Normal
BINDEC	C	Binary to Decimal ASCII Code Conversion
BLINK	B	Turn Warning Light On and Off
BUFFER	A	System Tables and Buffers
BUILDS	G	Table Builder
CB	E	Purge to Shutdown
CCOM	G	Computer Communication Driver
CDHNLR	B	Front Panel Command/Data Handler
C4HTFS	D	Control 4, Hydrazine Tank Fill Sequence
C2NDT	D	Control 2, NGM Dissociator Temperature
C1NOP	D	Control 1, NGM Operating Pressure
C3NST	D	Control 3, NGM Separator Temperature
CMIDBG	G	On-line Debug Conversion
CONST	C	Constants for Timers
CONVRT	C	Input Data Conversion
DAS24	F	Data Acquisition Handler
DBG20B	G	Off-line Debug Program
DISPLY	B	Display the Contents of an ASCII Buffer
DSCNTL	B	Display Control
EKOSNX	B	Echo Input and Syntax Check
ELSTMR	B	Elapsed Timer List
EQUDEF	A	System Definition and Mnemonics
ERCODE	D	Coded Error Messages
ERRCOD	C	Component Error Request
ERRTXT	C	Text Error Message Request
ERTEXT	D	Text Error Messages
EXAMIN	B	Examine & On-line Operation of Operator Command
FDMSG	D	Fault Message Handler
FPDSPK	B	Front Panel Display Package
FPRQST	B	Front Panel Request Service
FPTEST	G	Front Panel Test
FTDT	D	Fault Detection
HARDCP	F	Hard Copy Service
IDSRCH	B	Sensor Identification Code Search
INPUT	C	Analog & Digital Sensor Data Inputs
LIBRY	C	Subroutine Library
LIGHT	B	Front Panel Indicator Driver
LMPTST	G	Front Panel Lamp Diagnostic
LPT	F	Line Printer Driver

continued-

Table 18 - continued

Mnemonic	Category	Description
LTDSP	C	Programmer's Panel Light Display
MACSUB	C	Macro Subroutines
MCSUB	C	Open/Close Motorized Valve
MODIFY	B	Modify Setpoints, Allowable Range or Timing
MSGBUF	B	Display Message Text
OEMSUB	B	On-line, Examine and Modify Library
ONLIN2	B	Second Page On-line Display
OPCON	E	Operating Mode Control
OPRSRV	E	Operator Command Service
OUTPUT	C	Analog & Digital Actuator Command Outputs
OVRACT	C	Actuator Override Handler
PWRUP	E	Powerup/Restart/Power Fail Handler
RQSTFP	B	Front Panel Request Service
RTE	C	Real Time Executive
SCALE	C	Analog Sensor Value Scaling
SDCODE	D	Decode the Sensor Code into ASCII Characters
SDP	C	Self Diagnostics, BID
SNRDEF	A	Sensor Definition Cards
SNRTYP	D	Sensor Type Decoder
SPCRFP	B	Setpoint Cross-reference Lookup for Front Panel
SPFIND	D	Determine an Analog Sensor Setpoint Status
SYSKEY	B	System Control Operation
TCWUL	D	Temperature Control with Upper Limit
TMRUPD	B	Timer Counter Update
VERIFY	B	Passwork Verification
VLSTP	D	Valve - Stop Simulator

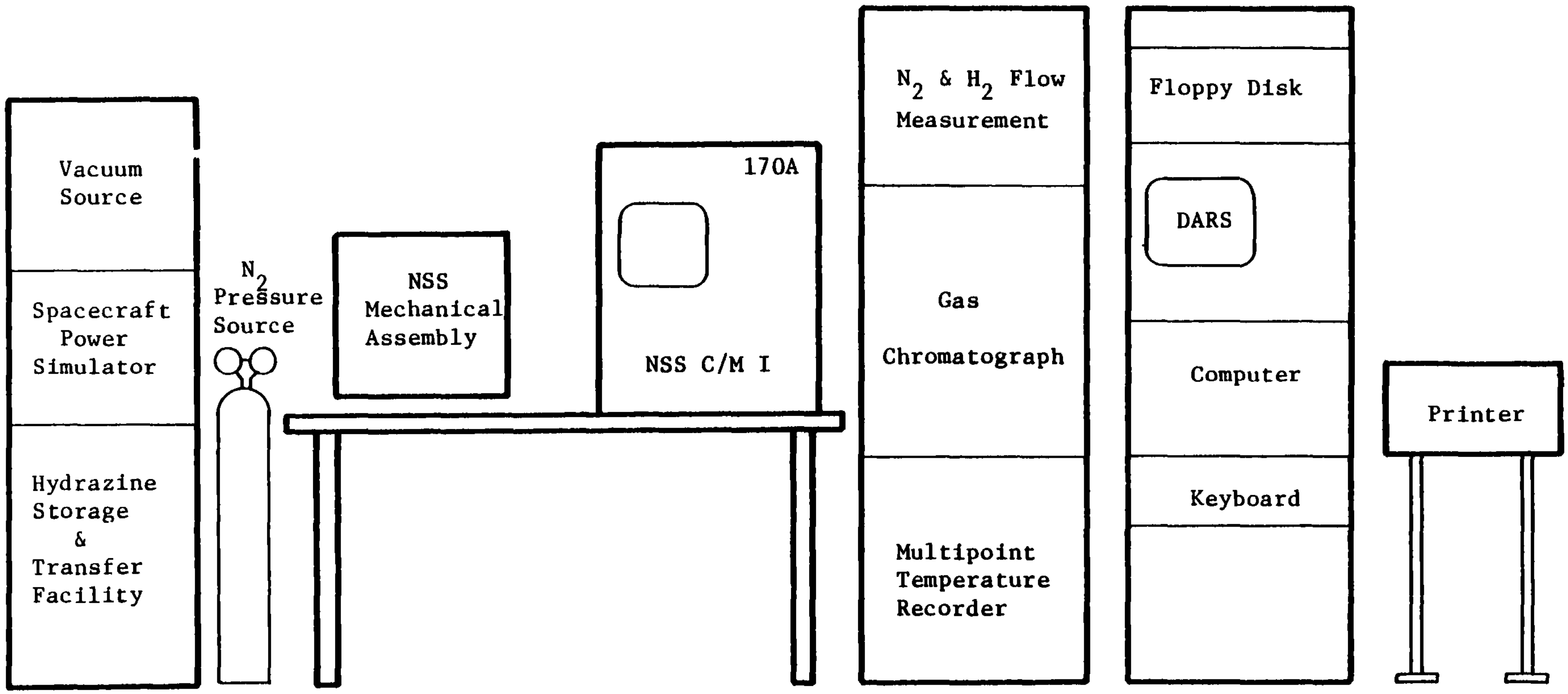


FIGURE 33 NSS AND TSA PACKAGING

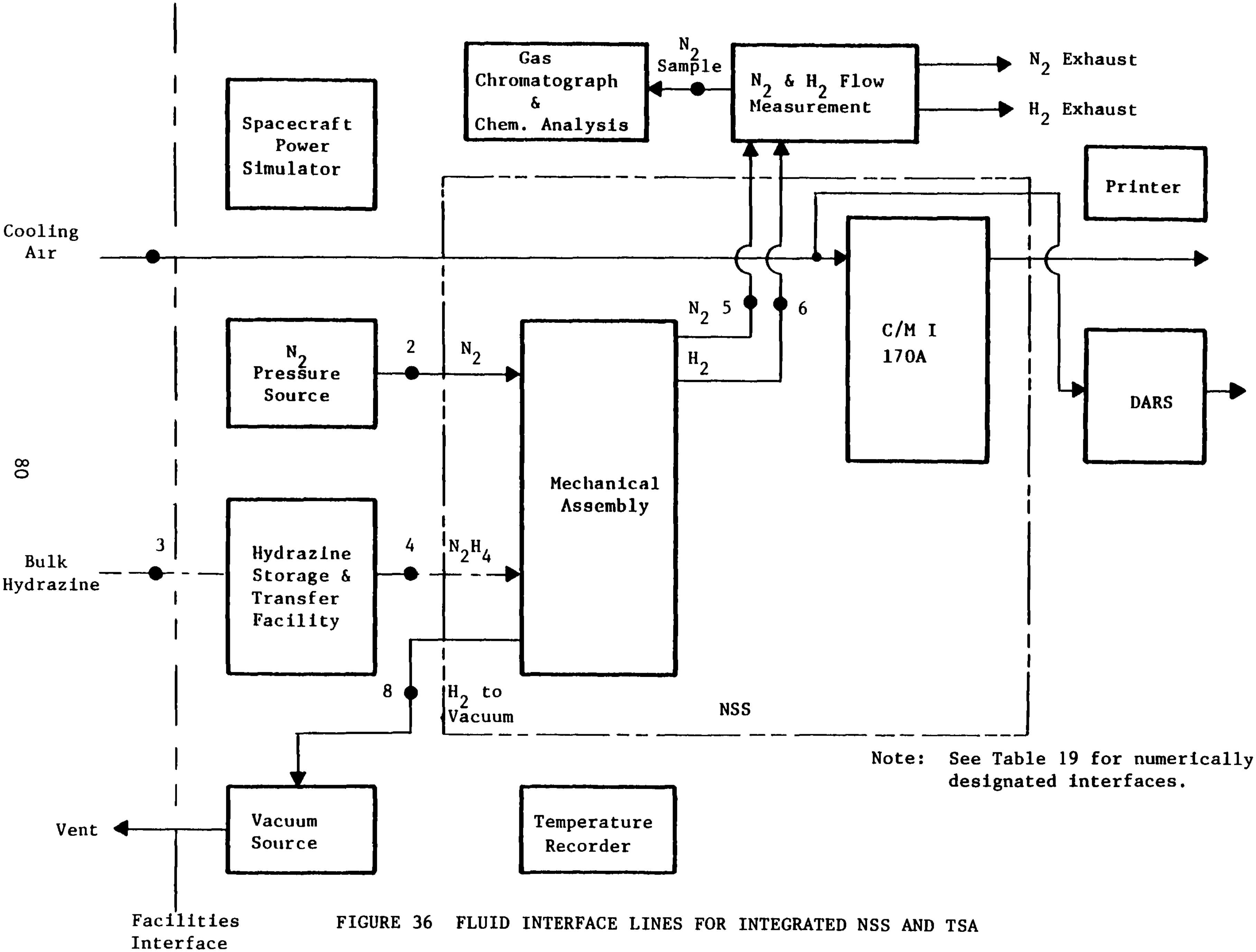


FIGURE 36 FLUID INTERFACE LINES FOR INTEGRATED NSS AND TSA

TABLE 19 TSA INTERFACE SPECIFICATIONS

Line Number[a]	Type/Characteristic	Value
Fluid		
1	Cooling Air	
	Source	Ambient
	Temperature, K (F)	293 to 295 (68 to 72)
	Volume Flow Rate, m^3/min (ft^3/min)	28 to 56 (100 to 200)
2	Purge/Pressurization N_2	
	Source	Bottle
	Pressure, kPa (psia)	2,170 (315)
	Rate, kg/d (lb/d)	Purge/Pressurization only
3	Hydrazine to NSS	
	Pressure, kPa (psia)	138 (20)
	Temperature, K (F)	293 to 295 (68 to 72)
	Usage Rate, kg/d (lb/d)	5.0 (11.0)
	Volume Flow Rate (to NSS), cm^3/min	17
	Time to Fill, min	5
	Fill Frequency, d	1
5	Product N_2	
	Pressure, kPa (psia)	103 (15)
	Temperature, K (F)	294 to 300 (70 to 80)
	Flow Rate, kg/d (lb/d)	4.4 (9.6)
	Volume Flow Rate, dm^3/min (ft^3/min)	2.6 (0.092)
6	Product H_2	
	Pressure, kPa (psia)	103 (15)
	Temperature, K (F)	294 to 300 (70 to 80)
	Flow Rate, kg/d (lb/d)	0.56 (1.24)
	Volume Flow Rate, dm^3/min (ft^3/min)	4.7 (0.164)
7	N_2 Sample to GC	
	Pressure, kPa (psia)	101 (14.7)
	Volume Flow Rate, cm^3/min	20
	Duration of Sample, min	10
	Frequency of Sampling, d	1
8	H_2 to Vacuum Vent	
	Pressure, Pa (mm Hg)	0 to 1,330 (0 to 10)
	Flow Rate, kg/d (lb/d)	0.064 (0.14)
	Volume Flow Rate, dm^3/min (ft^3/min)	0.52 (0.018)

(a) See block diagram shown in Figure 34.

1. Proceed with the fabrication of a preprototype NSS capable of a nominal 14.4 kg/d (9.6 lb/d) N_2 generation rate. The NSS will consist of a mechanical assembly with an advanced NGM and a Model 170A C/M I.

2. Test the fabricated NSS to obtain confidence in its operation. Both performance and endurance testing (60 to 90 days) is required. Such a test program will provide system planners and designers, along with the developers, with details on operational characteristics and confidence of subsystem readiness.

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APPENDIX 1

NSS MODE TRANSITION SEQUENCES

Step	A. Shutdown to Standby (B to E) Standby to Normal (E to A) Shutdown to Normal (B to A)
1	Inhibit all fault detection monitoring
2	Switch to Standby setpoint table
3	Enable fault detection of high P1, T1, T2, T3, T4, and high and low P2, P3, P4
4	If transition is Standby to Normal go to Step 18
5	Open V8 and V7 (to purge), wait 0.3 s and verify
6	Enable NGM Dissociator Temperature Control (Control 2) and NGM Separator Temperature Control (Control 3)
7	Wait 2.0 min. Enable Control 1 (B to E transition)
8	Check P1 every 1.0 s for 10 min. If P1 is greater than 0 psig proceed to next step. If after 10 min P1 $\leq$50 psig, display warning message, "P1 less than 50 psig" proceed to next step
9	Close V7 wait 0.3 s and verify
10	Check T1 and T3 every 1 s for 90 min, if T1 is greater than 1350 F and T3 is greater than 700 F proceed to next step. If after 90 min, conditions not met display alarm message, "T1 less than 1350 F, or T3 less than 700 F" and begin A to B transition
11	If P1 is greater than 250 psig proceed to step 12, if not open V7, wait 0.3 s and verify
12	Check P1 every 1.0 s for 1.0 min, if P1 is greater than 250 psig proceed to next step. If after wait, display alarm message "P1 less than 250 psig" and begin A to B transition shutdown
13	Close V7 wait 0.3 s and verify
14	Open V5, wait 0.3 s and verify
15	Wait 1.0 min
16	Close V8 wait 0.3 s and verify

continued-

Appendix 1 - continued

Step	Shutdown to Standby (B to E) Standby to Normal (E to A) Shutdown to Normal (B to A)
17	If transition is Shutdown to Standby (B to E) enable all fault detection, enable Standby mode. Switch Control 1 to E mode
18	Inhibit fault detection low P4
19	Open V8 wait 0.3 s and verify
20	Switch to Normal Setpoint Table. Switch Control 1 to E to A transition
21	Open V2 wait 0.3 s and verify
22	Wait 10.0 s
23	Close V4 wait 0.3 s and verify
24	Enable all fault detection. Disable P4
25	Check P4 every 1.0 s, for 10.0 min, if greater than 15 psia proceed to next step. If after wait display alarm message, "P4 less than 15 psia" and begin A to B transition
26	Open V3, wait 0.3 s and verify
27	Enable N_2H_4 Tank (WT1) fill control (Control 4)
28	Enable fault detection of P4, enable Normal mode (Stop). Switch Control 1 to A mode

continued-

Appendix 1 - continued

Step	B. Normal to Standby (A to E) Normal to Shutdown (A to B) Standby to Shutdown (E to B)
1	If transition is Standby to Shutdown proceed to Step 12
2	If N_2H_4 Tank (WT1) fill Sequence Control (Control 4) is running, wait until completed
3	Disable N_2H_4 Tank (WT1) fill Sequence Control (Control 4)
4	Close V2 and V8 wait 0.3 s and verify. Switch Control 1 to A to E transition
5	Inhibit high P4 fault detection
6	Switch to Standby setpoint table
7	Close V3 wait 0.3 s and verify
8	Open V4 wait 0.3 s and verify
9	Wait 30.0 s
10	Enable all fault detection
11	If transition is Normal to Standby enable Standby Mode (Stop)
12	Disable NGM Dissociator Temperature Control (Control 2) and NGM Separator Temperature Control (Control 3)
13	Inhibit all fault detection monitoring
14	Enable fault detection of high P1, T1, T2, T3, T4 and high and low P2, P3, P4. Switch Control 1 to E to B transition
15	Open V6 wait 0.3 s and verify
16	Check T1 and T3 every 1.0 s for 90 min; if both are less than 145 F proceed to next step, if not display warning, message "T1 greater than 145 F or T3 greater than 145 F and proceed to next step
17	Open V7 wait 0.3 s and verify
18	Wait 2.0 min
19	Close V7, V5 and V6, wait 0.3 s and verify

continued-

Appendix 1 - continued

Step	B. Normal to Standby (A to E) Normal to Shutdown (A to B) Standby to Shutdown (E to B)
20	Switch to Shutdown setpoint table
21	Enable all fault detection
22	Enable Shutdown mode (Stop). Switch Control 1 to mode B

Step	C. Shutdown to Purge (B to C)
	(Switch Control 1 to B to C transition)
1	Enable all fault detection monitoring
2	Switch to Purge setpoint table
3	Open V7 wait 0.3 s and verify
4	Enable Purge mode (Stop). Switch Control 1 to mode C

Step	D. Purge to Shutdown (C to B)
	(Switch Control 1 to C to B transition)
1	Enable all fault detection monitoring
2	Close V7 wait 0.3 s and verify
3	Wait 10 s
4	Switch to Shutdown setpoint table. Enable Shutdown mode (Stop). Switch Control 1 to Mode B

APPENDIX 2

NSS C/M I (MODEL 170A) FRONT PANEL DESCRIPTION

Nomenclature	Description/Function
A. SUBSYSTEM CONTROL	
Operating Mode/Commands	Pushbutton switches for mode transition requests. Light displays indicate present mode (in green) or transition in process (in amber).
• MODE CHANGE PERMIT	This key must be held down simultaneously with any one of the OPERATING MODE keys to allow an OPERATING MODE REQUEST.
• NORMAL	Requests the subsystem to make a transition to the NORMAL operating mode from present operating mode when pressed with MODE CHANGE PERMIT.
• STANDBY	Requests the Subsystem to make a transition to the STANDBY operating mode from present operating mode when pressed with MODE CHANGE PERMIT.
• PURGE	Requests the Subsystem to make a transition to the PURGE operating mode from present operating mode when pressed with MODE CHANGE PERMIT.
• SHUTDOWN	Requests the Subsystem to make a transition to the SHUTDOWN operating mode from present operating mode when pressed with MODE CHANGE PERMIT.
Control Status	
• AUTOMATIC PROTECTION OFF	Indicator will be illuminated if any auto protection switch on the recessed panel is at the OFF position.
• ACTUATOR OVERRIDE ON	Indicator will be illuminated if any actuator override switch on the recessed panel is not at the AUTO position.

continued-

Appendix 2 - continued

Nomenclature	Description/Function
• PANEL SWITCHES DISABLED	Indicator will be illuminated if the front panel keyboard control switch is set to DISABLE. All front panel switches are disabled.
Auto Protection	Selected sensors can be removed from automatic shutdown protection by setting these switches on the recessed manual override panel to the OFF position.
• NGM OPERATING PRESSURE	Switch which turns on and off the shutdown protection for NGM operating pressure P1 high/low pressure alarm.
• N_2H_4 FEED Δ PRESSURE	Switch which turns on and off the shutdown protection for N_2H_4 Feed Δ pressure P2 high/low pressure alarm.
• FEED TANK Δ PRESSURE	Switch which turns on and off the shutdown protection for Feed tank Δ pressure P3 high/low pressure alarm.
• H_2 DELIVERY PRESSURE	Switch which turns on and off the shutdown protection for H_2 delivery pressure P4 high/low pressure alarm.
• DISSOCIATOR TEMP	Switch which turns on and off the shutdown protection for dissociator temperature T1 alarm.
• DISSOCIATOR HEATER TEMP	Switch which turns on and off the shutdown protection for dissociator heater temperature T2 alarm.
• SEPARATOR TEMP	Switch which turns on and off the shutdown protection for separator temperature T3 alarm.
• SEPARATOR HEATER TEMP	Switch which turns on and off the shutdown protection for separator heater temperature T4 alarm.
Actuator Overrides	Switches for manual override of actuators.
• V1 N_2H_4 TANK FILL	Switch for N_2H_4 supply Valve V1.
• V2 N_2H_4 FEED	Switch for N_2H_4 feed Valve V2.

continued-

Appendix 2 - continued

Nomenclature	Description/Function
• V3 H_2 PRODUCT	Switch for H_2 product Valve V3.
• V4 H_2 PRODUCT PURGE	Switch for H_2 product purge Valve V4
• V5 TANK PRESSURE	Switch for N_2H_4 Supply tank pressure Valve V5
• V6 TANK VENT	Switch for N_2H_4 Supply tank vent Valve V6
• V7 N_2 PRODUCT PURGE	Switch for N_2 product purge Valve V7
• V8 SOURCE PRESSURE	Switch for source pressure Valve V8
• H1 DISSOCIATOR HEATER	Switch to turn on or off the Dissociator heater
• H2 SEPARATOR HEATER	Switch to turn on or off the Separator Heater
• M2 N_2H_4 FEED (PR2)	Switch to turn on or off the indicated pressure regulator override. When turned on, regulator pressure setpoint is controlled by the corresponding actuator control switch below. When turned off, the pressure regulator will maintain the pressure at the previous setpoint.
• M1 N_2 PRODUCT (PR1)	Switch to turn on or off the indicated pressure regulator override. When turned on, regulator pressure setpoint is controlled by the corresponding actuator control switch below. When turned off, the pressure regulator will maintain the pressure at the previous setpoint.
• NORMAL/DISPLAY	CRT Display format selection.
• KEYBOARD ENABLE	Enable/Disable front panel keyboard switches
• LAMP TEST	Lamp Test.
Actuator Controls	
• N_2H_4 FEED (PR2)	This spring-loaded momentary toggle switch controls the pressure regulator PR2 setpoint when the override switch above is turned on. The pressure setpoint will remain unchanged if this switch is in the center position. The setpoint will increase or decrease when the switch is held at the increase or decrease position, respectively.

continued-

Appendix 2 - continued

Nomenclature	Description/Function
• N_2 PRODUCT (PR1)	This spring-loaded momentary toggle switch controls the pressure regulator PR1 setpoint when the override switch above is turned on. The pressure setpoint will remain unchanged if this switch is in the center position. The setpoint will increase or decrease when the switch is held at the increase or decrease position, respectively.
B. SUBSYSTEM STATUS	
Status Summary	
• NORMAL	Green indicator for no faults in subsystem.
• CAUTION	Amber indicator of caution level faults.
• WARNING	Flashing red indicator of warning level faults.
• ALARM	Red indicator of alarm level faults.
• RESET	Pushbutton which stops the flashing message "SUBSYSTEM IS IN ALARM" on the cathode ray tube (CRT) and silences the audio alarm signal.
C. OPERATING COMMANDS	
Operation	Operator commands for EXAMINE, MODIFY, CLEAR, ON-LINE DISPLAY or NEXT DISPLAY Operations.
• EXAMINE	Examines the present reading, scale factor, setpoint, allowable range, sequence timing of a component or the subsystem.
• MODIFY	Modifies the scale factor, setpoint, allowable range, sequence timing of a component or the subsystem. A valid password must be entered beforehand.
• CLEAR	Clears the CRT display and the password.
• ON-LINE DISPLAY	Displays present reading of a sensor and updates it every two seconds.
• NEXT DISPLAY	Advances the information on CRT display when there are more fault messages than the display capacity.

continued-

Appendix 2 - continued

Nomenclature	Description/Function
	Operator commands for selection of data function.
• PRESENT VALUE	The present value of the requested component in engineering units.
• SCALE FACTOR	Factors used to convert binary values to engineering units.
• SETPOINT	Subsystem operational setpoints, two for control and six for monitor.
• ALLOWABLE RANGE	The limits for subsystem operation setpoints.
• SEQUENCE TIMING	The transition sequence timing constants for subsystem operation.
Sensor/Actuator	Type of sensor/actuator.
• Sensor Type Buttons	There are 11 buttons available for different types of sensors in the subsystem.
• TIMER	The software timers for the subsystem.
• OTHER SENSOR	Any sensors that are not included in the specific 11 types above.
• ACTUATOR	Status of digital/analog actuators.
• CLEAR ENTRY	Erases command/data just entered in case of typing error.
Code/Data	Data or code for the sensor/actuator selected.
• Numbers (0-9)	Part of the component code, data or password.
• MINUS (-)	Minus sign of a number of delete operation for setpoint modifications.
• PERIOD (.)	Decimal point of a number or end of operation for MODIFY.
• NEXT SENSOR	Next sensor in sequence.
• ENTER	End of command/data, also used to change input modes.
• PRIOR SENSOR	Previous sensor in sequence

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15 Supplementary Notes

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16 Abstract

The design and development of a test stand for the Nitrogen Generation Module (NGM) and a series of tests which verified its operation and performance capability are described. Over 900 hours of parametric testing were achieved. The results from this testing were then used to design an advanced NGM and a self-contained, preprototype Nitrogen Supply Subsystem. The NGM consists of three major components - nitrogen generation module, pressure controller and hydrazine storage tank - and ancillary components. The NGM is an advanced version of the module tested in this program and offers several improvements. The most important is the elimination of all sealing surfaces, achieved with a total welded or brazed construction. Additionally, performance was improved by increasing hydrogen separating capability by 20% with no increase in overall packaging size.

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