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EVALUATION OF A SPACECRAFT NITROGEN GENERATOR

SECOND ANNUAL REPORT

by

R. D. Marshall and W. J. Knebel

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January, 1977

Prepared Under Contract NAS2-8732

by

Life Systems, Inc.

Cleveland, Ohio 44122

for

AMES RESEARCH CENTER

National Aeronautics and Space Administration

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FOREWORD

The development work described herein was conducted by Life Systems, Inc. during the period February 1, 1976 to January 31, 1977. The Program Manager was Richard D. Marshall. Support was provided as follows:

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LIST OF ACRONYMS

ARS	Air Revitalization System
CRS	Carbon Dioxide Reduction Subsystem
EC/LSS	Environmental Control/Life Support System
NGM	Nitrogen Generation Module
NGS	Nitrogen Generation System
NSS	Nitrogen Supply Subsystem
TSA	Test Support Accessories

SUMMARY

A research and development program is presently being conducted at Life Systems, Inc. to develop a method of generating nitrogen for cabin leakage makeup aboard space vehicles having longer duration missions. The nitrogen generation concept is based on using liquid hydrazine as the stored form of nitrogen to reduce the higher tankage and expendables weight associated with high pressure gaseous or cryogenic liquid nitrogen storage. The hydrazine is catalytically dissociated to yield a mixture of nitrogen and hydrogen. The nitrogen/hydrogen mixture is then separated to yield the makeup nitrogen. The excess supply of hydrogen would be available for use in the reduction of metabolic carbon dioxide.

The design of a seven-stage Nitrogen Generation Module has been completed. The design successfully integrates a hydrazine catalytic dissociator, three ammonia dissociators and three palladium/silver hydrogen separators. Alternate ammonia dissociation and hydrogen separation stages are used to remove hydrogen and ammonia formed in the dissociation of hydrazine, and results in very low ammonia and hydrogen concentrations in the product nitrogen stream. The Nitrogen Generation Module has been designed to generate 3.6 kg/d (8.0 lb/day) of high-purity nitrogen containing less than or equal to 0.2% hydrogen and 50 ppm ammonia. The dissociation and separation stages are packaged as a single unit to minimize heat rejection to ambient since both operate at elevated temperatures. The single package concept allows the heat generated during the dissociation of hydrazine to reduce the heater power required to maintain the Nitrogen Generation Module at temperature.

The design of a Nitrogen Supply Subsystem as an integratable subsystem for a central spacecraft Air Revitalization System has been completed. The Nitrogen Supply Subsystem consists of the hydrazine storage and feed mechanism, the Nitrogen Generation Module, the peripheral mechanical and electrical components required to control and monitor subsystem performance, and the advanced instrumentation required for the Nitrogen Supply Subsystem to interface with other Air Revitalization System subsystems and controls. The Nitrogen Supply Subsystem has been designed to deliver nitrogen at a rate of 3.6 kg/d (8.0 lb/day) at pressures less than or equal to 1,725 kN/m^2 (250 psia). The subsystem recovers 84% of the hydrogen contained in the feed hydrazine stream and delivers 0.44 kg/d (0.96 lb/day) of hydrogen for use in the central Air Revitalization System Carbon Dioxide Reduction Subsystem.

Supporting technology activities were completed to characterize palladium/silver hydrogen separator performance and to verify the Nitrogen Generation Module staging concept of ammonia removal. The effect of nitrogen generation rate and delivery pressure on separator performance was characterized over the operating ranges of 3.2 to 9.0 kg/d (7.0 to 19.8 lb/day) and 690 to 2,070 kN/m^2 (100 to 300 psia), respectively. The data collected for the palladium/silver separator was used to develop a mathematical model to size the separation stages in the Nitrogen Generation Module.

An experiment was completed to demonstrate that low ammonia concentrations in the product nitrogen stream are possible using the staging concept. Mixtures of nitrogen, hydrogen and ammonia were fed into a temperature controlled packed bed ammonia dissociator. The experiment demonstrated that an ammonia concentration of 1.03% in the feed stream is reduced to less than 50 ppm at temperatures greater than or equal to 777K (940F). The actual inlet ammonia concentration to the final Nitrogen Generation Module ammonia dissociation stage is only 0.09%. The Nitrogen Generation Module should therefore meet design requirements.

INTRODUCTION

Future long-term manned spacecraft missions will utilize an atmosphere of nitrogen (N_2) and oxygen (O_2). Space vehicle gas leakage and cabin depressurization requirements necessitate on-board storage of the primary cabin atmospheric constituents N_2 and O_2. The N_2 component of 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 is then separated to yield the makeup N_2. The excess supply of H_2 would be available for use in the reduction of metabolic carbon dioxide (CO_2).

A research and development program has been established to evolve the capability for generating N_2 for cabin leakage makeup aboard a space vehicle of mission duration requiring regenerative methods for reprocessing the crew's metabolic products. The development program is focused on the Nitrogen Supply Subsystem (NSS) for a regenerative Environmental Control/Life Support System (EC/LSS).

Background

During the previous program[1] Life Systems, Inc. (LSI) identified two attractive N_2 generation systems based on the catalytic dissociation of N_2H_4. In the first system, liquid N_2H_4 is catalytically dissociated to yield an N_2/H_2 gas mixture. Separation of the gas mixture to yield N_2 and the supply of H_2 is 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 is separated in a Palladium/Silver (Pd/Ag) N_2/H_2 Separator.

The program culminated in the successful design, fabrication and testing of an N_2H_4 Catalytic Dissociator, a Polymer Electrochemical N_2/H_2 Separator and a two-stage Pd/Ag N_2/H_2 Separator. Based on the results of this program it was recommended that a N_2 Generation System (NGS), and subsequently an NSS, be developed based on N_2H_4 catalytic dissociation and the Pd/Ag method of H_2 separation.

Program Objectives

The objectives of the present program are to develop and evaluate:

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

1. a laboratory breadboard of an NGS based on the catalytic dissociation of N_2H_4,

2. a Nitrogen Generation Module (NGM) to reduce ammonia (NH_3) concentrations in the product N_2 and

3. an engineering model of the NSS which incorporates the NGM and is integratable within an Air Revitalization System (ARS).

The NGS consists of the N_2H_4 Catalytic Dissociator and the two-stage Pd/Ag Separator developed on the previous contract (NAS2-7057). The NGM consists of an advanced Pd/Ag Separator design and N_2H_4 dissociator design to lower NH_3 concentration in the product N_2. The NSS incorporates the N_2H_4 storage and feed mechanism, the NGM and the advanced instrumentation required to control and monitor NSS performance, and to interface with other ARS subsystems and controls.

Program Organization

The program was organized into five tasks whose specific objectives were to:

1. Design, fabricate, assemble and functionally check out the Laboratory Breadboard NGS, the NGM and the NSS.

2. Design, fabricate, assemble and functionally check out the Test Support Accessories (TSA) required for the NGS and the NSS testing.

3. Establish, implement and maintain a Product Assurance Program throughout the contractual performance period to search out quality weaknesses and to define appropriate corrective measures.

4. Conduct an extensive test program on the NGS to establish the quantitative effects of key engineering parameters.

5. Conduct supporting technology studies to support NSS technology development.

Program Status

The following activities were completed during the present reporting period:

- Nitrogen Generation Module Design
- Nitrogen Supply Subsystem Design
- Supporting technology activities in the area of Pd/Ag Separator testing for the NGM design math model and NH_3 dissociation testing to demonstrate <50 ppm NH_3 in the product N_2.

NITROGEN GENERATION MODULE DESIGN

The function of the NGM is to generate N_2 and by-product H_2 from a liquid N_2H_4 feed stream. The NGM consists of alternate catalytic dissociation and Pd/Ag 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 allows the heat generated during the dissociation of N_2H_4 to reduce the heater power required to maintain the NGM at temperature.

Concept Description

A block diagram showing the staging concept is presented in Figure 1. The NGM consists of one N_2H_4 dissociation stage, three NH_3 dissociation stages and three Pd/Ag separation stages. The N_2H_4 feed/N_2 product stream flows in series from stage to stage. The gas concentrations following each dissociation and H_2 separation stage are presented in the block diagram to demonstrate the method of obtaining low NH_3 and H_2 concentrations.

Hydrazine is dissociated in the first stage via the following reactions:[4]

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

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

$$N_2H_4 = N_2 + 2H_2 \qquad (3)$$

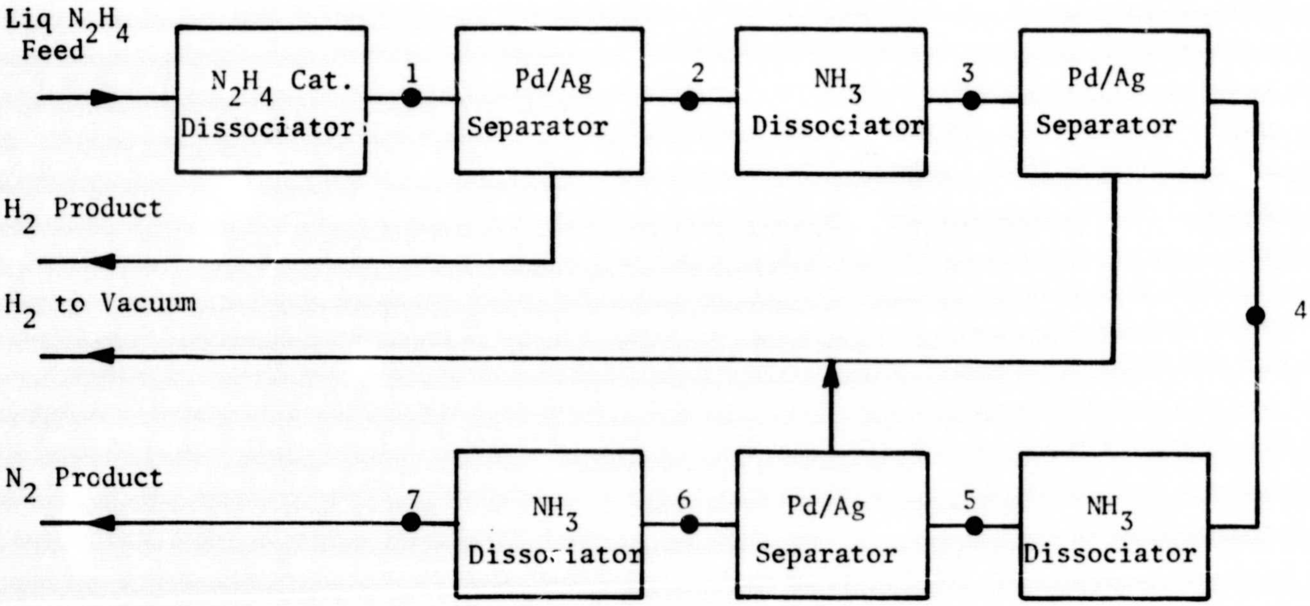
All the N_2H_4 is dissociated in this initial stage. Not all of the NH_3 formed by equation 1, however, is dissociated in the N_2H_4 dissociation stage.

The N_2/H_2 and unreacted NH_3 from the first stage, enters the first Pd/Ag separation stage. Most (90%) of the H_2 entering this stage is removed and collected at 172 kN/m^2 (25 psia) for use in the CO_2 Reduction Subsystem (CRS). The N_2 product gas from the first separation stage is then manifolded to the first NH_3 dissociation stage. The high NH_3 and N_2 concentration entering the dissociator favors 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 remaining H_2 separation stages is vented to space vacuum and is therefore not available for use in the CRS. The H_2 separation to vacuum is required to attain the low H_2 concentration required in the product N_2.

Design Specifications

The NGM design specifications are presented in Table 1. The detailed NGM component design specification is located in Appendix 1. The NGM was sized to



Stream	% N_2	% H_2	% NH_3	Eff. %	Temp, K (F)
1	32.8	64.0	3.2	93	1000 (1340)
2	77.3	15.1	7.6	90	644 (700)
3	75.8	22.8	1.4	80	811 (1000)
4	96.7	1.5	1.8	95	644 (700)
5	95.9	4.0	0.09	95	811 (1000)
6	99.8	0.08	0.09	98	644 (700)
7	99.78	0.2	19 ppm	98	811 (1000)

FIGURE 1 NGM STAGING CONCEPT BLOCK DIAGRAM

TABLE 1 NGM DESIGN SPECIFICATIONS

N_2H_4 Feed Rate, kg/d (Lb/Day)	4.15 (9.14)
N_2 Generation Rate, kg/d (Lb/Day)	3.63 (8.00)
H_2 Generation Rate, kg/d (Lb/Day)	0.44 (0.96)
N_2 Product Composition, Volume %	
H_2	≤ 0.2
NH_3	$\leq 5 \times 10^{-3}$
Water	≤ 0.1
H_2 By-product Purity, Volume %	>99.9
Surface Temperature Guidelines, K (F)	$\leq$322 (120)

deliver 3.63 kg/d (8.00 lb/day) of N_2 and 0.44 kg/d (0.96 lb/day) of H_2. The NH_3 concentration in the product N_2 is of prime concern in the NGM design since less than 50 ppm are required for direct utilization of N_2 in a spacecraft cabin atmosphere. The requirement for less than or equal to 0.2% H_2 in the product N_2 is not as critical since lower H_2 concentrations have been demonstrated previously.(5) A final or cleanup H_2 separation stage could be added to any prototype/flight NGM design if required.

Hardware Description

Photographs of the assembled and disassembled NGM mockup are presented in Figures 2 and 3 respectively. The NGM was designed as an experimental laboratory unit. The goal of the NGM design was to demonstrate the staging concept. Volume and weight optimization were not primary considerations. The NGM was configured similar to that projected for the prototype/flight hardware. The NGM configuration is a cylinder having a diameter of 26.2 cm (10.3 in) and a length of 41.7 cm (16.4 in) including the outside layer of insulation not shown in Figure 2. The total NGM volume is 0.022 m^3 (0.79 ft^3) and the NGM will weigh approximately 61 kg (135 lb). The NGM's size corresponds to that projected for a six-man spacecraft application.

Operation

Figure 4 is a functional schematic of the NGM showing the orientation of the individual stages. 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. Coolant N_2 is provided between the two temperature zones in the event cooling is required to control the two zones independently.

Hydrazine Dissociation

Hydrazine dissociation takes place in the center cavity of the NGM. Liquid N_2H_4 at a pressure of approximately 2070 kN/m^2 (300 psia) is injected into the dissociator through a capillary orifice in the header assembly. 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 feed tanks. In the feed orifice N_2H_4 is taken 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 autocatalytically dissociates. The central feed tube is packed with 10 to 20 mesh tungsten chips to allow heat to transfer to the gas phase which promotes the autocatalytic reaction. A platinum screen is located at the end of the central feed tube to insure that any undissociated N_2H_4 reacts prior to entering the packed catalyst bed in the concentric annular housing.

At the end of the central tube the flow pattern of the product gases is reversed in direction. The product gases flow in the annular housing concentric with the central tube and exit at the hottest zone in the reactor. The

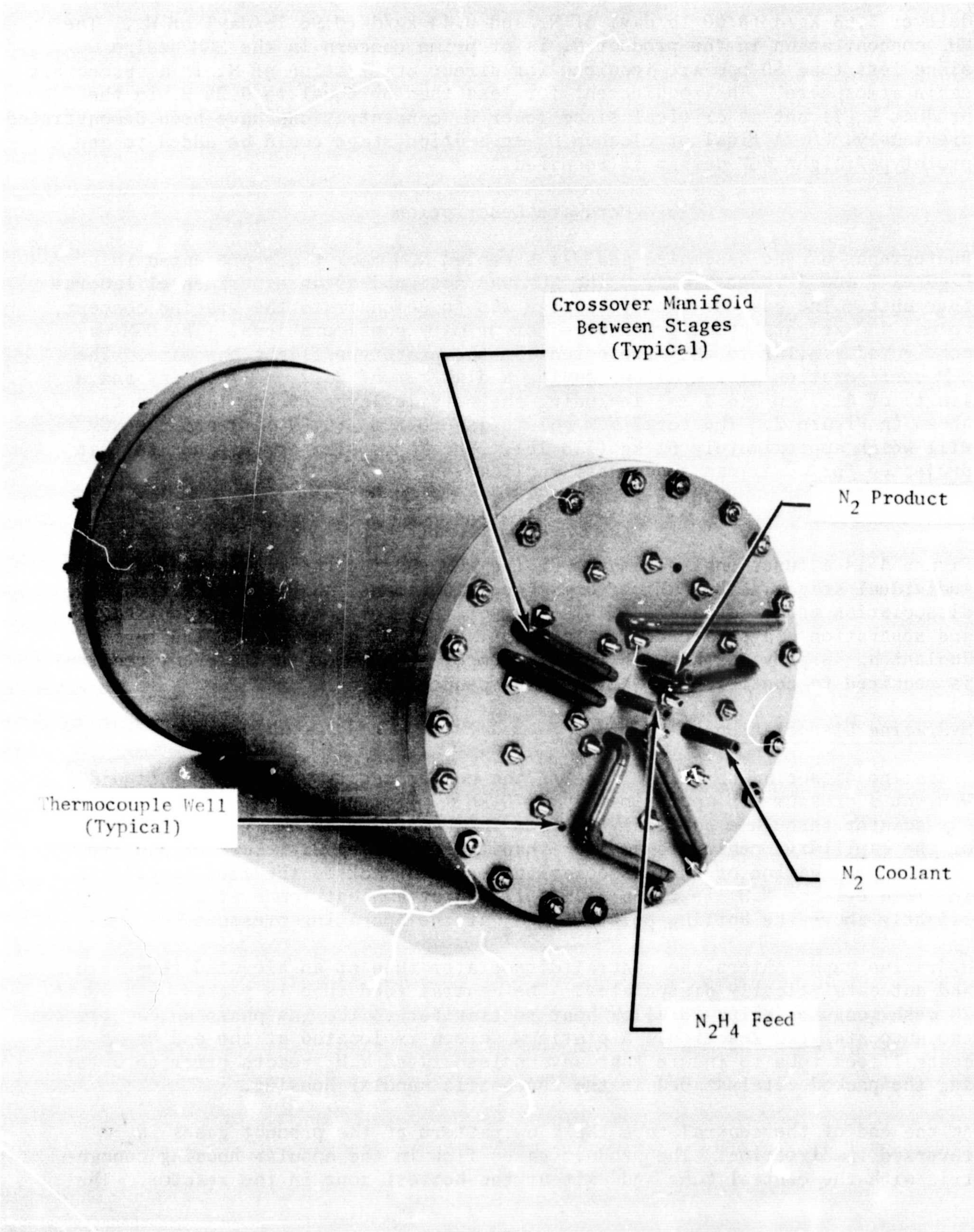


FIGURE 2 NITROGEN GENERATION MODULE MOCKUP (ASSEMBLED)

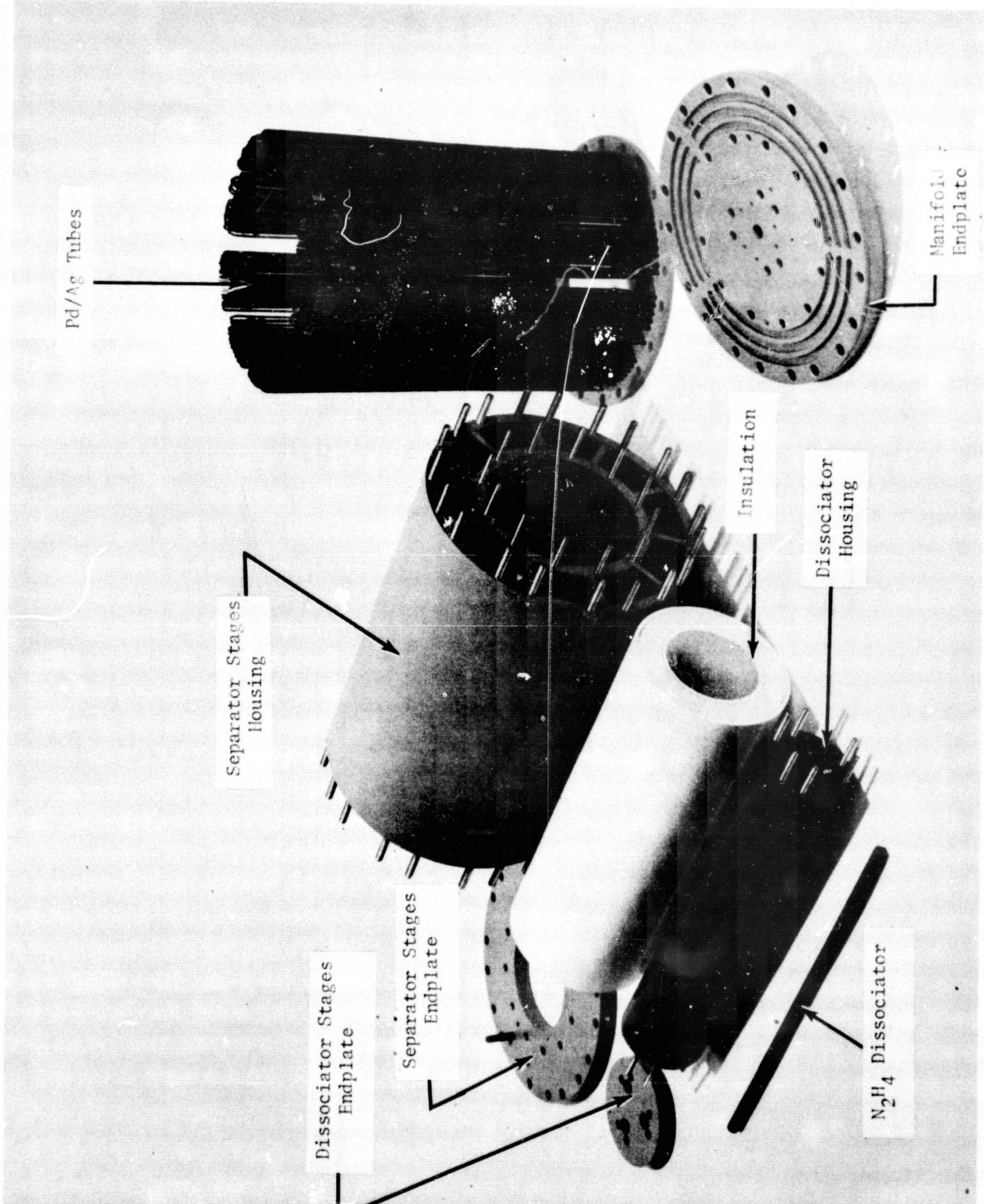


FIGURE 3 NITROGEN GENERATION MODULE MOCKUP (DISASSEMBLED)

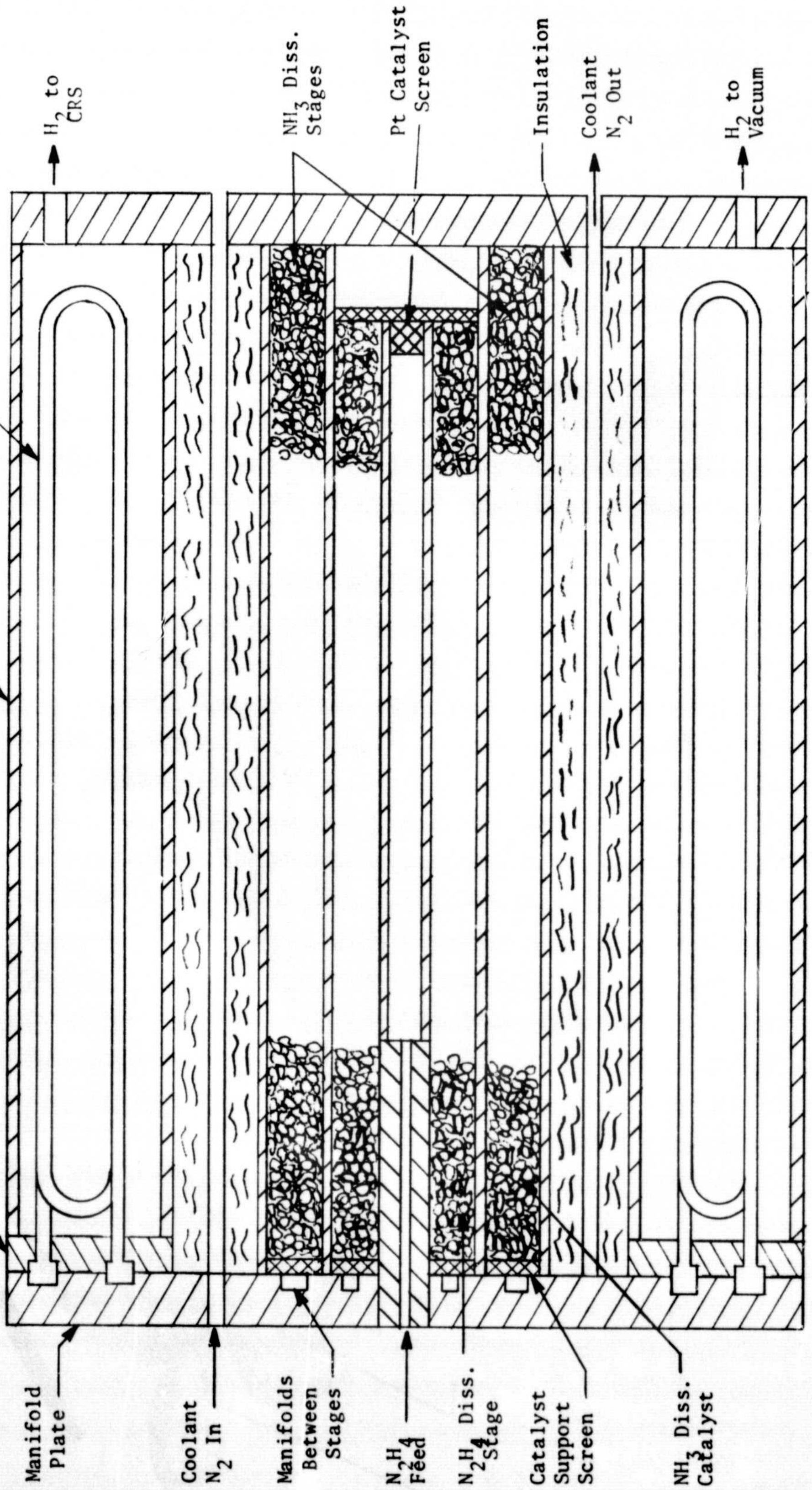


FIGURE 4 NGM FUNCTIONAL SCHEMATIC

decomposition of NH_3 into N_2 and H_2 (equation 2) is favored kinetically and thermodynamically at higher temperatures.[6] The "hairpin" type reactor design will therefore result in higher NH_3 conversion efficiencies in the N_2H_4 dissociation stage.

Tungsten catalyst retaining screens are used to prevent catalyst particles from being removed by the product gases. The product gas from the N_2H_4 dissociation stage is manifolded to the first Pd/Ag separation stage.

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 an H_2 separation stage, is fed into an 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 dissociator 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 tubes packed with catalyst (see Figure 3).

Pd/Ag Separation

The three H_2 separation stages are located around the outside 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 reason for the thermal isolation is the difference in operating temperatures. The H_2 separation stages operate at 644K (700F) and the dissociator core is maintained at 1000K (1340F).

The H_2 separation stages are connected to the main manifold plate which manifolds the process gases between the H_2 separation and the dissociation stages. The N_2/H_2 mixture from a dissociation stage enters the inside ends (i.e., closest to the center of the NGM) of 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 outside ends of the tubes to the next dissociation stage.

In the first H_2 separation stage, H_2 is collected at less than or equal to 172 kN/m^2 (25 psia) for use in the CRS. The H_2 removed in the second and third H_2 separation stages is vented to vacuum. The H_2 removed in the second and third stages exhausts the NGM through a common manifold.

Temperature control of the Pd/Ag separation stages is provided through metal fins which connect the outside and inside concentric cylinders which form the housing for the separation stages (see Figure 3). Band heaters located on the outside wall are able to transmit heat to the inside surface through these fins, thereby keeping the Pd/Ag tubes at a constant temperature.

Operating Conditions

Table 2 gives the projected steady-state operating conditions for the NGM. Only temperature is controlled in the module using three cartridge heaters located in the dissociator core and five band heaters located around the outside of the H_2 separator housing. Thermocouples located within the NGM are used to provide closed loop temperature feedback control. The central dissociator core is controlled at 1000K (1340F) and the Pd/Ag Separator tubes are controlled at 644K (700F). In addition to the heaters, a port for N_2 coolant gas is provided between the central dissociator core and the Pd/Ag separator stages in the event that the Pd/Ag tubes should start to overheat due to the heat generation in the central dissociator core.

Interfaces

The NGM has five mechanical interfaces and two electrical interfaces. The mechanical interfaces are the N_2H_4 liquid feed stream, the N_2 product stream, the H_2 by-product, the H_2 vented to vacuum and the N_2 coolant supply. The electrical connections include power to the heaters and the temperature sensor connectors. The NGM contains eight temperature sensors, two are used for control and six are used for fault detection and isolation. The NGM also has provisions for an additional 20 thermocouples for temperature profile mapping during development testing.

NITROGEN SUPPLY SUBSYSTEM DESIGN

The NSS has been designed as an integratable subsystem for a central ARS. Those components which would be redundant in another ARS subsystem have been eliminated. In addition, certain functions that would be performed by the NSS for the entire central ARS have been included.

The NSS consists of the N_2H_4 storage and feed mechanism, the NGM, the peripheral mechanical and electrical components required to control and monitor subsystem performance, and the advanced instrumentation required for the NSS to interface with other ARS subsystems and controls. The NSS design has been completed with the exception of the detailed instrumentation control software programs and the specific associated computer hardware. The instrumentation control concepts have been defined and are discussed in the following sections.

Design Specifications

The NSS has been designed to deliver N_2 at a rate of 3.63 kg/d (8.0 lb/day) at pressures less than or equal to 1725 kN/m^2 (250 psia). The detailed design specifications for the NSS are listed in Table 3.

Subsystem Operation

Figure 5 is a block diagram of the NSS. High pressure N_2 at approximately 2070 kN/m^2 (300 psia) is used to pressurize the N_2H_4 storage tanks. Hydrazine is forced from the tanks through a flow control which controls the N_2H_4 feed

TABLE 2 NGM NOMINAL OPERATING CONDITIONS

Catalytic Dissociator Temperature, K (F)	1000 (1340)
Pd/Ag Separator Temperature, K (F)	644 (700)
N_2H_4 Feed	
Source	Liquid N_2H_4
N_2H_4 Flow Rate, kg/d (Lb/Day)	4.15 (9.14)
cm^3/min	2.9
Composition, Weight %	
N_2H_4	99.5 to 100
Water	0 to 0.5
Temperature, K (F)	291 to 297 (65 to 75)
Pressure, kN/m^2 (Psia)	1932 (280)
N_2 Product	
Flow Rate, kg/d (Lb/Day)	3.63 (8.0)
dm^3/min (Slpm)	2.2 (2.2)
Composition, Volume %	
H_2	0.2
NH_3	1.9×10^{-3}
Water	<0.1
Temperature, K (F)	644 (700)
Pressure, kN/m^2 (Psia)	1725 (250)
H_2 By-Product	
Flow Rate, kg/d (Lb/Day)	0.44 (0.96)
dm^3/min (Slpm)	3.6 (3.6)
Purity, Volume %	99.9999 to 100
Temperature, K (F)	644 (700)
Pressure, kN/m^2 (Psia)	173 (25)
H_2 Vented	
Flow Rate, kg/d (Lb/Day)	0.08 (0.18)
dm^3 (Slpm)	0.68 (0.68)
Temperature, K (F)	644 (700)
Pressure, N/m^2 (mm Hg)	0 to 1334 (0 to 10)

Table 2-continued

Coolant Supply	
Type	Ambient Air or N_2
Temperature, K (F)	291 to 297 (65 to 75)
Flow Rate, dm^3/min (Scfm)	28 (1)
Cabin Environment Data	
Operational Gravity, m/s^2 (G)	0 to 1.0
Total Pressure, kN/m^2 (Psia)	101.4 (14.7)
O_2 Partial Pressure, kN/m^2 (Psia)	21.4 (3.1)
Diluent	N_2
H_2 Concentration, Volume %	0.2
NH_3 Concentration, Volume %	5.0×10^{-5}
Temperature, K (F)	291 to 297 (65 to 75)

TABLE 3 NITROGEN SUPPLY SUBSYSTEM DESIGN SPECIFICATIONS

Leakage Data	
Air Leakage Rate, kg/d (Lb/Day)	4.74 (10.43)
N_2 Leakage Rate, kg/d (Lb/Day)	3.63 (8.00)
O_2 Leakage Rate, kg/d (Lb/Day)	1.10 (2.43)
Cabin Atmosphere Data	
Operational Gravity, m/s^2 (G)	0 to 9.8 (0 to 1)
Total Pressure, kN/m^2 (Psia)	101.4 (14.7)
O_2 Partial Pressure, kN/m^2 (Psia)	21.4 (3.1)
Diluent	N_2
Volume	
Initial, m^3 (Ft^3)	439 (15,500)
Growth, m^3 (Ft^3)	960 (33,900)
Ventilation Rate	
Minimum, cm/s (Ft/Min)	7.6 (15)
Maximum, cm/s (Ft/Min)	20.3 (40)
H_2 Concentration, Volume %	0.2
NH_3 Concentration, Volume %	5.0×10^{-3}
Temperature, K (F)	291 to 297 (65 to 75)
Surface Temperature Guidelines, K (F)	$\leq$322 (120)
Acoustical Guidelines	$\overline{\text{N}}$C-65

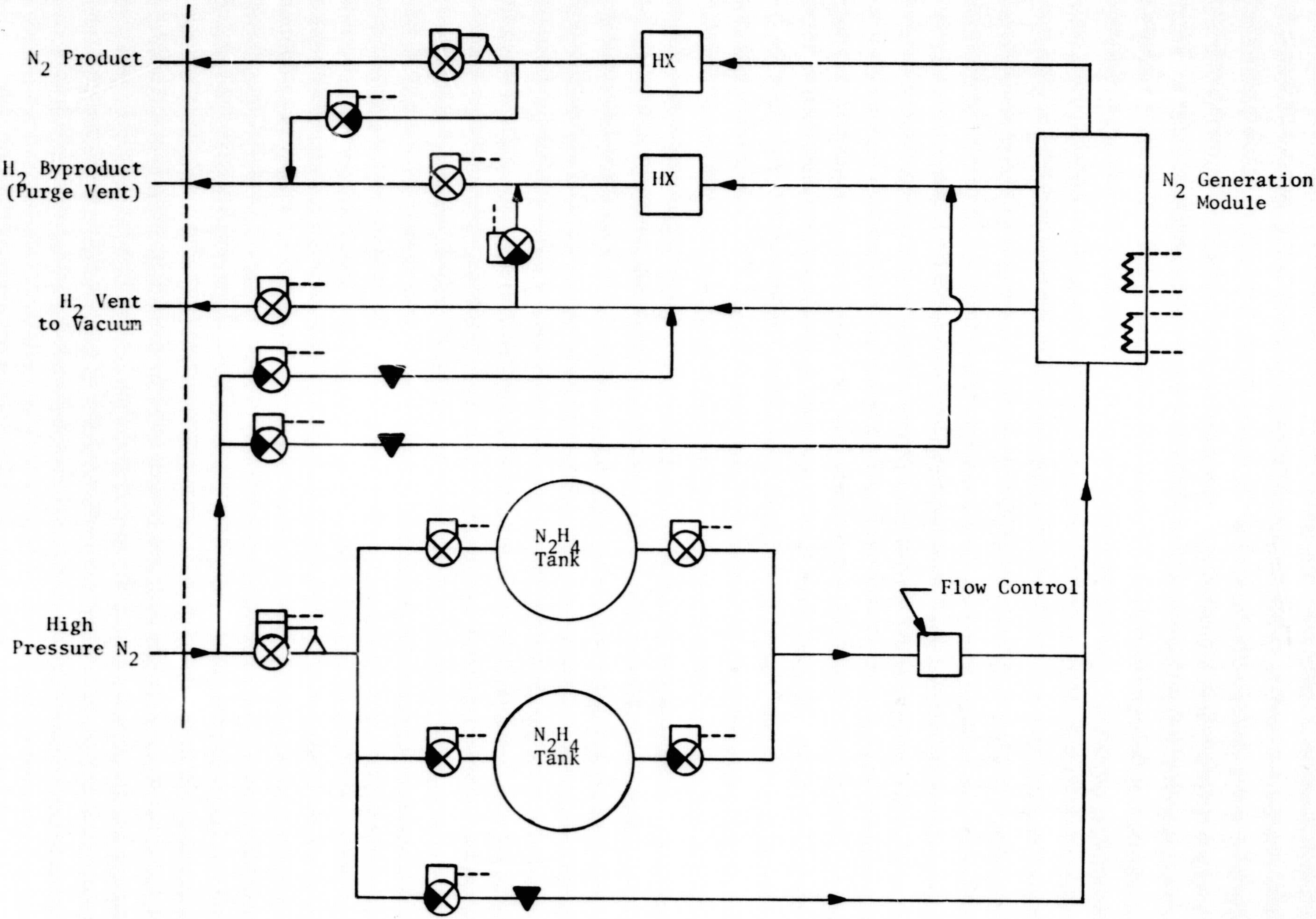


FIGURE 5 NITROGEN SUPPLY SUBSYSTEM BLOCK DIAGRAM

rate to the NGM by adjusting the feed pressure to the tanks. The N_2 and H_2 product streams are cooled in air heat exchangers prior to exiting the subsystem. The N_2 product pressure is controlled at 1725 kN/m^2 (250 psia) by a backpressure regulator. The H_2 vent-to-vacuum for the second and third H_2 separation stages in the NGM is not cooled prior to exiting the subsystem. The absolute mass flow rate and heat capacity in the stream is very small and the gas stream will reach ambient temperature in just the length of tubing required to vent the stream from the subsystem.

Solenoid valves are provided on the two N_2H_4 tanks to allow continuous operation of the NSS. One tank is always operating while the other tank remains in standby. As the first tank is emptied, the second tank is switched on line and the first tank is isolated for refilling.

Solenoid valves and flow control orifices are used to distribute the high pressure N_2 for purging the three process gas streams. Solenoid valves on the H_2 vent-to-vacuum and N_2 product streams allow all purge gas to be vented through the H_2 by-product stream which would be connected to the CRS. As part of an integrated ARS, the CRS would handle the purge vent for all ARS subsystems to prevent duplication of valving required to exhaust purge gas to space vacuum. The H_2 vent-to-vacuum requirements would be handled similarly as part of the ARS so duplication is not required in the NSS.

The detailed schematic of the NSS is presented in Figure 6. The detailed schematic shows the specific valves and sensors that will be used in the NSS. The N_2 feed to the supply tanks is controlled using a motor driven regulator (V30) and a closed loop feedback control from flow control Q8. The flow control monitors the pressure drop across a fixed orifice and automatically adjusts the feed tank pressure to give the desired flow rate as measured by differential pressure across the orifice.

The N_2H_4 storage tanks are shown as being located in a non-habitable compartment of the spacecraft. Hydrazine stored on-board a spacecraft would be fed to the NSS from outside the inhabited cabin atmosphere.

Manual valves (MV2 through MV6) are provided to refill the tanks since each supply tank was sized to only last approximately five days. Solenoid valves V32 through V35 determine which tank is on line. The control instrumentation automatically alerts the operator when a tank needs to be refilled and automatically switches in the reserve tank. Pressure sensors and orifices are used to measure the amount of N_2H_4 in the reserve tank prior to switching to the reserve tank. This prevents switching in an N_2H_4 tank which has not been filled. The concept works on the principal of timing how long it takes to pressurize the tanks with N_2 pressure through a fixed resistance flow orifice. A very short pressurization time (less than 0.1 seconds) would indicate that the tanks were relatively full whereas a longer pressurization period (up to ten seconds) would indicate a lower level of N_2H_4 in the tanks.

Redundant solenoid valve V28 and manual valves MV4 and MV7 are used as a safety precaution to insure that during a shutdown the N_2H_4 feed stream is

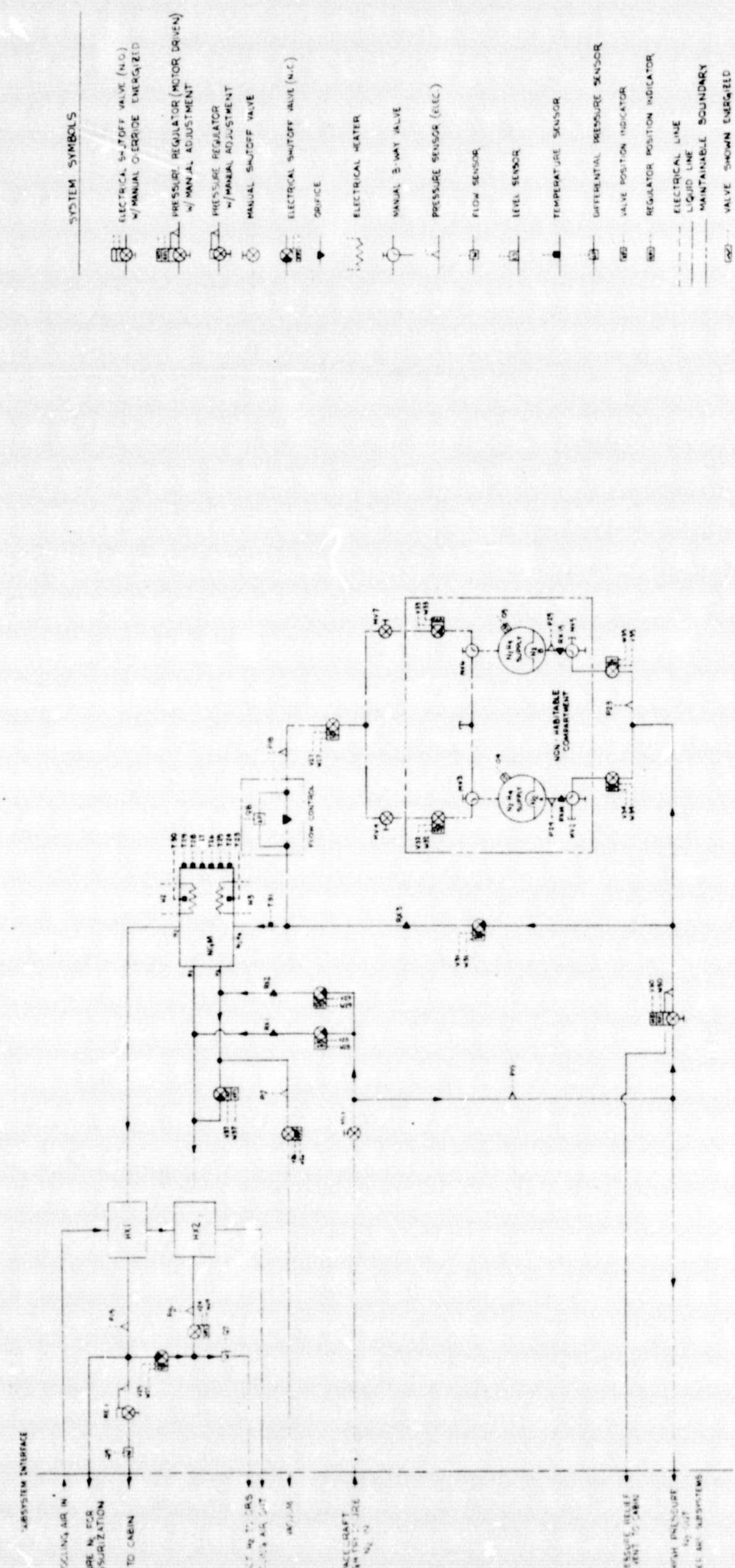


FIGURE 6 NITROGEN SUPPLY SUBSYSTEM SCHEMATIC

disconnected from the NGM both automatically and manually. Nitrogen purge is provided through solenoid valves V28, V29 and V31. Solenoid valve V31 also serves the dual purpose of prepressurizing the NGM prior to startup. Various pressure temperature and flow sensors are located throughout the subsubsystem for sequencing control and fault isolation and detection.

The N_2 generated by the NSS is vented to the cabin for cabin leakage makeup. The high pressure N_2 stream is also used for pressurization purposes in other ARS subsystems. The NSS serves as the interface with spacecraft high pressure N_2 that is used to purge other ARS subsystems. The spacecraft N_2 supply, therefore, interfaces with the NSS which interfaces with other subsystems requiring N_2 purge.

Control and Monitor Instrumentation

The NSS will have computer-based Control/Monitor Instrumentation (C/M I) that is integratable with a central ARS C/M I which controls and monitors all ARS subsystems.

The function of the C/M I is to provide:

1. Automatic mode control and mode transitions
2. Automatic shutdown provisions for self-protection
3. Provisions for monitoring critical parameters
4. An interface with TSA instrumentation

The NSS has five operating modes: Shutdown, Normal, Standby, Purge and Unpowered. The five modes and the allowable mode transitions are shown in Figure 7. There are eight allowable mode transitions that can be programed or commanded during NSS operation. In the event of a power failure, however, all modes can transition to the unpowered mode during which time all actuators and valves will go to the de-energized position. Upon repowering the NSS, all actuators will be put in the shutdown position.

Subsystem Controls

The preliminary control function of the NSS C/M I is to control mode transitions and steady-state operation. Table 4 lists the actuator conditions for the five steady-state modes.

In addition to steady-state mode control and transition sequences, the NSS C/M I contains two temperature controls and the N_2H_4 feed control. Temperature control is achieved using heaters H2 and H3 and sensors T23 and T30 respectively (see Figure 6). The N_2H_4 feed control uses flow sensor Q8 and adjusts the motor-driven pressure regulator (V30) which feeds high pressure N_2 to the N_2H_4 storage tanks to give the desired N_2H_4 flow rate. The feed control also determines which N_2H_4 tank will be used during operation and changes tanks as

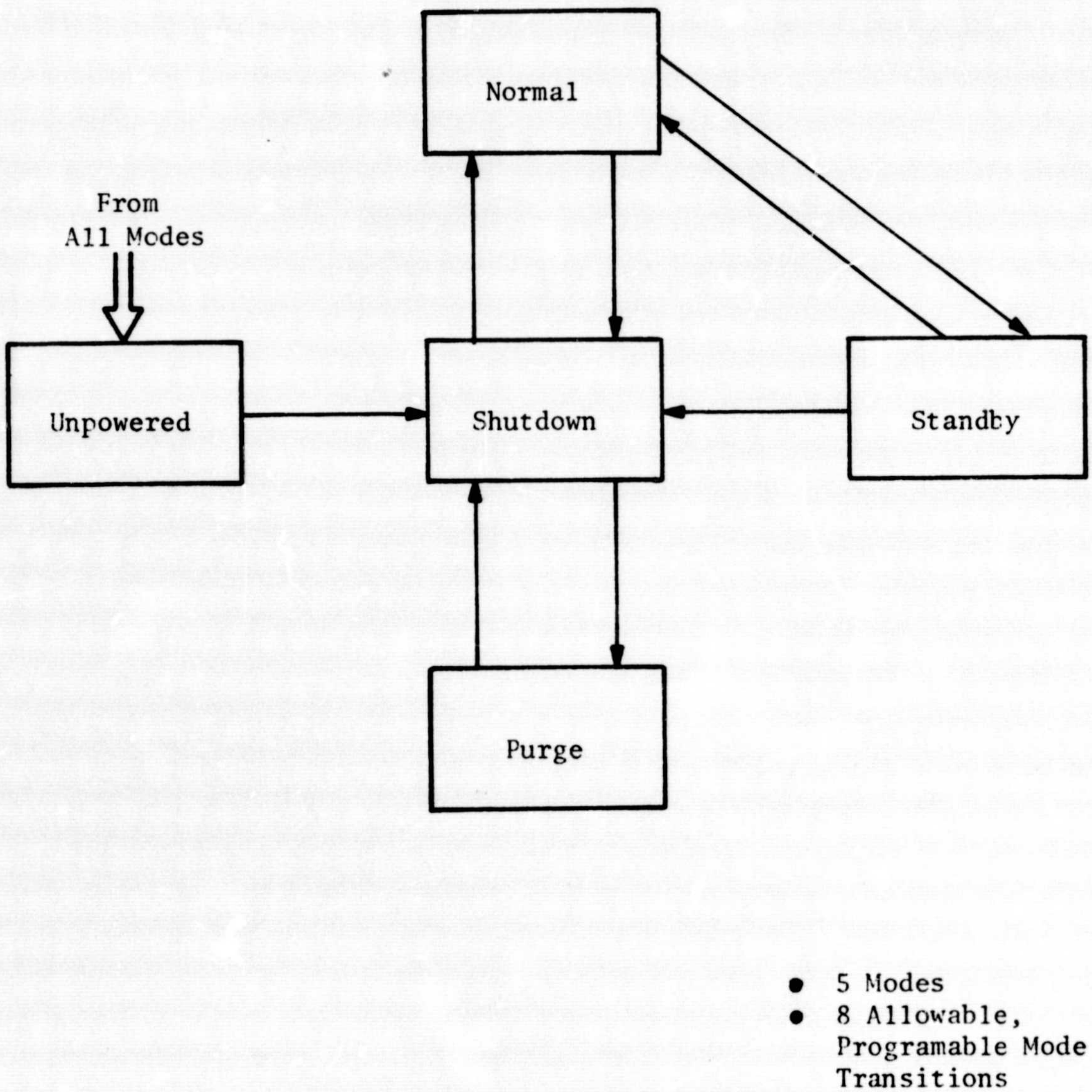


FIGURE 7 NSS OPERATING MODES AND ALLOWABLE TRANSITIONS

TABLE 4 ACTUATOR CONDITIONS FOR NSS OPERATING MODES

	Shutdown	Normal	Standby	Purge
V24	O[a]	O	O	O
V25	O	X[b]	X	O
V26	O	X	X	O
V27	O	X	X	O
V28	X	X	X	O
V29	X	X	X	O
V30	O	X	X	O
V31	X	X	X	O
V32	O	X[c]	X[c]	O
V33	O	O[c]	O[c]	O
V34	O	X	X	O
V35	O	X	X	O
V37	O	X	X	O
H2	O	X	X	O
H3	O	X	X	O

(a) O indicates actuator de-energized
(b) X indicates actuator energized
(c) Condition depends on which N_2H_4 tank is used

required to maintain a constant N_2H_4 flow to the NGM. The absolute pressure level of the NGM is set using a manual pressure regulator (RE1) and is not automatically adjusted during normal NSS operation.

Subsystem Monitoring

Various temperature flow and pressure sensors are located throughout the NSS to protect the subsystem by initiating a shutdown should a critical parameter exceed a preset level. The NSS sensor list is presented in Table 5. The list shows the monitoring range for each sensor and the shutdown point on critical sensors. The flow sensors for the NSS are used only for monitoring and have no shutdown capability as indicated in the table. Additional sensors which are not called out as part of the NSS are the combustible gas sensors located near the ARS subsystems and a combustible gas sensor located in the line that vents the N_2 and O_2 generated by the O_2 Generation Subsystem (OGS) from an ARS into the cabin. These two sensors protect against possible internal/external H_2 leakage and failure of the NGM to deliver high purity N_2 to the cabin. These sensors were not listed in Table 5 since they are considered part of another ARS subsystem but could shut down the NGM for internal-to-external H_2 leakage.

SUPPORTING TECHNOLOGY ACTIVITIES

Experimental activities were completed in two areas to support NSS technology development and, specifically, the NGM design:

1. Pd/Ag Separator performance characterization.

2. NH_3 removal through staging.

Palladium/Silver Separator Performance Characterization

The effect of N_2 generation rate and delivery pressure on Pd/Ag Separator performance was characterized over the operating ranges of 3.2 to 9.0 kg/d (7.0 to 19.8 lb/day) and 690 to 2,070 kN/m^2 (100 to 300 psia), respectively. The effect of N_2 generation rate on the H_2 recovery and the final H_2-in-N_2 product concentration is presented in Figure 8. The effect of N_2 delivery pressure on H_2 recovery and H_2-in-N_2 product concentration is presented in Figure 9. The baseline conditions for the testing are presented in Table 6.

For a fixed Pd/Ag Separator surface area, lower N_2 generation rates and higher N_2 delivery pressures improve separator performance over the operating range examined. Nitrogen delivery pressure has the greatest effect on separator performance for pressures below 1,035 kN/m^2 (150 psia). The benefits of increasing N_2 delivery pressure, however, decrease as the pressure level approaches 2,070 kN/m^2 (300 psia). For the N_2 generation rate range envisioned for future NSS application, a pressure range of 1,035 to 2,070 kN/m^2 (150 to 300 psia) is recommended.

TABLE 5 NSS SENSOR LIST

Type	Sensor[a] Number	Range[b]	Shutdown[b] Point
Pressure	P15	0 to 2070 (0 to 300)	2070 (300)
Pressure	P16	0 to 345 (0 to 50)	345 (50)
Pressure	P17	0 to 173 (0 to 25)	173 (25)
Pressure	P18	0 to 2070 (0 to 300)	2070 (300)
Pressure	P19	0 to 3450 (0 to 500)	3450 (500)
Pressure	P23	0 to 2070 (0 to 300)	2070 (300)
Pressure	P24	0 to 2070 (0 to 300)	2070 (300)
Pressure	P25	0 to 2070 (0 to 300)	2070 (300)
Temperature	T23	294 to 700 (70 to 800)	N/A
Temperature	T24 to T26	294 to 700 (70 to 800)	700 (800)
Temperature	T27 to T29	294 to 1089 (70 to 1500)	1089 (1500)
Temperature	T30	294 to 1089 (70 to 1500)	N/A
Temperature	T31	294 to 311 (70 to 100)	100
Flow	Q5	0 to 5000	N/A
Flow	Q7	0 to 5000	N/A
Flow	Q8	0 to 5	N/A

(a) See Figure 6 for sensor location.
(b) Pressures given in kN/m^2 (Psia), temperatures in K (F) and flow rates in cc/min.

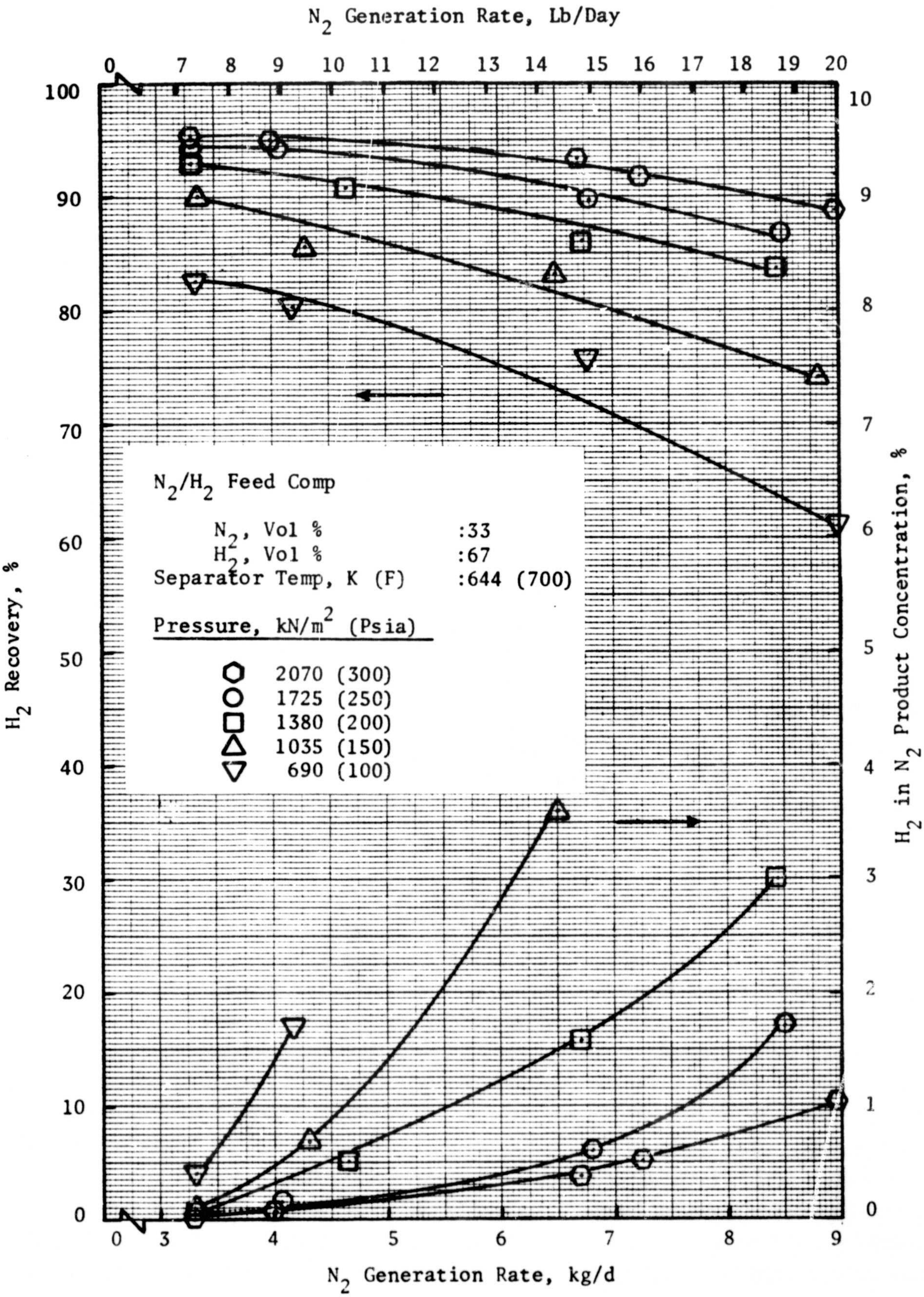


FIGURE 8 EFFECT OF N_2 GENERATION RATE AND PRESSURE ON SEPARATOR PERFORMANCE

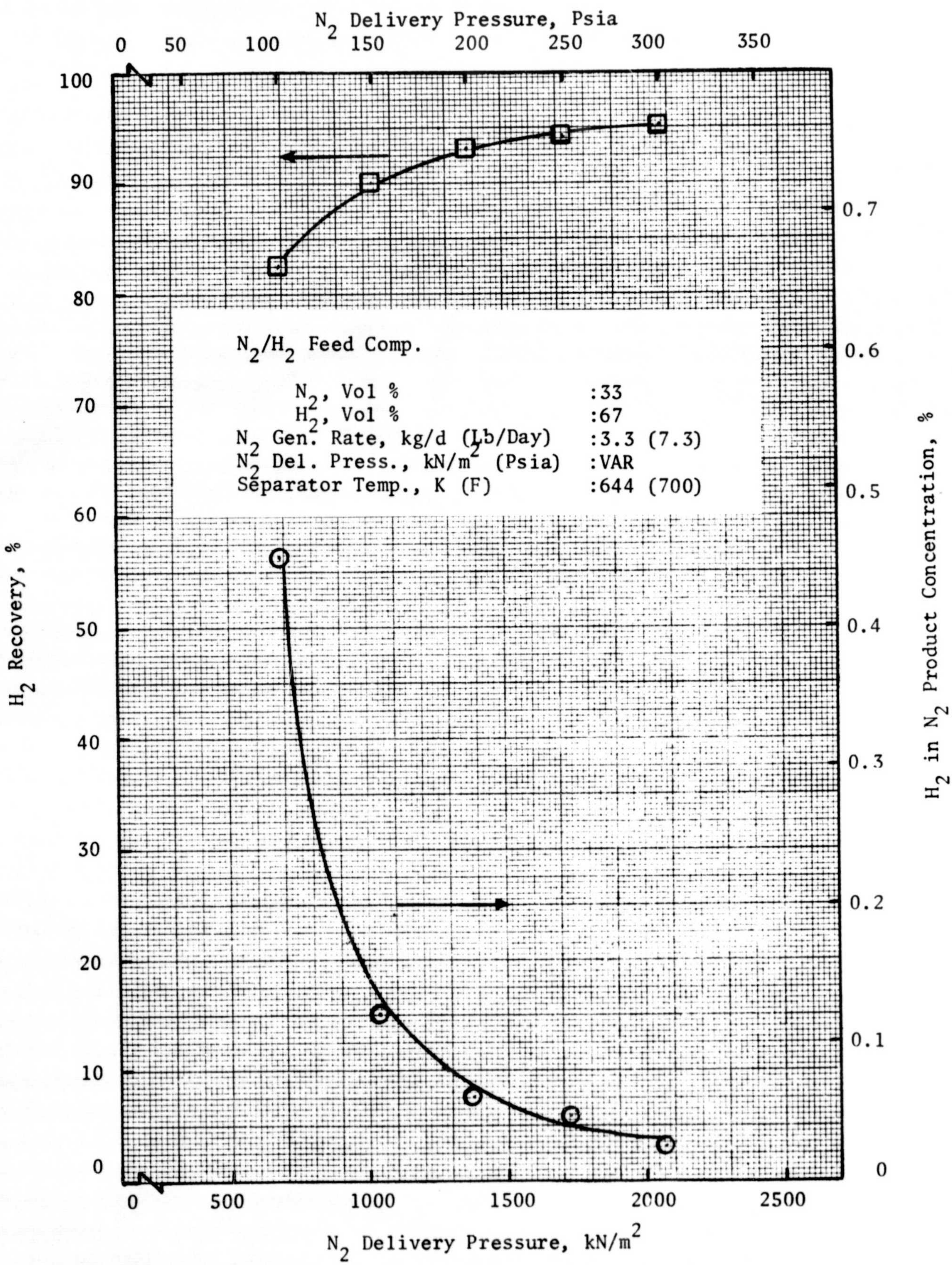


FIGURE 9 EFFECT OF N_2 DELIVERY PRESSURE ON SEPARATOR PERFORMANCE

TABLE 6 PALLADIUM/SILVER SEPARATOR BASELINE OPERATING CONDITIONS

N_2/H_2 Feed	
Flow Rate, kg/d (Lb/Day)	3.3 ±0.1 (7.3 ±0.1)
Composition (by volume)	
N_2, %	33 ±0.5
H_2, %	67 ±0.5
Temperature, K (F)	294 ±2 (70 ±4)
N_2 Product	
Temperature, K (F)	294 ±2 (70 ±4)
Pressure, kN/m^2 (Psia)	1725 ±35 (250 ±5)
H_2 Product	
Temperature, K (F)	294 ±2 (70 ±4)
Pressure, kN/m^2 (Psia)	172 ±7 (25 ±1)
H_2 Vent to Vacuum	
Temperature, K (F)	294 ±2 (70 ±4)
Pressure, kN/m^2 (mm Hg)	0.3 ±0.3 (2 ±2)
Pd/Ag Diffusion Unit	
Temperature, K (F)	644 ±14 (700 ±25)

The data collected for the Pd/Ag separator was used to develop a mathematical model to size the Pd/Ag Separator stages in the NGM. The data presented, however, is conservative for the NGM application since it represents flow over the outside of the Pd/Ag tubes. The NGM has been designed with flow on the inside of the tubes thereby reducing the mass transfer limit in the gas phase which limits the H_2 separation process at low H_2-in-N_2 concentrations. The specific gain attributed to the flow on the inside of the Pd/Ag tubes, however, cannot be estimated from the data gathered to date and additional performance data for flow on the inside of the tubes will be gathered before the final number of tubes is selected for the NGM design.

Ammonia Removal Test

An experiment was completed to demonstrate that low NH_3 concentrations in the product N_2 stream are possible using the staging concept. Mixtures of N_2, H_2 and NH_3 were fed into a temperature controlled packed bed reactor. The reactor was a 25.4 cm (10 in) long, 1.3 cm (0.5 in) OD stainless steel tube packed with approximately 24 cm^3 (1.5 in^3) of 12 to 20 mesh NH_3 dissociation catalyst.

The objective of the experiment was to demonstrate the highest NH_3 inlet concentration allowable and reactor temperature required to reduce the NH_3 concentration to less than or equal to 50 ppm. A gas chromatograph was used for quantitative analyses above 0.1% NH_3. The error in the gas chromatographic technique used did not allow accurate data at the lower NH_3 concentrations. The determination of less than or equal to 50 ppm was accomplished by smelling the N_2 product gas exiting the reactor. The odor threshold of NH_3 is 50 ppm and therefore this technique provided a simple and effective method of analysis.

The results of the NH_3 removal experiment are presented in Table 7. An NH_3 concentration of 1.03% in the feed stream is reduced to less than 50 ppm at temperatures greater than or equal to 777K (940F). The actual inlet NH_3 concentration to the final NGM NH_3 dissociation stages is only 0.09%. The NGM should therefore meet its design requirement.

CONCLUSIONS

The following conc ions were reached:

1. The inte ion of multiple H_2 separation and N_2H_4 and NH_3 dissociation stages into an NGM is feasible. The design completed successfully integrates seven dissociation/separation stages into a single package to effectively use the heat generated in the N_2H_4 dissociation process to heat the other stages.

2. An NSS can be designed and integrated into a central ARS. The NSS design completed is fully integratable with an ARS and has been sized to deliver 3.63 kg/d (8.0 lb/day) of N_2 at greater than or equal to 1,725 kN/m^2 (250 psia). This N_2 generation rate corresponds to a six-man spacecraft application.

TABLE 7 AMMONIA REMOVAL TEST RESULTS

Inlet N_2 Flow kg/d (Lb/Day)	Temperature, K (F)	Inlet Conc, % NH_3	Inlet Conc, % H_2	Outlet NH_3 Conc, %
3.92 (8.64	1089 (1500)	4.32	0	0.88
3.92 (8.64)	1089 (1500)	3.46	20	0.65
4.01 (8.82)	1089 (1500)	0.76	0	<0.005
4.37 (9.63)	1089 (1500)	1.03	0	<0.005
4.37 (9.63)	1005 (1350)	1.03	0	<0.005
4.37 (9.63)	889 (1140)	1.03	0	<0.005
4.37 (9.63)	777 (940)	1.03	0	<0.005
4.37 (9.63)	683 (770)	1.03	0	0.22

3. The NGM staging technique is an effective method of delivering high purity N_2 for spacecraft leakage makeup. Data gathered on a laboratory NH_3 dissociator verified that low NH_3 concentrations (less than 50 ppm) are attainable using the NGM.

RECOMMENDATIONS

The following recommendations are a direct result of the work completed:

1. The NGM should be fabricated and tested to determine its performance as a function of N_2 generation rate and delivery pressure.

2. The NSS should be fabricated and integrated into a central ARS for testing.

3. The NGM separation stages should be tested and the design upgraded based on these test results to reduce the number of Pd/Ag tubes required. The present design data is conservative and does not allow for improvements in separator performance projected for the NGM tube configuration.

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APPENDIX 1

NGM DESIGN SPECIFICATION

Life Systems, Inc. CLEVELAND, OHIO 44122	SPECIFICATION	NO.	REVISION LTR.
		PAGE 1 OF 5	DATE
TITLE NITROGEN GENERATION MODULE (NGM)			

FUNCTION

The function of the Nitrogen (N_2) Generation Module (NGM) is to generate N_2 and by-product hydrogen (H_2) from a liquid hydrazine (N_2H_4) feed stream.

DESCRIPTION

The NGM consists of the catalytic dissociation and palladium/silver (Pd/Ag) separator stages required to generate high purity N_2 and H_2. A block diagram showing the staging concept is presented in Figure A1-1. The dissociator and separator stages are packaged as a single unit to minimize insulation requirements since both operate at elevated temperatures. The single package concept also allows the heat generated during the dissociation of N_2H_4 to be used to maintain the temperature of the entire NGM.

DESIGN DATA

Design Specifications

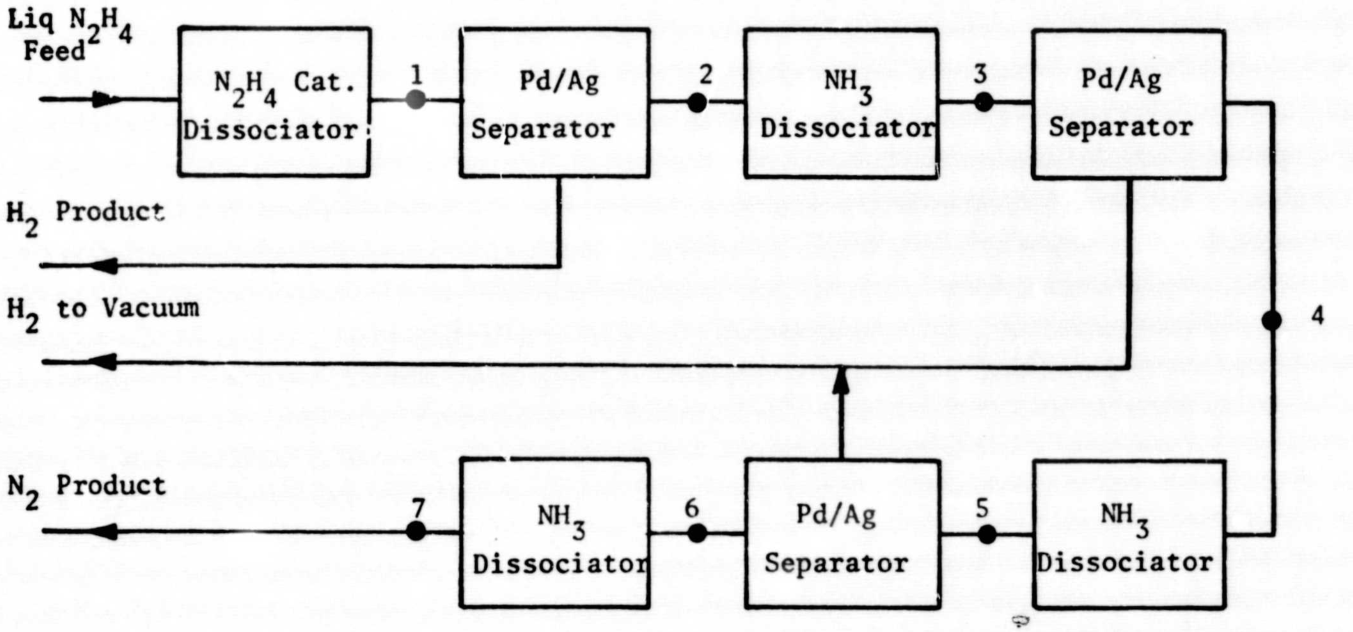
N_2H_2 Feed Rate, kg/d (Lb/Day)	4.15 (9.14)
N_2 Generation Rate, kg/d (Lb/Day)	3.63 (8.00)
H_2 Generation Rate, kg/d (Lb/Day)	0.44 (0.96)
H_2 Product Composition, Volume %	
H_2	≤ 0.2
NH_3	$\leq 5 \times 10^{-5}$
Water	≤ 0.1
H_2 By-product Purity, Volume %	>99.9
Surface Temperature Guidelines, K (F)	≤ 322 (120)

Cabin Environment Data

Operational Gravity, G	0 to 1.0
Total Pressure, kN/m^2 (Psia)	101.4 (14.7)
O_2 Partial Pressure, kN/m^2 (Psia)	21.4 (3.1)
Diluent	N_2
H_2 Concentration, Volume %	0.2
NH_3 Concentration, Volume %	5.0×10^{-5}
Temperature, K (F)	291 to 297 (65 to 75)

Nominal Operating Conditions

Catalytic Dissociator Temperature, K (F)	1000 (1340)
Pd/Ag Separator Temperature K (F)	644 (700)
N_2H_4 Feed	
Source	Liquid N_2H_4
N_2H_4 Flow Rate, kg/d (Lb/Day)	4.15 (9.14)
cm^3/min	2.9



Stream	% N_2	% H_2	% NH_3	Eff. %	Temp, K (F)
1	32.8	64.0	3.2	93	1000 (1340)
2	77.3	15.1	7.6	90	644 (700)
3	75.8	22.8	1.4	80	811 (1000)
4	96.7	1.5	1.8	95	644 (700)
5	95.9	4.0	0.09	95	811 (1000)
6	99.8	0.08	0.09	98	644 (700)
7	99.78	0.2	19 ppm	98	811 (1000)

FIGURE A1-1 NGM STAGING CONCEPT BLOCK DIAGRAM

Life Systems, Inc. CLEVELAND, OHIO 44122	SPECIFICATION	NO.	REVISION LTR.
		PAGE 3 OF 5	DATE
TITLE NITROGEN GENERATION MODULE (NGM)			

Composition, Weight %

N_2H_4	99.5 to 100
Water	0 to 0.5
Temperature, K, (F)	291 to 297 (65 to 75)
Pressure, kN/m^2 (Psia)	1932 (280)

N_2 Product

Flow Rate, kg/d (Lb/Day)	3.63 (8.0)
dm^3/min (Slpm)[a]	2.2 (2.2)
Composition, Volume %	
H_2	0.2
NH_3	1.9×10^{-3}
Water	<0.1
Temperature, K, (F)	644 (700)
Pressure, kN/m^2 (Psia)	1725 (250)

H_2 By-Product

Flow Rate, kg/d (Lb/Day)	0.44 (0.96)
dm^3/min (Slpm)[a]	3.6 (3.6)
Purity, Volume %	99.9999 to 100
Temperature, K, (F)	644 (700)
Pressure, kN/m^2 (Psia)	173 (25)

H_2 Vented

Flow Rate, kg/d (Lb/Day)	0.08 (0.18)
dm^3 (Slpm)[a]	0.68 (0.68)
Temperature, K (F)	644 (700)
Pressure, N/m^2 (mm Hg)	0 to 1334 (0 to 10)

Coolant Supply

Type	Ambient Air or N_2
Temperature, K (F)	291 to 297 (65 to 75)
Flow Rate, dm^3/min (Scfm)[a]	28 (1)

(a) At standard conditions of 294K (70F) and one atmosphere.

Life Systems, Inc. CLEVELAND, OHIO 44122	SPECIFICATION	NO.	REVISION LTR.
		PAGE 4 OF 5	DATE
TITLE NITROGEN GENERATION MODULE (NGM)			

Performance Characteristics

NH_3 Conversion Efficiency, %	99.996
H_2 Recovery, %	84
NH_3 Generated, kg/d (Lb/Day)	4×10^{-5} (9×10^{-5})
Water Generated, kg/d (Lb/Day)	0.02 to 0.04 (0.04 to 0.09)
Power Required, W (Average)	138
Heat Rejected, J/s (BTU/Hr)	138 (472)
Reliability Data	
Goal	TBD
MTBF, Hr	TBD
Mission Length, Day	180

Physical Characteristics

Weight, kg (Lb)	61 (135)
Volume, m^3 (Ft^3)	0.022 (0.79)
Basic Dimensions, cm (In)	26.2 Dia x 41.7 (10.3 Dia x 16.4)

Material Characteristics

A. Nonmetallic	Graphite (gaskets) Min-K (insulation)
B. Metallic	SS310, SS316, SS304 Inconel X-750, Nickel 200

Electrical Characteristics

Supply Voltage to Heaters, VAC	120, 240
Hz	60
Supply Power to Heaters, W	400, 1200, 1600

INTERFACES

Mechanical

N_2 Product	1/4 In Tube
N_2H_4 Feed	1/4 In Tube
H_2 By-Product	1/4 In Tube
H_2 to Vacuum	1/2 In Tube
Cooling Air	1/4 In Tube
Cabin Air	Ambient

Life Systems, Inc. CLEVELAND, OHIO 44122	SPECIFICATION	NO.	REVISION LTR.
		PAGE 5 OF 5	DATE
TITLE NITROGEN GENERATION MODULE (NGM)			

Electrical

Thermocouples	Connector-Series 348
Heaters	Connector-Series 348
Mounting	TBD

ENVIRONMENT

Cabin Atmosphere

MAINTENANCE LEVEL AND METHOD:

First Level - Line Replaceable Component
Second Level - Lab maintenance through disassembly